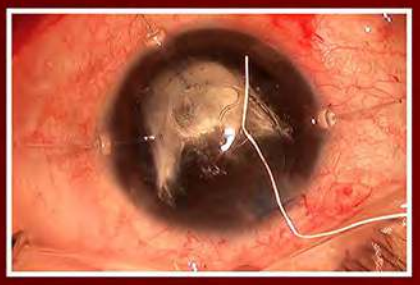

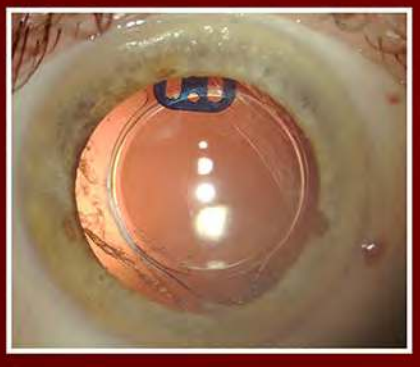

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FOURTH EDITION

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We find it fitting to use Roger's favorite dedication for works he edited because it was true in the past and still rings true at present.

To our parents
For nurturing our development and imbuing fundamental values

To our families
For your support, your encouragement, your tolerance every day

To our teachers
We try to honor you by building on your foundation

To our residents and fellows
You are the future; learn, then lead

To our patients
In return for entrusting us with the most precious of senses,
we commit to an unrelenting pursuit of excellence

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This project began when Roger was still alive. He very much wanted to participate in bringing the next edition of his text to life. Sadly, his illness got the best of him, and we took it upon ourselves to revise his work into the newly named *Steinert's Cataract Surgery*.

Cataract surgery has certainly evolved since the last edition in 2010: new IOLs, advances in biometry and IOL formulas, updated phacoemulsification platforms, femtosecond laser cataract surgery, and light adjustable IOLs, techniques to prevent and manage complications, to name a few advancements. To this end, while we included many past contributors to preserve the spirit of the prior work, we also selected new Associate Editors and added many new contributors, all with the goal of bringing a wealth of new content. A major emphasis of this edition has been the inclusion of an extensive library of videos. These have been selected to demonstrate the myriad techniques described in the book, with voice-over narration to match the chapter content.

We owe a major thank you to all our contributors, including Authors and Associate Editors. Without their hard work, dedication, and adherence to the numerous deadlines and requirements, this project would not have happened.

The second major acknowledgment is to all the wonderful people who support the authors and editors. From office assistants who organize schedules, respond to emails, type, and coordinate manuscripts' fragments, through residents, fellows, technicians, and nurses, and ending with family who tolerate and support the authors, we are grateful and thank you for the key roles you have played in bringing our teaching to a successful conclusion.

We are particularly grateful to our spouses and families who give us moral support and time to engage in these academic endeavors. Certainly, there is an opportunity cost to anything, but I know that our families (who also loved Roger) understand how important this text is to us, so thank you to them.

At Elsevier, many people have helped bring this edition to fruition. Our principal contacts have been Kayla Wolfe, Senior Content Strategist; Sharon Nash and Rishi Arora, Senior Content Development Specialists; and Beula Christopher and Janish Paul, Book Production Managers. You all have worked tirelessly, through countless communications, with patience and professionalism.

Finally, we would like to thank Roger Steinert. This man was a great colleague, friend, and mentor (to Sam). It is because of your love for education and teaching that this book is coming to life. We hope that you look down from heaven, take a read while enjoying a cocktail, and know how much we all love you and miss you. Until we meet again.

Sumit (Sam) Garg
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Video 41.2: IOL Exchange, Zaina Al-Mohtaseb, MD. Dr. Zaina Al-Mohtaseb demonstrates an IOL exchange in which the IOL is freed from the capsule, prolapsed into the anterior chamber, bisected using intraocular scissors, and removed from the eye.

Video 41.3: IOL Exchange with Capsular Phimosis, Douglas Koch, MD. Dr. Douglas Koch demonstrates two cases of IOL exchange in patients with capsular phimosis. In one case the anterior capsular opening is enlarged with intraocular forceps. In the second case the anterior capsular opening is first enlarged with femtosecond laser. The haptics are found to be adherent to the capsular bag and are cut from the optic and left in place.

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Video 41.6: Double Needle, Zaina Al-Mohtaseb, MD. Dr. Zaina Al-Mohtaseb demonstrates sutureless sclera fixation of a three-piece IOL in a patient with no capsular support. The haptics of the IOL are withdrawn through the sclera using two 30-G needles placed exactly 180 degrees apart. Heat is used at the end of the haptics to create a flange to permit intrascleral fixation.

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Video 43.2: Macro model demonstrating the Ogawa intraocular knot. The bicolored strings in this model along with the narration make it easy for one to see the steps to successfully create this knot. The three throws are formed outside the eye, then an angled IOL manipulator is used to pull each throw inside the eye and cinch them at the location desired for the knot. A 2-1-1 example.

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INTRODUCTION

How do we learn and grow as cataract surgeons? We are fortunate to have many educational resources in a range of media. In the past 50 years, two major texts stand out for their detailed, comprehensive, and elegant descriptions of anatomy, techniques, and approaches to prevent, recognize, and manage complications.

The first text was *Cataract Surgery and Its Complications* by Norman Jaffe. First published in 1973, the 6th and final edition was printed in 1997. It was a tour-de-force as essentially a single-author book, and it quickly became the go-to book in our field.

In the early 1990s, Roger Steinert recognized that the rapid advances in our field required a new and more expansive text. Roger devised the outline of the book, invited many colleagues to contribute, wrote some masterful chapters himself, and in 1995 *Cataract Surgery* was born. A unique feature at that time was the inclusion of numerous videos of techniques for removing cataracts and managing complications. Two editions followed, with the third published in 2010. Roger was making plans for the 4th edition when his illness struck, and we lost our dear friend in 2017.

Now, in 2022, a new edition is in order. We have followed Roger's template, inviting some of the great cataract surgeons and educators from around the world. Some were Roger's students, most were Roger's friends, and all have benefited from his contributions to our field. We want to recognize the contributions of our section editors and chapter authors. We are deeply appreciative of their dedication and extraordinary efforts in writing this book.

To honor Roger, we have added his name to the title. We hope that this book is a valuable resource for cataract surgeons, a worthy successor to Roger's last three editions, and a fitting tribute to him and all that he contributed to our field.

Sumit (Sam) Garg
Douglas D. Koch

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PART I

Preoperative Considerations

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1

Pathology and Classification of Cataracts

Mark D. Bailey and Masih U. Ahmed

CONTENTS

KEY POINTS

- Lens development begins early in gestation and progresses through week 8.
- There are important biochemical changes that occur in the formation of cataracts.
- Systemic, metabolic, and traumatic insults can precipitate cataract formation.
- Nuclear cataracts are age related and the most common type.
- A classification/grading system like LOCS III allows consistency in monitoring and research.

LENS EMBRYOLOGY

The first step of lens embryogenesis occurs during gastrulation (day 22), when a single eye field forms in the center of the anterior neural plate. This separates into two *optic vesicles*, which are neuroectodermally derived outpouchings of the diencephalon.[1] The optic vesicles enlarge and come into contact with the adjacent surface ectoderm. This action induces the surface ectoderm to thicken and differentiate into a lens precursor called the *lens placode* by day 28 of gestation.[2] The lens placode then begins to invaginate, creating an indentation known as the *lens pit*. As the lens pit continues to invaginate, the surface ectoderm cells propagate. The invagination progresses from the shape of a cup to a sphere of cells called the *lens vesicle*. The lens vesicle breaks off the stalk, connecting it to the surface ectoderm. At this moment of separation, the lens vesicle consists of a single layer of cuboidal cells surrounded externally by their basement membrane. The outer basement membrane hypertrophies to become the elastic lens capsule.

By the end of week 4 of gestation, the lens vesicle's posterior cells have already begun to rapidly elongate anteriorly, obliterating the lumen of the vesicle (Fig. 1.1). These form what are now the *primary lens fibers*. As these fibers finally meet the anterior lens cells, the primary lens fibers now constitute the *embryonic nucleus*. The anterior lens cuboidal cells are now known as the *lens epithelial cells* (LECs). Anatomically, the LECs are present anteriorly and just posterior to the equator but are not present in the posterior lens. Rather, the portion of the vesicle that faced posteriorly toward the lens placode forms the retina. The retina plays an important role in lens embryogenesis by providing inductive signals to regulate growth and the A-P axis of the lens.[2]

Secondary lens fibers form around weeks 6 to 7 from the epithelial cells at the equator of the lens. However, these new fibers must form circumferentially around the preexisting primary lens fibers, multiplying and elongating anteriorly under the lens epithelium and posteriorly under the lens capsule. The secondary fibers continue to grow and add layers in this manner during gestation, making up the *fetal nucleus*. As these fibers grow from the equator to meet at the anterior and posterior poles of the nucleus, their terminal tips come into contact centrally, forming Y-shaped sutures unique to the fetal growth stage at around week 8. This terminal differentiation involves the removal of the nucleus and organelles from the fiber cells to minimize light scattering. During fetal development, the lens nucleus becomes enveloped within the tunica vasculosa lentis—a nutritive structure supplied by the hyaloid artery—which atrophies and typically disappears by birth.

After gestation, the lens continues to grow by adding layers, and during childhood and adolescence, these new fibers surround the fetal nucleus and become the *juvenile* or *infantile nucleus*. Further growth of these lens fibers forms the *adult nucleus*. Finally, more lens fibers grow to surround the entire nucleus, resulting in the *lens cortex*.

THE CRYSTALLINE LENS

The normal crystalline lens is a clear, biconvex structure that changes shape during normal aging from a slightly rounded ovoid shape in childhood to a more flattened ovoid in advanced age (Fig. 1.2). The adult lens is elliptical in shape, measuring about 4 to 5 mm in anteroposterior thickness[3] and approximately 9.5 mm in diameter.[4] It is located posterior to the iris and attached to the ciliary body by zonules. The zonular fibers span from the basement membrane of the nonpigmented epithelium of the ciliary body to attachment sites just anterior and posterior to the lens equator. During accommodation, the ciliary body contracts to relieve tension on the zonules, allowing the lens to become more spherical, thus increasing its refractive power.

CATARACT FORMATION

Cataracts are, by definition, crystalline lenses that are opacified to any degree given that the normal human lens is virtually transparent.

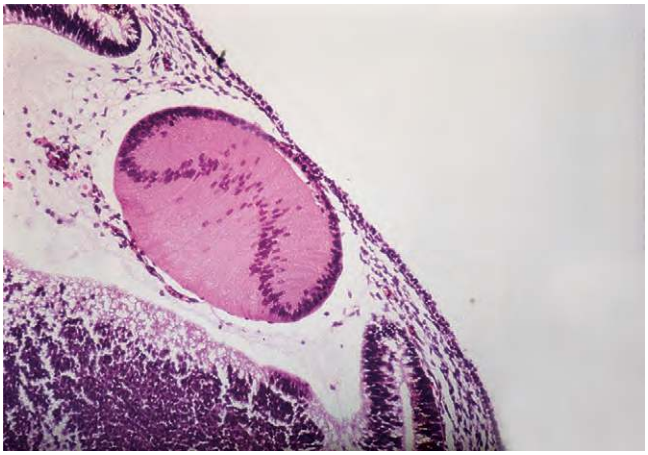

Fig. 1.1 Embryo lens. Posterior epithelial cells of the lens vesicle elongate to become lens fibers. (Hematoxylin and eosin [H & E] stain, x10.)

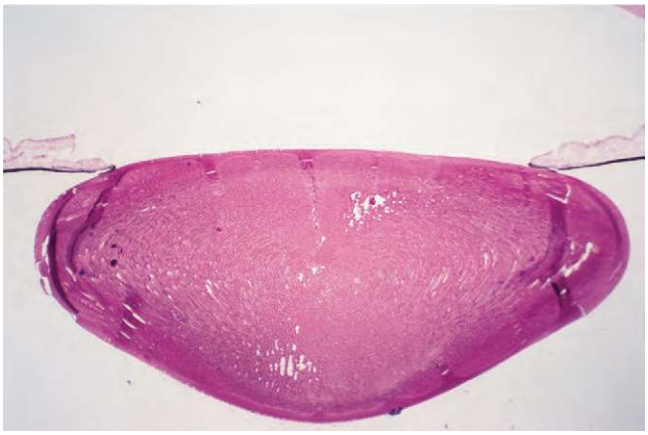

Fig. 1.2 Normal lens. This histologic section of a normal lens from an enucleated globe showing artefactual clefts and folds. (H & E stain, x2.)

Cataracts contain three unique types of crystallin proteins: α, β, and ψ. As the lens ages, these crystallins aggregate to form light-scattering structures. Aggregation of millions of these constitutes a cataract.[5]

Oxidative Stress

- Oxidative stress has been proposed as the major cause of age-related cataract.[6–8]
- Adverse effects are seen in lens components as a result of exposure to oxygen and its various redox forms.
- If antioxidant mechanisms are insufficient, the oxidative stress leads to deactivation of sulfhydryl-dependent enzyme systems, aggregation of proteins, changing of lens color, and membrane disruption.
- Glutathione (GSH) is an important antioxidant in the lens that is critical to the redox cycle that serves to protect against harmful oxidants. Loss of GSH is associated with opacifying membrane damage and protein aggregation. GSH detoxifies oxidative species in the nucleus, then diffuses back to the lens surface to be reduced, subsequently diffusing back to the nucleus to continue the cycle.
- With aging, the lens grows larger and its cytoplasm becomes stiffer, impairing that diffusion. This impairment may partly explain why the nucleus is particularly susceptible to oxidation with increasing age[6] because the lens cannot produce its own GSH and relies on transport of GSH from the outer cortex.[9]

Osmotic Stress

- Osmotic stress, particularly in diabetics, is a common mechanism for cataract formation.
- The polyol pathway converts sugars to their respective sugar alcohol using the enzyme aldose reductase.
- These polyols (e.g., sorbitol from glucose) are unable to traverse the plasma membrane after their formation and, in chronically hyperglycemic states, can accumulate intracellularly in epithelial and lens fiber cells.[10] Water then follows the osmotically active substances to neutralize hyperosmolarity of the cytoplasm, leading to cellular swelling and subsequent opacifying changes to the index of refraction.
- Osmotic stress can work synergistically with oxidative stress to increase the likelihood that cataracts will form in diabetics.[5] Chronic oxidative stress and nonenzymatic glycation in diabetes leads to a breakdown of the lens's osmoregulatory mechanism, leaving the lens susceptible to cataract-forming osmotic stress in cases of modest sorbitol fluctuations that would be expected even in patients with well-controlled diabetes.

LENS OPACITIES CLASSIFICATION SYSTEM

There are numerous methods of classifying/describing cataracts; however, a standardized method is important in many aspects. This includes establishing consistency in monitoring clinical progression and comparative research. The Lens Opacities Classification System III (LOCS III)[11] is the most predominant one in use today (Fig. 1.3).

The system works with the use of a slit lamp and a set of standards on a nearby light box. The cataract is graded on the following:

- 0 to 6.9 grade for nuclear opalescence (opaqueness/intensity of light scatter)
- 0 to 6.9 grade for nuclear color (yellowness)
- 0 to 5.9 grade for cortical changes
- 0 to 5.9 grade for posterior subcapsular changes

The grading is done on a decimal scale in 0.1-unit increments to denote cataracts that are between two images on the classification system. LOCS III has been validated[11–13] (Fig. 1.4).

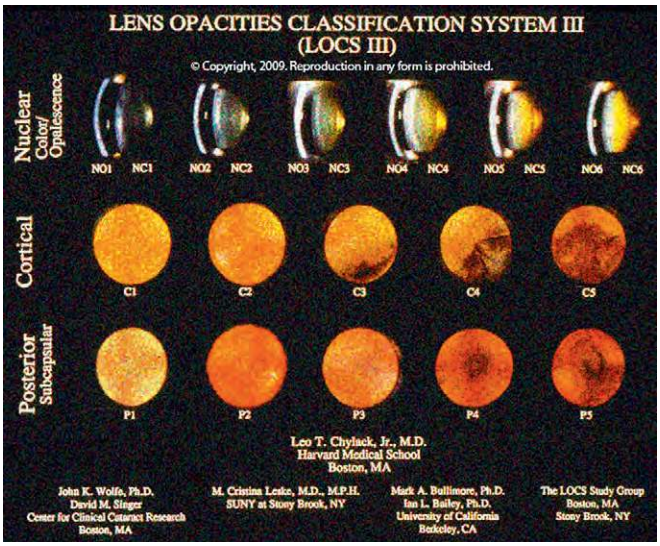

Fig. 1.3 LOCS III standards.[11] These are reproduced images to demonstrate the standards used to classify/grade cataract types. There are six standard images for nuclear color and opalescence, five standards for cortical changes, and five standards for posterior subcapsular changes.
(Photos courtesy Dr. Chylack holds copyright for the image and it may not be reproduced.)

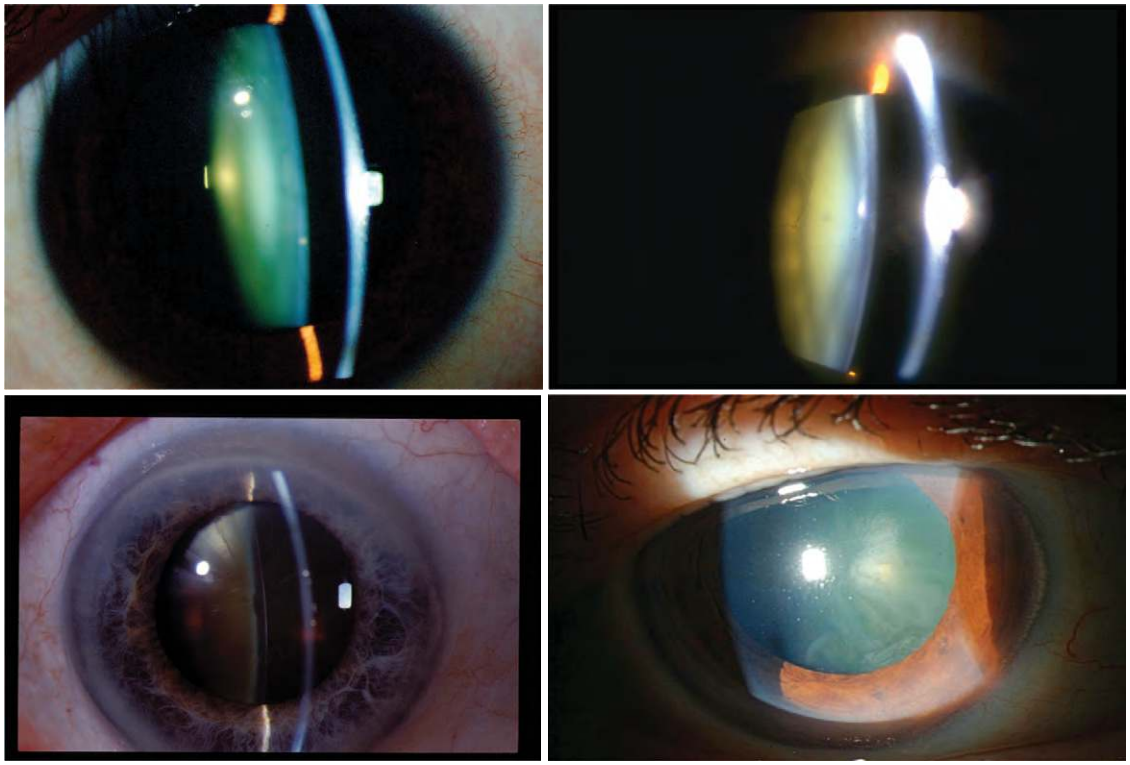

Fig. 1.4 Nuclear cataracts demonstrating increasing degrees of nuclear yellowing and opacification. Diffuse view of nuclear sclerotic cataract showing early nuclear color changes and yellowing (Photos courtesy M. Bowes Hamill, MD, and Douglas D. Koch, MD.)

A 2012 study found significant associations between certain LOCS III cataract grades and vision-specific functioning.[14] Davidson and Chylack found that LOCS III grading correlates well with nuclear cataract phacoemulsification time, making LOCS III a useful tool in creating operative plans for nuclear cataract procedures.[15]

TYPES OF CATARACTS

Congenital Cataracts

Congenital cataracts are present at birth or are diagnosed during the first year of life. They are the most common cause of lifelong visual loss in children worldwide.[16] Usually bilateral, this type of cataract can be inherited or associated with other medical problems such as chromosomal trisomies, metabolic disorders, congenital syndromes, and TORCH infections. In more dense cataracts, early diagnosis and surgical intervention are necessary for good visual outcome without irreversible deprivation amblyopia.

Congenital cataracts are classified according to their age of development and/or location within the lens.

- An *embryonal nuclear cataract* results from early insult within the first 2 months of gestation and appears as a small central opacity.
- A *fetal nuclear cataract* is formed from disruption 3 months into gestation and lies between the anterior and posterior Y-sutures or at the sutures (also termed *sutural cataract*) (Fig. 1.5).
- *Congenital zonular cataracts* (also termed *lamellar* or *perinuclear cataracts*), formed later in gestation, are opacities restricted to one layer of the lens and arranged concentrically to the lens capsule.[5]
- *Polar cataracts* are opacities located on the anterior or posterior pole of the lens. They are dominantly inherited with variable expressivity but can also appear sporadically (Fig. 1.6).

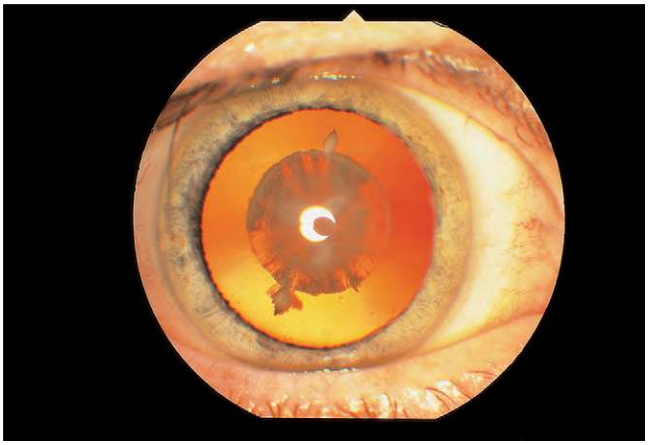

Fig. 1.5 Fetal nuclear cataract. Clinical appearance of a central cataract surrounded by normal lens tissue.

Nuclear Cataracts

The most common age-related opacity of the lens is the nuclear cataract. This type of cataract results from a cascade of events beginning with the depletion of antioxidants in the nucleus such as GSH and leading to oxidation of lens proteins, aggregation of those proteins, and yellowing of the lens nucleus. Increased compaction of the nucleus as a result of new lens fiber layers added throughout growth may contribute to light scattering in age-related nuclear cataracts (Fig. 1.7).

Cortical Cataracts

The development of cortical cataracts is age related and correlates with the onset of nuclear hardening and presbyopia. Shear forces between

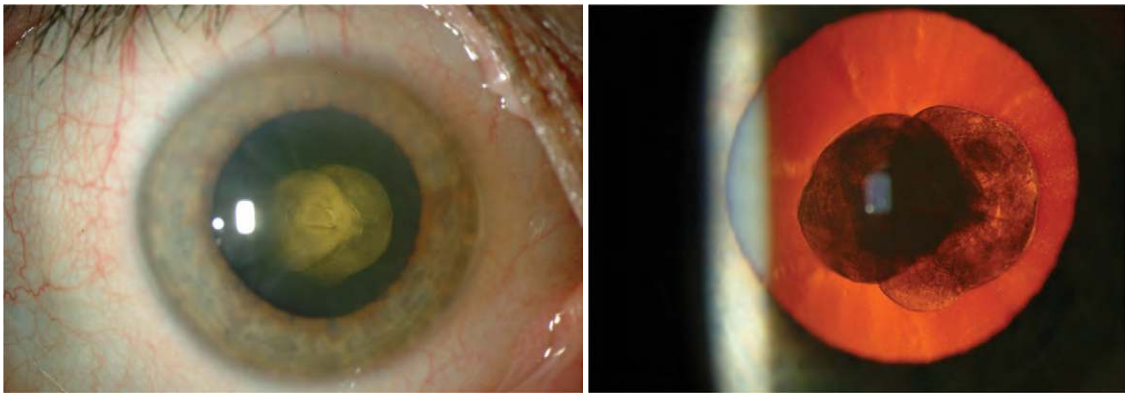

Fig. 1.6 Posterior polar cataract under direct and retroillumination demonstrating axial opacification with paraxial extension. (Photos courtesy M. Bowes Hamill, MD.)

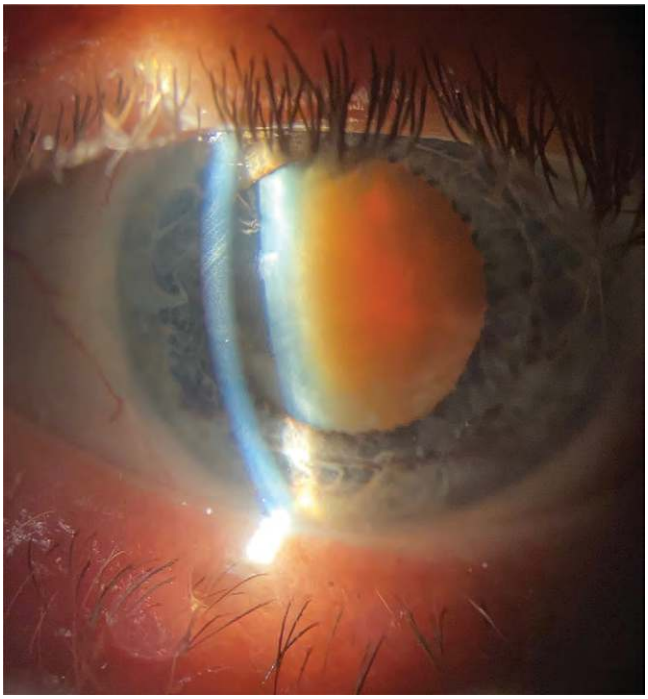

Fig. 1.7 Slit lamp photograph of a dense nuclear sclerotic cataract with brunescence.

the hard nucleus and softer cortex lead to rupture of lens fibers and development of sharp, clear fluid clefts, causing opaque spokes. Defective DNA repair in LECs also appears to be associated with the loss of transparency in cortical cataracts[17] (Fig. 1.8).

Histopathologically, cortical cataracts show accumulation of eosinophilic fluid between lens cells with displacement and degeneration of bordering cells. The breakdown of these cortical cell walls can lead to the release of spherical droplets called *morgagnian globules*. The accumulation of these globules can eventually replace the entire cortex to form a mature *morgagnian cataract* characterized by a gravity-dependent interior hard nucleus that is displaced inferiorly without the structural support of surrounding cortex (Fig. 1.9).

Posterior Subcapsular Cataracts

Although the posterior subcapsular cataract (PSC) has a lower prevalence (4%–6.5%) compared with the more common nuclear and

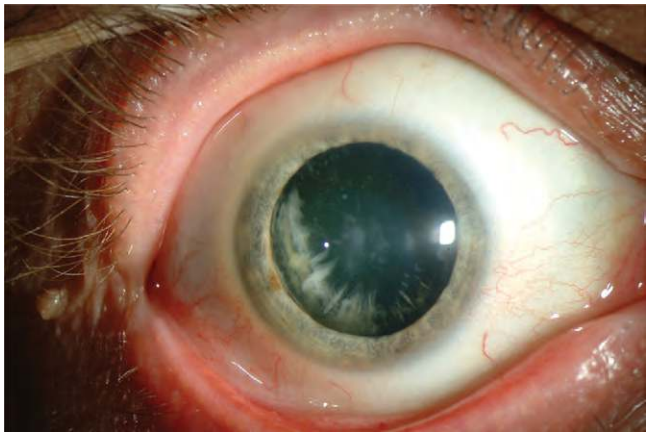

Fig. 1.8 Cortical cataracts typically begin with peripheral spoke-like opacities in the lens cortex with central extension. (Photo courtesy M. Bowes Hamill, MD.)

cortical cataract, it causes an earlier and quicker reduction in visual function[18] (Table 1.1).

Equatorial and posterior cortical degeneration in conjunction with posterior migration of equatorial lens cells forms a clinically visible area of opacification just anterior to the posterior lens capsule. The abnormally positioned lens cells enlarge to form bladder cells, also known as Wedl cells, that are characterized by shrunken nuclei, sparse organelles, and crystallin proteins (Fig. 1.10). Slit lamp examination of PSCs reveals features ranging from dot-like granular areas of the subcapsular pole to large granular-vacuolar plaques in the posterior pupillary zone of the lens.

Anterior Subcapsular Cataracts

Anterior subcapsular cataracts appear as plaques just posterior to the anterior lens capsule. These opacities can form from proliferation and subsequent degeneration of LECs as a result of irritation, uveitis, or trauma.

Increased intraocular pressure can form grayish opacities posterior to the anterior lens capsule, which histologically appear as focal areas of epithelial cell necrosis. This association between glaucoma and subepithelial lens opacity is called *Glaukomflecken*.

Traumatic Cataracts

Formation of a traumatic cataract can occur either after mechanical eye injury or after nonmechanical eye injury, such as infrared energy, electric shock, or ionizing radiation.[19]

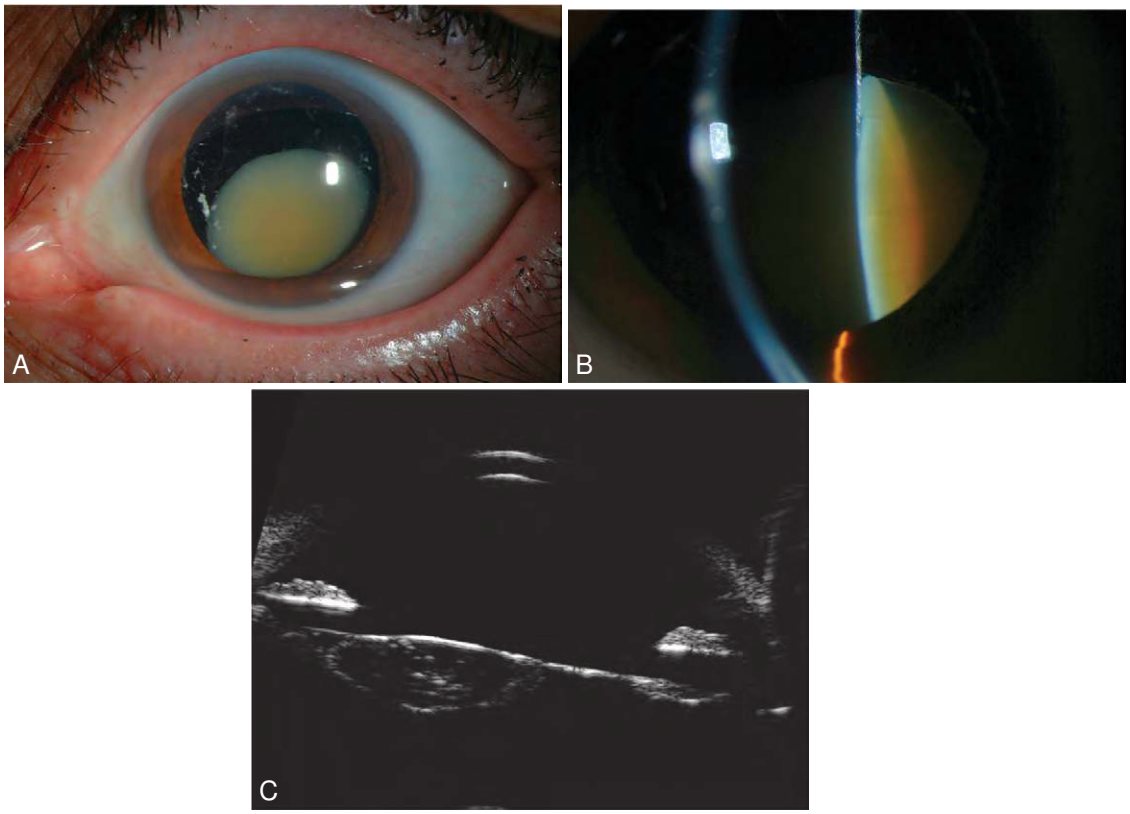

Fig. 1.9 (A) Slit lamp photograph demonstrating a dense morgagnian cataract that appears to be a subluxed crystalline lens. (B,C) Ultrasound biomicroscopy reveals a dense nuclear component that is shrink wrapped in capsule without cortical material to support it as this has dissipated through the capsule.

TABLE 1.1 The table lists some of the conditions that are associated with PSC

Ocular conditions	Idiopathic/aging Retinitis pigmentosa High myopia Gyrate atrophy Trauma Uveitis
Iatrogenic	Radiation therapy Glucocorticoid (steroid) use Posterior segment surgery/injections
Associated systemic conditions	Rheumatoid arthritis Asthma Atopic dermatitis Diabetes

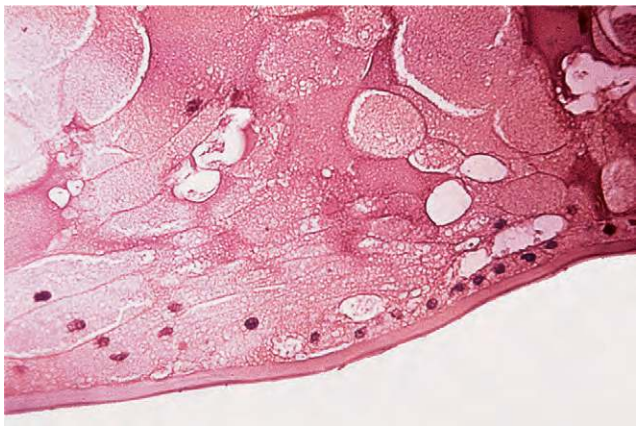

Fig. 1.10 Bladder cells (Wedl cells). LECs have become swollen after abnormally migrating to the posterior pole of the lens. (H & E stain, x20.)

The pathogenesis of traumatic cataracts is thought to be related to direct rupture of the lens capsule or a coup-countercoup force and equatorial expansion as a consequence of hydraulic forces transferring energy from the trauma across the eye.[20] The cataract initially appears stellate with opacities in the cortex or capsule. Lens dislocation or subluxation can occur as a result of disruption of the zonular fibers during trauma (Fig. 1.11). Although many of the injuries directly related to the initial blunt force can cause visual obscuration, much of the pathology of lens opacification after trauma is thought to be rooted in epithelial and subsequent cortical fiber deterioration.[5] Trauma-induced oxidative stress and free oxygen radicals cause the initial LEC dysfunction. Dysfunctional LECs fire a cascade of related protein changes in the Na-K pump, which results in inward osmotic pressure, swelling, and perinuclear vacuole formation in the LECs. The superficial cortical

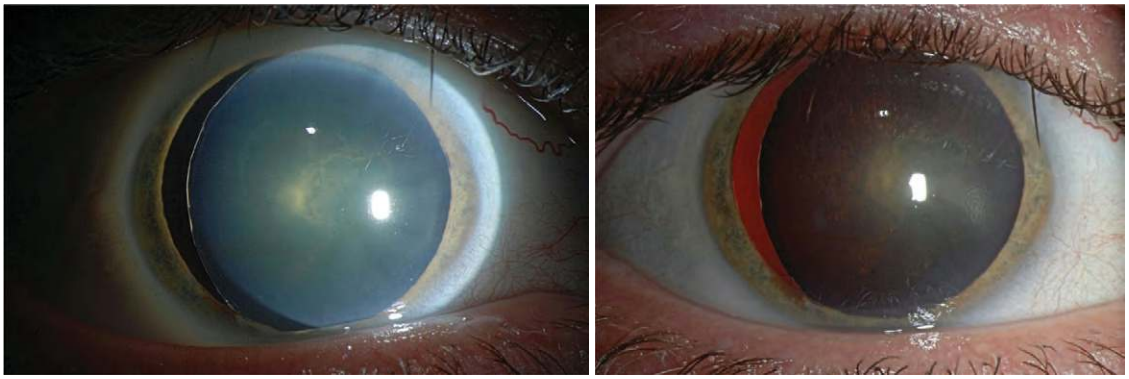

Fig. 1.11 Patient presenting for cataract surgery with a history of being punched in the eye with a fist. A crescent zone of clearing is seen temporally on retroillumination where zonular loss has occurred.

lens fibers subsequently undergo degeneration and produce a localized lamellar zone of vacuolization.[19] Time and formation of new clear lens fiber cells gradually compress the layer and displace it deeper into the cortex.

An open globe injury can lead to laceration or perforation of the lens capsule, which results in a localized opacity that usually expands to opacification of the entire lens. Much of the pathophysiology is similar to contusion-related traumatic cataracts. The difference here is that discontinuity of the epithelium results in much quicker opacification than simply damage to cellular function. The opacities that result from localized, small capsular injuries may remain as a focal cortical cataract if the tear is small enough (<3 mm). However, exposed cortex is susceptible to swelling, and the opacification often expands past the local tear, leading to the formation of a traumatic white cataract within 24 hours when a capsular tear is greater than 3 mm.[19] Penetrating ocular trauma that results from a foreign body may leave intralenticular retained metallic foreign bodies that appear as focal rusty-appearing opacities, also known as *siderosis lentis*.

Iatrogenic injury to the capsule from surgery is also considered a precipitant of traumatic cataract. LECs displaced through the capsule can regenerate and proliferate to form *Elschnig pearls*, which microscopically appear as clusters of bladder cells on either the anterior lens surface or the iris stroma. Another iatrogenic mechanism for traumatic cataract is seen in *Soemmering's ring cataract*, which can form after trauma or cataract extraction. This occurs when retained equatorial LECs and cortical material undergo proliferation or fibrous metaplasia to form a ring of fibers between the posterior capsule and the edges of the postcapsulorrhexis anterior capsule remnant.[21]

PSEUDOEXFOLIATION AND TRUE EXFOLIATION

True exfoliation of the lens capsule primarily occurs in persons exposed to intense heat or infrared radiation over a long period of time. This condition was originally described by glassblowers in 1922.[22] In these patients, there is a rupture of the superficial layer of the capsule, which becomes shredded in appearance or peels off outwardly in curling scrolls.[23] Histopathology reveals significant thickening of the lens capsule with lamellar separation of the outer portion from the intact layer closest to the lens epithelium.

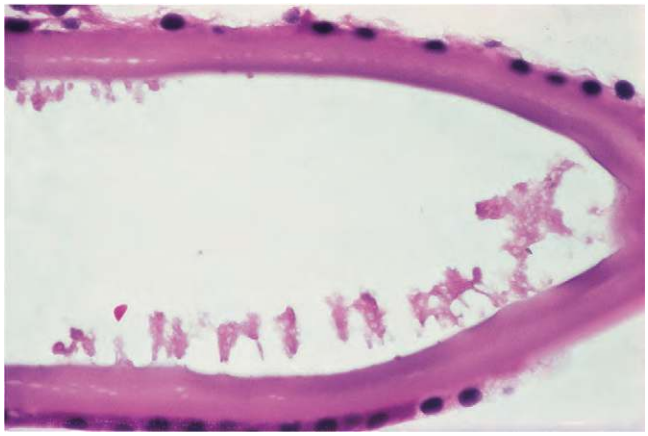

Fig. 1.12 Pseudoexfoliation. This curled up piece of anterior lens capsule removed during cataract surgery shows deposits lined up, resembling iron filings on a magnet. The outer surface of the lens capsule is opposite the remaining LECs. (H & E stain, x100.)

Much more common is *pseudoexfoliation (PEX) syndrome*, which is caused by accretions of deposits onto the anterior and posterior surfaces of the lens capsule, iridocorneal angle, iris, ciliary body, zonular fibers, and anterior vitreus membrane.[23] Histopathological analysis of PEX material shows straight deposits on the capsule lined up, resembling iron filings aligned on a magnet (Fig. 1.12). Clinically, PEX syndrome shows a frostlike appearance of the lens capsule with a detached, roughened membrane that curls forward and away from the lens surface (Fig. 1.13). The anterior lens capsule is significantly thickened in patients with PEX syndrome.[24] Blue-gray flakes or tufts can be seen floating in the anterior chamber and filling the iridocorneal angle. The floating pigments can eventually obstruct the trabecular meshwork in the angle, leading to development of secondary open-angle glaucoma. Zonular fiber weakening in these cases can complicate cataract surgery. Degeneration of the iris muscle cells and increased iris rigidity causes poor pupillary dilation in patients with PEX syndrome, which also serves as a challenge in cataract surgery (Fig. 1.14).

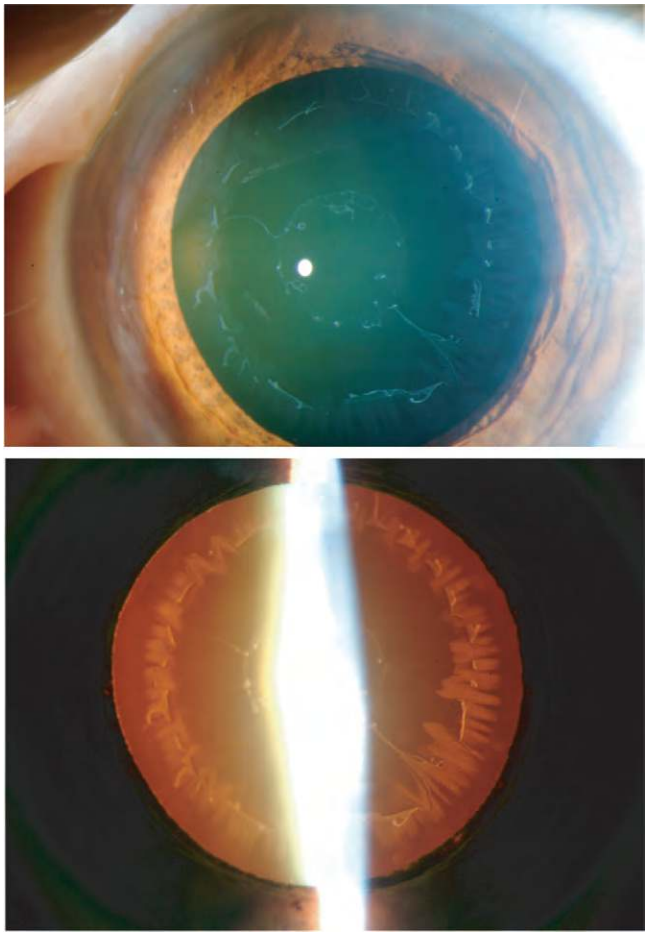

Fig. 1.13 These two photographs elegantly show the pseudoexfoliation deposits that occur on the anterior lens surface in the pattern of the iris, giving a frosted look. This can be seen in the retroillumination photographs as well. (Photos courtesy *M.* Bowes Hamill, MD.)

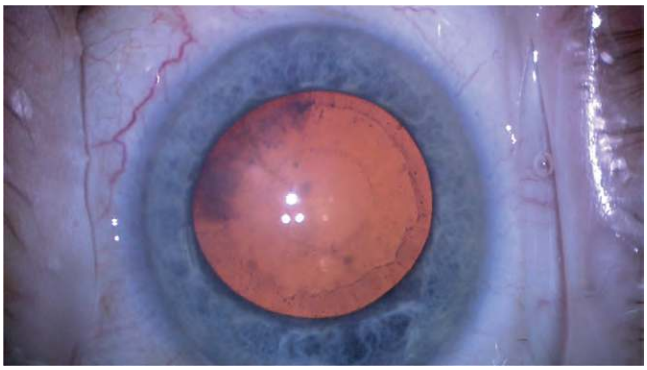

Fig. 1.14 The circumferential pattern of pseudoexfoliation deposits can be visualized under the operating microscope as seen here. (Photo courtesy Sumit Garg, MD.)

SUMMARY

Cataracts are a heterogenous diagnosis with varying histologic changes. There are intrinsic and extrinsic causes as discussed previously that cause proliferation of cataracts of which the provider must be aware. This allows accurate diagnoses and formulation of a surgical plan for successful visual rehabilitation.

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2

Preoperative Evaluation and Preparation of the Cataract Patient

Charles Daniel McGuffey, Nicholas Hackett, Surendra Basti, and Kourtney Houser

CONTENTS

KEY POINTS

- Evaluation of cataract severity and degree of visual and functional disability guides surgical decision.
- Assessment of potential visual function influences intraocular lens (IOL) selection and preoperative discussion.
- Treatment of ocular surface disorder preoperatively improves refractive outcomes.
- Identification of potential complicating factors preoperatively such as intraoperative floppy iris syndrome and conditions associated with zonular instability aids in surgical planning, preparation, and consent.
- A thorough medical history is important because systemic associations with eye disease can have implications for cataract surgery.
- Implantation of advanced technology IOL requires a comprehensive evaluation, discussion, and specific informed consent to optimize patient selection, expectations, and outcomes.

INTRODUCTION

Evaluation of a patient for cataract surgery includes quantification of visual and functional disability attributed to the cataract and a thorough examination of ocular and systemic pathology that could complicate surgery or the postoperative course. After a comprehensive evaluation of each patient's visual goals, a thorough discussion of the benefits and limitations of available intraocular lens (IOL) technologies sets reasonable expectations for the future.

EVALUATION OF VISUAL DISABILITY

Advanced cataracts reduce overall visual acuity, typically measured with Snellen visual acuity in dark lighting conditions. Early cataracts of particular types such as posterior subcapsular can cause significant functional decline without a significant reduction in high contrast Snellen visual acuity.[1,2] As indications to perform cataract surgery have broadened with advancements in technology and safety, it has become important to evaluate functional vision objectively in a clinical setting, especially when a patient has visual complaints and preserved Snellen acuity.

CONTRAST SENSITIVITY FUNCTION

- Contrast sensitivity function (CSF) is useful in assessing the visual and functional significance of a cataract.
- CSF is an expanded Snellen acuity test, with the resolving power of various object sizes measured at different contrast thresholds. In a normal visual system, higher spatial frequencies require higher levels of contrast.

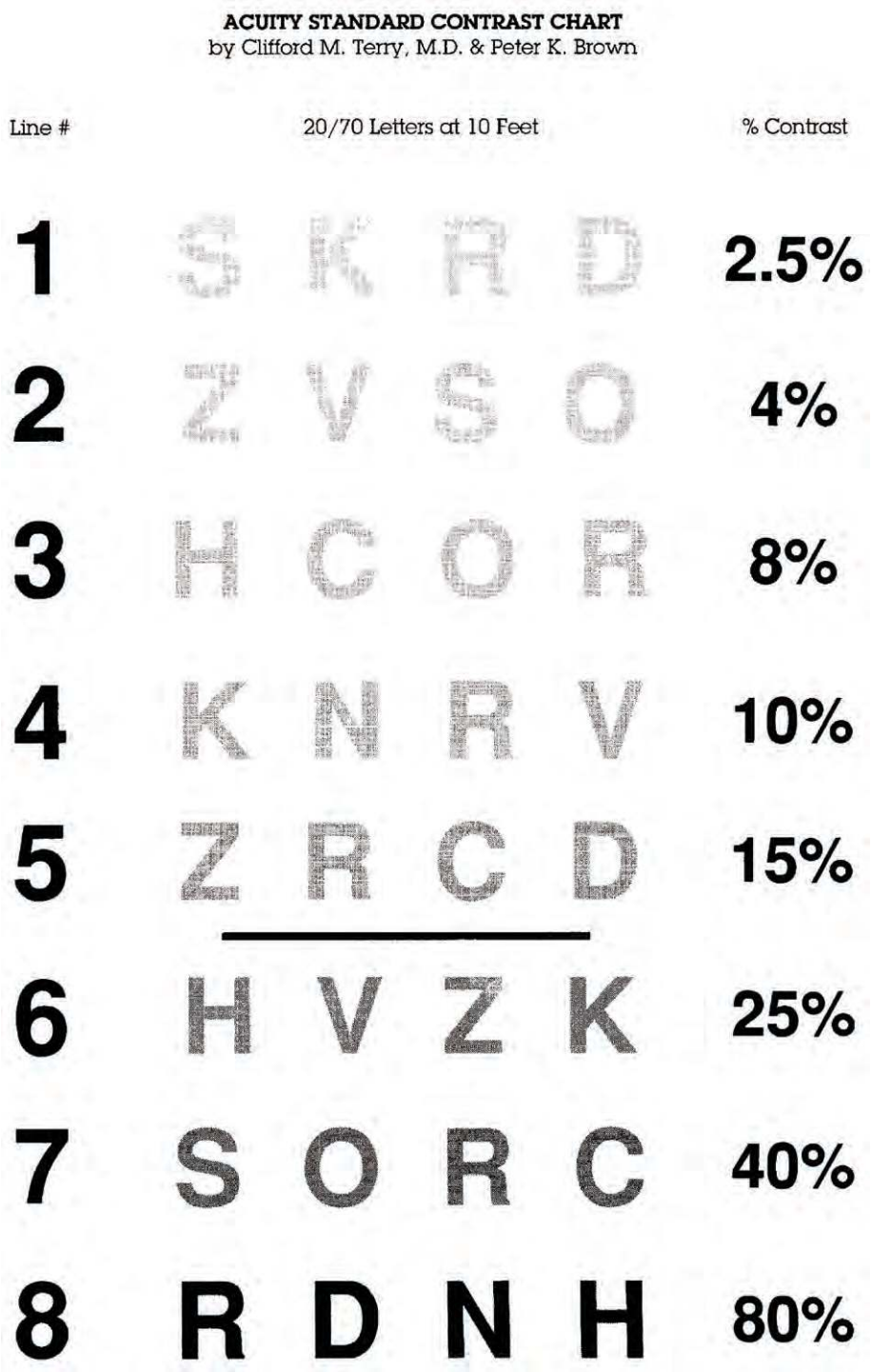

Fig. 2.1 CSF test using an electronic Snellen visual acuity chart. Contrast is documented as a percentage of maximum contrast.

- CSF can be measured on most electronic charts by testing Snellen visual acuity at various reduced contrast settings, often documented as a percentage of maximal contrast (Fig. 2.1).
- CSF is sensitive but not specific, and can be reduced by anterior and posterior ocular pathologies such as keratoconus, pterygia, and macular degeneration. Findings must be interpreted with care in the face of concomitant disease.[3]
- Tools available for testing CSF are shown in Table 2.1.

GLARE DISABILITY

- Glare is a subjective visual response to light, and, although it can lead to discomfort before retinal adaptation, it does not result in diminished visual function in the absence of ocular disease.
- Glare-induced vision loss or glare disability results from scattering of incoming light by inhomogeneity of ocular media, with more anterior opacities resulting in more severe scattering than opacities closer to the retinal plane.

TABLE 2.1 Tools for Measuring Contrast Sensitivity

Instrument	Format
Pelli-Robson	Chart
Terry	Chart
Regan	Chart
Vistech Charts (VCTS 6500)	Chart
CSV-1000/2000 (Vector Vision)	Illuminated chart
Functional Vision Analyzer (Optec)	Tabletop device
B-Vat II (Mentor)	Computer screen

TABLE 2.2 Automated Instruments for Measuring Glare Disability

Instrument	Glare Light Source
Brightness Acuity Tester (BAT) (Marco Ophthalmic)	Background
EpiGlare (OptegoUSA)	Background
CSV-1000/2000 (Vector Vision)	2-Point source
Miller-Nadler (Titmus Optical)	Background
Functional Vision Analyzer (Optec)	Radial point sources
IRAS GT (Randwal Instrument Co)	4-Point source
MCT 8000 (Vistech)	Point/background

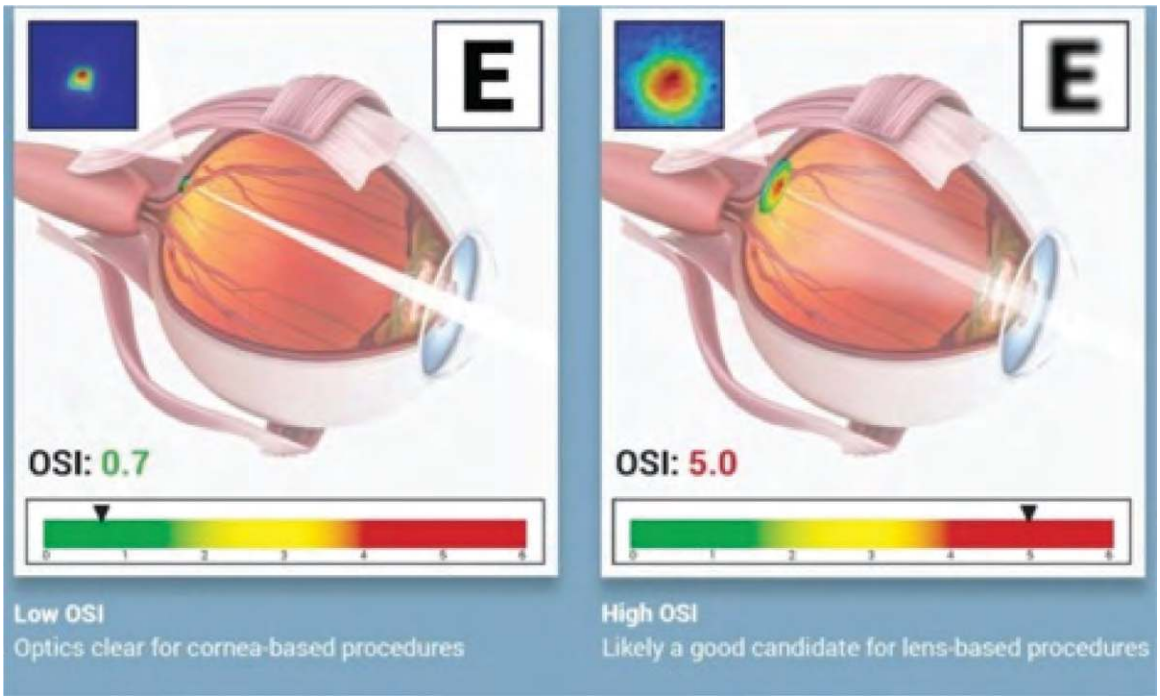

Fig. 2.2 Representative diagnostic image from an optical quality analysis device, HD Analyzer (Visiometrics SL). The *OSI* obtained from retinal point spread analysis objectively provides measurement of visual quality aside from Snellen acuity alone.

- Glare disability is a significant cause of visual decline in patients with cataracts and should be measured when a patient's functional complaints do not correlate with Snellen visual acuity.
- Glare disability is more specific than contrast sensitivity, but other etiologies of glare such as corneal opacities should be noted and considered.
- A simple test of a penlight source directed obliquely into the patient's visual axis can simulate glare disability in clinic.
- Other glare testing modalities are shown in Table 2.2.

OCULAR SCATTER INDEX AND HIGHER ORDER ABERRATIONS

- Increased optical aberrations and scatter from an opacified lens contribute to the loss of functional vision in patients with cataracts.
- Ocular scatter index (OSI) measurement from retinal point spread analysis and wavefront aberrometry quantify increased scatter and aberrations associated with lens dysfunction[4,5] (Fig. 2.2).
- Dysfunctional Lens Index (DLI) measured with a ray-tracing aberrometry system has also been correlated with objective and subjective lens density measurements and visual performance[6] (Fig. 2.3).

ASSESSMENT OF VISUAL POTENTIAL

The decision to proceed with cataract extraction largely depends on the expected visual improvement after surgery. A comprehensive examination including analysis of the optic nerve, retina, and cornea should be performed on every patient presenting for cataract surgery evaluation. Macular optical coherence tomography (OCT) routinely performed preoperatively is useful in the detection of macular pathology in patients with a normal funduscopic examination. In one prospective study of patients referred for cataract surgery, 12.35% of patients with a normal funduscopic examination had an abnormal macular OCT finding with potential adverse effect on visual outcome.[7] The results of macular OCT aid in visual potential determination, IOL selection, delivering complete informed consent and setting appropriate patient expectations.

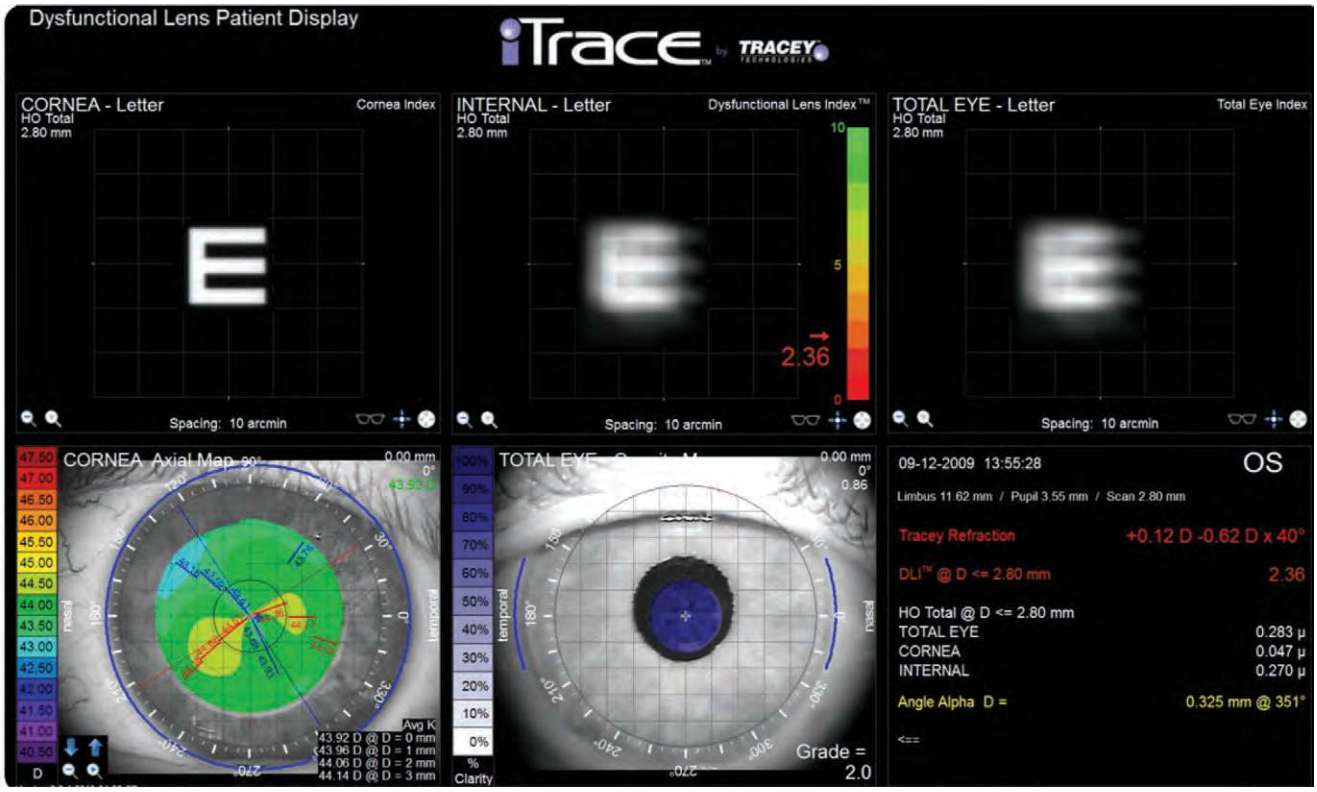

Fig. 2.3 Representative diagnostic image showing the DLI measured with the iTrace (Tracey Technologies) to quantify visual disturbance from the lens.

TABLE 2.3 Methods to Assess Visual Potential

Instrument	Format	Application
Guyton-Minkowski Potential Acuity Meter (PAM)	Snellen projected through aperture	Cataracts less than 20/200 density
Laser interferometer	Laser interference stripe projected	Cataracts less than 20/200 density
Potential acuity pinhole test	Illuminated near card visualized through pinhole	Cataracts less than 20/200 density
Yellow filter test	Transparent yellow filter over reading material	Macular disease- improves in macular disease, worsens in cataract
Two-point discrimination test	Identification of two light sources held 25 inches away	Dense media opacity
Penlight-generated entoptoscopy	Penlight over closed lid/on globe stimulates perception of Purkinje vascular tree image	Dense media opacity
Gross color perception	Cobalt blue light source/green filter at slit lamp	Dense media opacity
Blue-field entoptoscopy	Visualization of white blood cell movement with blue light projection	Macular function in dense media opacity
Maddox rod testing	Visualization of continuous red line with light source and Maddox rod suggests macular function	Macular function in dense media opacity
Electroretinography (ERG)	Electrical activity of retina measured in response to light	Rod function in dense media opacity
Visual Evoked Potential (VEP)	Electrical activity measured over occipital cortex in response to light	Macular function in dense media opacity
Scanning laser ophthalmoscopy	Confocal laser scanning microscopy to image retina	Retinal image through dense media opacity

Determining the degree of visual improvement in patients with concomitant ocular disease or mature cataracts that obscure full posterior examination is challenging. Several tools can be used to assess visual potential (Table 2.3).

All of the listed methods have benefits and limitations. In general, an improvement of four or more lines on a visual potential response suggests a significant visual improvement after cataract extraction. The potential acuity meter, laser interferometer, and pinhole acuity test are of limited utility in cataracts that have progressed beyond a 20/200 level, as the projections cannot pass through dense media opacities. Additionally, macular disease can yield falsely positive results.

When cataracts are too dense to view the posterior pole, evaluation for an afferent pupillary defect is useful to assess optic nerve function as cataracts, regardless of density, do not result in abnormal

pupil response. The modern advent of nonmydriatic, ultrawide-field fundus imaging via scanning laser ophthalmoscopy (e.g., Optos pcl, Dunfermline, United Kingdom) enables clinicians to view the retina in more detail through a small pupil and/or moderate media opacity. B scan-ultrasonography can evaluate the structural integrity of the retina but does not assess function. Other tools such as electroretinography and visual-evoked potential are of limited availability and may be too costly and difficult to interpret for routine use.

OBTAINING A HISTORY

Evaluation of Subjective Visual Impairment

Ascertaining the chief complaint and history of the presenting illness are the first steps in the screening process of any medical condition, but in a patient with cataracts, it should be thought of as comprising two key elements: the description of the visual impairment and the patient's expectations for improvement. The first is more important for diagnosis, whereas the second is vital to ensure that the capabilities of the intervention match patient expectations.

One can localize the pathology to cataract (while moving away from confounders such as ocular surface disorder (OSD) or endothelial dysfunction) by asking about fluctuation in the symptoms or additional symptoms such as burning or foreign body sensation. The latter are typically not associated with cataract. One common descriptive term used by patients is *blurriness*. The physician should attempt to parse out whether the patient is referring to decreased overall acuity (as we may see in cataract) rather than complaints such as binocular diplopia, scotoma, or metamorphopsia. Presence of the latter descriptors should compel the physician to evaluate for other vision- or life-threatening pathologies that may need to be addressed before cataract surgery.

Once the patient's primary complaint is understood, it is helpful to elicit his or her understanding of what can and cannot be gained through cataract surgery. In the modern era of widely available information (and misinformation), it is particularly important to ensure that the patient's expectations match with reality.

CONTACT LENS USE

Accurate biometry relies in part on accurate keratometry. Contact lens wear can distort the shape of the corneal surface and therefore lead to inaccurate measurements.

- Spherical soft contact lenses should be discontinued for 1 week before surgical measurements.
- Toric soft contact lenses should be discontinued 2 weeks before surgical measurements.
- Hard or rigid gas-permeable lenses should be discontinued longer, and documentation of topographic stability should be implemented before making a final surgical plan.

PRIOR CORNEAL REFRACTIVE SURGERY

Eliciting a history of prior corneal refractive surgery is critical because of its significant impact on biometric accuracy, formula performance, and IOL selection. In particular, underestimation of true corneal power after myopic laser in situ keratomileusis surgery can lead to a postoperative hyperopic surprise. Although a complete discussion of this topic is included in Chapter 4, it should be mentioned that there are many available methods for calculation; one comprehensive resource is the American Society of Cataract and Refractive Surgery (ASCRS) website, which compiles data from the most popular calculation methods (iolcalc.ascrs.org).

MEDICAL HISTORY

Anticoagulation and Antiplatelet Therapy

In the 2016 American Academy of Ophthalmology's Cataract in the Adult Eye Preferred Practice Pattern, the consensus was published that anticoagulation with warfarin need not be stopped before surgery as long as the international normalized ratio is within the therapeutic range, and that aspirin should only be discontinued if the risk outweighs the benefit.[8] As aspirin is typically implemented as prophylaxis against cardiovascular disease and stroke in high-risk patients, the risk seldom justifies discontinuation. Additional consideration may be given when planning for retrobulbar injection or if creation of large scleral wounds or iris repair is anticipated. Double antiplatelet therapy has not been associated with increased risk for vision-threating complications in cataract surgery performed with a clear corneal incision under topical anesthesia.[9] Double antiplatelet therapy has been shown to increase the risk for severe retrobulbar hematoma when retrobulbar or peribulbar anesthesia is given. Therefore in patients who are at high medical risk to discontinue double antiplatelet therapy, topical anesthesia should be used when possible and general anesthesia when necessary.[10]

SPINAL DISEASE, DEMENTIA, AND TREMOR

Back pain and spinal disease can be problematic when requiring a patient to lay still for a significant period of time. Planning for general anesthesia in the former and proper neck support for the latter can mitigate these obstacles.

Patients with dementia may also benefit from general anesthesia rather than monitored anesthesia care with topical anesthesia because their ability to follow directions intraoperatively may be further impaired by dissociative anesthetics. However, depending on the degree of dementia, these patients can do well with topical anesthesia alone, especially as some of these patients have longer term effects from anesthetic agents. Patients with tremor should also be considered for general anesthesia to ensure a stable operative field.

PREOPERATIVE EXAMINATION AND CONCOMITANT CONDITIONS

Detailed comprehensive examination of the cataract and the rest of the eye is necessary to prepare for surgery and validate that the patient's complaints and vision correlate with clinical examination. Systemic or ocular conditions that may complicate cataract surgery or the postoperative course should be identified and optimized preoperatively, when possible.

Examination of the lens itself should include assessment of the severity of various cataract components (e.g., level of nuclear sclerosis, grade of cortical opacification, presence of cortical spokes in the visual axis, and presence of posterior subcapsular cataract [PSC]). A validated method of grading cataract is the Lens Opacities Classification System III (LOCS III) (Fig. 2.4). First published in 1993, the system uses six standard slit beam images for grading nuclear color and opalescence and five retroillumination images for both cortical cataract and PSC classification.

Nuclear density can also be quantified (Fig. 2.5) using Scheimpflug imaging (Pentacam, Oculus Optikgeräte GmbH, Germany). This measure has also been shown to correlate well with LOCS III, best corrected visual acuity, and contrast sensitivity.[11] LOCS III has also been shown to correlate with intraoperative parameters of phacoemulsification energy, ultrasound time, and amount of fluid used intraoperatively.[12]

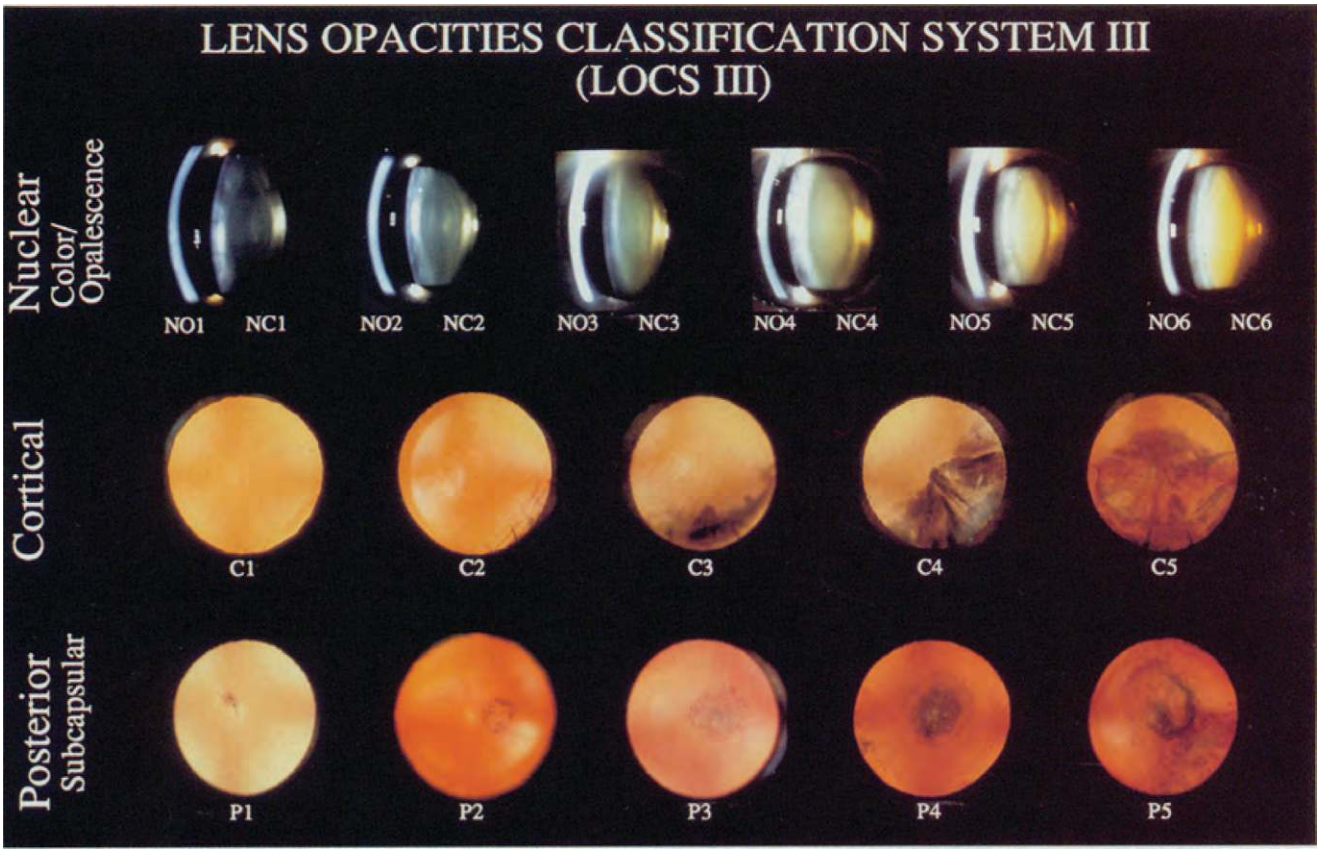

Fig. 2.4 LOCS III for grading nuclear cataracts, cortical cataracts, and PSCs.

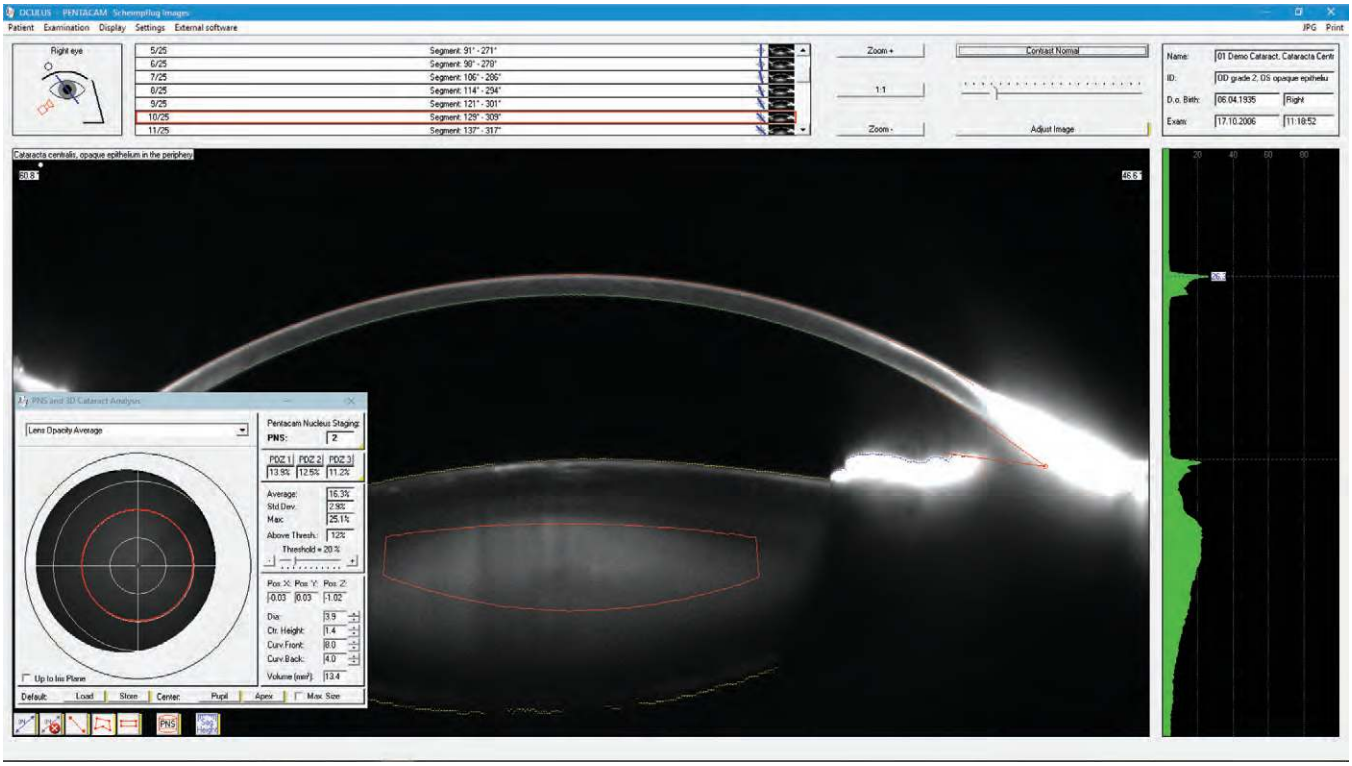

Fig. 2.5 Scheimpflug image of cataract (large image to the *left*) demonstrating nuclear density grading *(right)*. Note the increased width of the green density band corresponding to the high reflectivity of the lens nucleus in this nuclear sclerotic cataract.

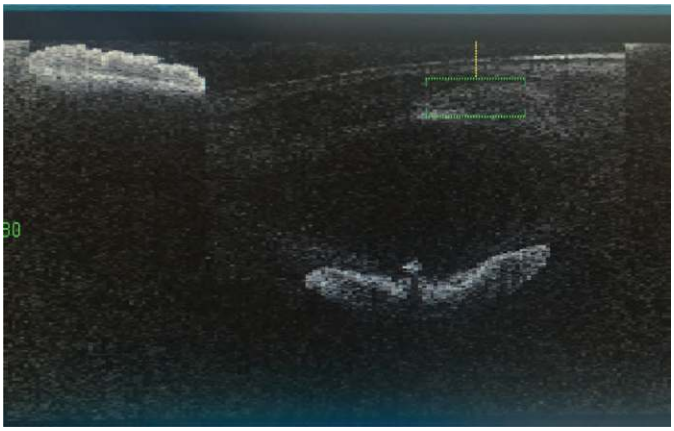

Fig. 2.6 Diagnostic anterior-segment OCT image of the lens and capsule in a patient with a posterior polar cataract, highlighting a discontinuity in the posterior capsule (Courtesy Sumit Garg, MD.)

Accurate identification of posterior polar cataracts is critical because these are often fused with the posterior capsule and can lead to capsular rupture with even the most careful removal. High-resolution anterior segment OCT devices can detect posterior capsular defects in such cases and thus aid in preoperative planning (Fig. 2.6).

OCULAR SURFACE DISORDER

One of the most common complaints that brings patients into the office for cataract surgery is fluctuating vision. It is important to distinguish the fluctuation associated with OSD versus the static/progressive drop in vision from the cataract. The prevalence of OSD in patients presenting for cataract surgery has been reported to be as high as high as 60% to 80%.[13] Visually significant OSD resulting in irregular astigmatism or erosions in the central 3 mm of the cornea should be treated before finalizing biometry and topography and proceeding to surgery. Dry eye disease (DED) often temporarily worsens after cataract surgery because of a combination of corneal incisions, topical anesthesia and toxicity from postoperative drops.[14] Optimization of the surface before surgery is necessary to avoid refractive error because of unrepresentative biometry and potentially visually limiting dryness (Fig. 2.7). Additionally, patients need to be educated that OSD needs to be treated proactively and will likely need to be treated after cataract surgery in addition to preoperative optimization.

A combination of tools such as questionnaires (Table 2.4), tear osmolarity, tear inflammation (MMP-9) and meibomian gland imaging can be used in conjunction with a thorough corneal examination to screen for and diagnose DED preoperatively (Fig. 2.8). Evaluation of the regularity of placido rings on topography and manual or automated tear break up time with the Keratograph (Oculus) or the HD Analyzer (Visiometrics) are also useful screening techniques (Fig. 2.9).

Treatment of DED should be based on the predominance of aqueous deficiency or evaporative disease. Limited-duration corticosteroids employed preoperatively may quickly rehabilitate the ocular surface. Concomitant steroid-sparing management should also be initiated, as long-term treatment is usually required. A combination of preservative-free lubricant drops, punctal occlusion, and topical steroid-sparing antiinflammatory agents, including LFA-1 or interleukin-2 antagonists, can be employed in a stepwise approach. In patients with significant meibomian gland dysfunction, treatment with compresses, scrubs, thermal pulsation, intense pulse light therapy and oral macrolides or tetracyclines is helpful in inflammation reduction and ocular surface rehabilitation.

Salzmann nodular dystrophy, anterior basement membrane dystrophy (ABMD), and pterygia should be addressed if involving or inducing irregular astigmatism in the central cornea (Fig. 2.10). Preoperative biometry and topography can be performed 4 to 8 weeks after treatment or once the corneal topography stabilizes on serial testing (Fig. 2.11A–C).

BLEPHARITIS

Blepharitis is an important risk factor for postoperative endophthalmitis.[15] Bacterial blepharitis should be treated preoperatively with lid-cleaning products, antibiotic ointments, hypochlorous acid, or mechanical blepharoexfoliation (BlephEx, LLC) to improve the ocular surface and reduce the risk for potential infection.

CORNEAL ENDOTHELIAL DISEASE

In eyes with preexisting corneal endothelial disease, such as in Fuchs' corneal dystrophy, cataract surgery can accelerate endothelial failure. Longer phacoemulsification time, dense cataracts, and shorter axial length are risk factors for endothelial cell loss. Careful examination for endothelial guttae and, if suspected, specular microscopy with endothelial cell profiling can identify patients who may require concomitant endothelial keratoplasty. Patients with endothelial dysfunction should be counseled about the potential need for endothelial keratoplasty in the future.

GLAUCOMA

On its own, cataract surgery can reduce intraocular pressure (IOP) regardless of glaucoma status. Also, cataract surgery is associated with intraoperative fluctuations in IOP, and in the postoperative period, temporary increases in pressure are not uncommon. A careful history, IOP measurement, and examination of the nerve should be conducted. Any abnormalities should lead to a more detailed workup and possible addition of a glaucoma procedure/MIGS to the surgical plan.

UVEITIS

Uveitis should be well controlled before surgery because uncontrolled postoperative inflammation can lead to poor outcomes. Most clinicians advocate for at least 3 months of quiescence before surgery.

Posterior synechiae associated with intraocular inflammation can pose challenges during cataract surgery (Fig. 2.12). The physician should plan for careful synechialysis and the use of ophthalmic viscosurgical devices (OVDs) to separate the iris and anterior lens capsule. The use of dilation-assisting and capsular support devices in the case of a small pupil and/or zonular instability may also be necessary.

INTRAOPERATIVE FLOPPY IRIS SYNDROME

Identification of patients at risk for intraoperative floppy iris syndrome (IFIS) is critical to preparation and consent for surgery. IFIS manifests with varying degrees of iris instability, billowing, and poor pupillary dilation. Systemic alpha-1 adrenergic blockers are classically associated with the syndrome, but benzodiazepines, antipsychotics, saw palmetto, and finasteride have also been independently linked.[16,17] The rate of IFIS in those taking alpha-1 blockers and other

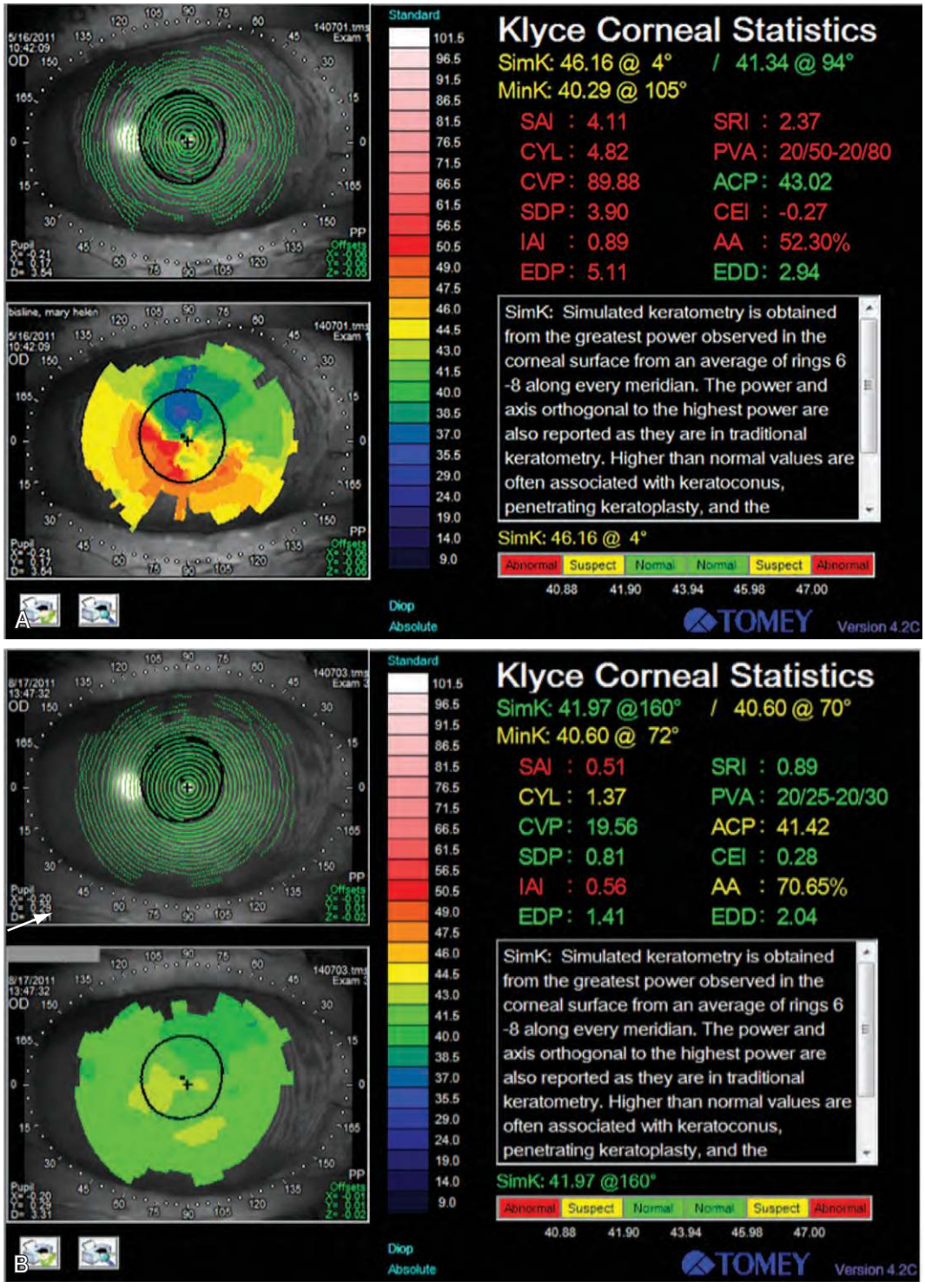

Fig. 2.7 Diagnostic image of corneal topography pretreatment (A) and posttreatment (B) for severe dry eye. Note the improvement in placido ring regularity and anterior corneal topography posttreatment. (Courtesy Stephen Pflugfelder, MD.)

TABLE 2.4 Dry Eye Disease Questionnaires

Questionnaire	Features
Ocular Surface Disease Index (OSDI)	12-Items, symptoms of dryness, and visual impact
Standard Patient Evaluation of Eye Dryness (SPEED)	14-Items and frequency and severity of symptoms
ASCRS-modified Preoperative OSD SPEED II	25-Items and frequency and severity of symptoms for preoperative refractive surgery patients
Symptom Assessment iN Dry Eye (SANDE)	2-Items and frequency and severity of symptoms
5-Item Dry Eye Questionnaire	5-Items and frequency and severity of symptoms

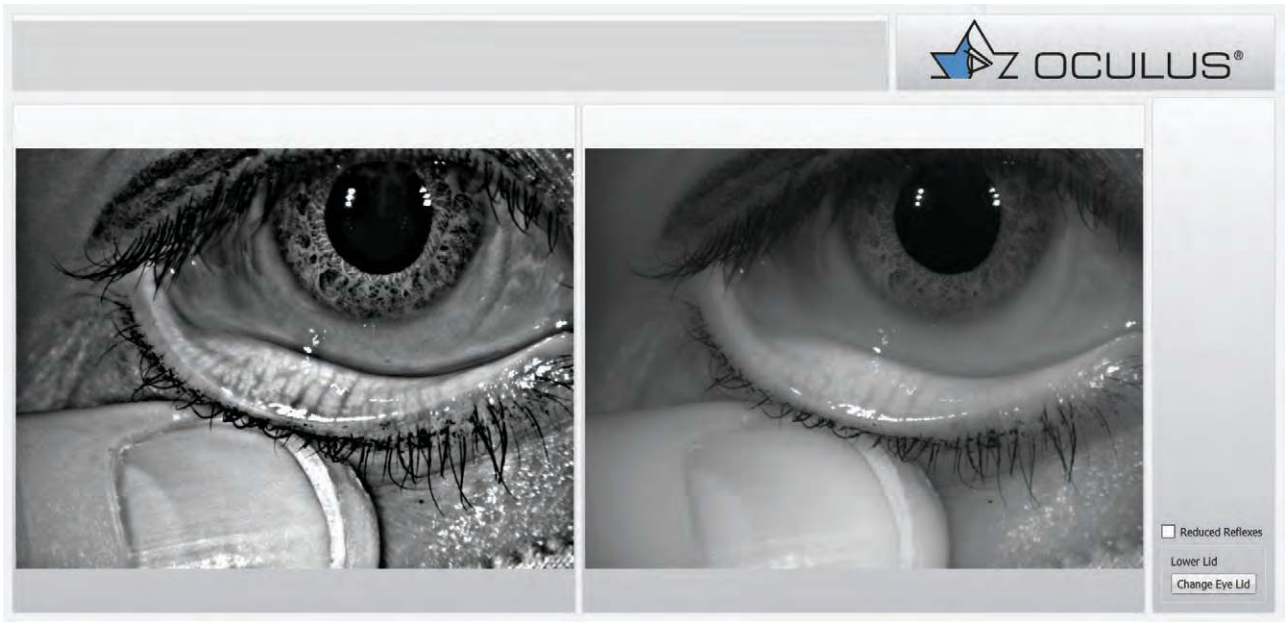

Fig. 2.8 Diagnostic image of meibomian glands on lid eversion from the Keratograph (Oculus). In-tact glands without atrophy are noted in the image.

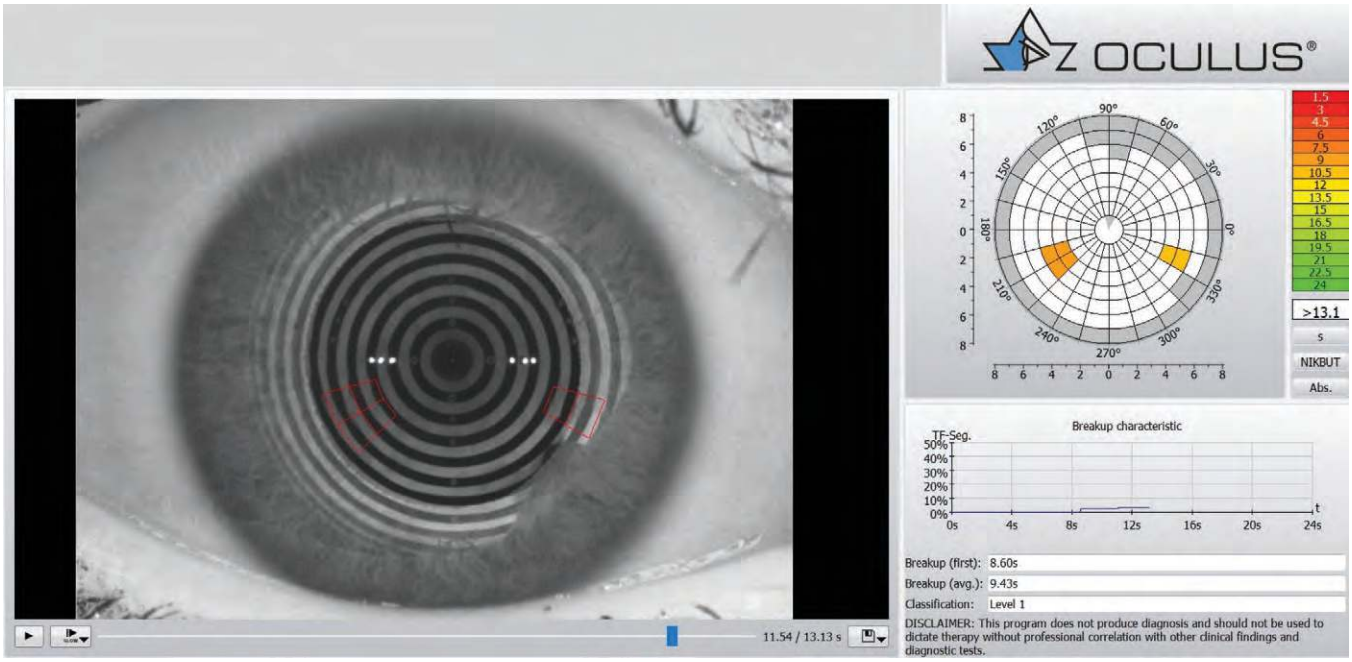

Fig. 2.9 Diagnostic image from an automated measurement of tear break up time (TBUT) from the Keratograph (Oculus). Highlighted portions in *red* on the *left* placido ring image indicate areas of tear break up. A measured average and earliest TBUT are shown in the *bottom right* display.

identified agents varies widely, and IFIS can also occur in those without known risk factors. Reduced pupillary dilation has been shown to be a strong predictor.[16]

Because of the higher risk for intraoperative complications, it is important to have a plan in place to manage IFIS. Discontinuing alpha antagonists preoperatively has not been shown to be useful in preventing or reducing the severity of IFIS.[16] Preoperative atropine drops for several days before surgery may be useful in increasing cycloplegia but has not been shown to be consistently reliable in preventing or managing IFIS.[16] At-risk patients should be noted, and adjuvant agents and devices should be made available at the time of surgery, should they be needed.

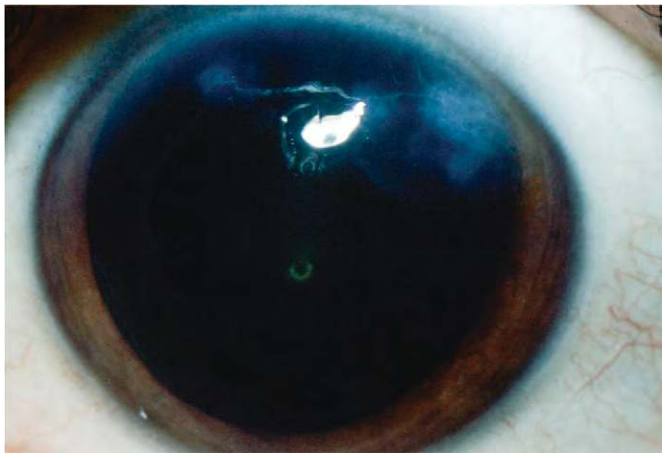

Fig. 2.10 Slit lamp photograph of Salzmann nodular dystrophy. (Courtesy Matthew Wilson, MD, and Louis Wilson, MD.)

SURGICAL PEARLS FOR PREVENTION AND MANAGEMENT OF INTRAOPERATIVE FLOPPY IRIS SYNDROME

- Intracameral preservative free phenylephrine, phenylephrine/ketorolac, epinephrine and epinephrine/lidocaine have all been shown to aid in the prevention and/or reduction of IFIS severity.[16,18]
- High-viscosity cohesive OVDs maintain chamber stability and block iris prolapse.
- Low-flow phacoemulsification settings may reduce iris billowing and prolapse.
- Pupil expansion devices should be available.

ZONULAR SUPPORT

Appropriate preoperative evaluation also includes an assessment of the natural lens support because zonular laxity can significantly increase the complexity and complication rate of surgery (Fig. 2.13).

! HISTORY AND CONDITIONS ASSOCIATED WITH ZONULAR INSTABILITY

- Trauma
- Pseudoexfoliation syndrome
- History of retinal surgery or intravitreal injections
- Marfan's syndrome
- Homocystinuria
- Retinitis pigmentosa
- Radiation

Findings that should be noted and considered signs of zonular instability include:

- Phacodonesis
- Lens subluxation
- Iridodonesis
- Visible zonular dialysis
- Vitreous in the anterior chamber

In cases of moderate to severe zonular laxity, it is helpful to lean the patient back and observe the extent of posterior rotation of the lens. If the lens falls significantly into the vitreous cavity, it may be beneficial to consider a posterior approach for surgery with a pars plana vitrectomy.

PATIENT COUNSELING AND INFORMED CONSENT

Informed consent for cataract surgery has expanded significantly. The preoperative discussion not only includes the risk profile, potential benefits, and complications of surgery, but it also includes a determination of visual goals and the advantages and disadvantages of an expanding list of IOLs, each with specific and nuanced characteristics.

POTENTIAL RISKS AND COMPLICATIONS OF CATARACT SURGERY (NOT ALL INCLUSIVE)

- Posterior capsule rupture
- Infection
- Vision loss
- Retained lens material
- Need for corrective lenses after surgery
- Posterior capsule opacification
- Cystoid macular edema
- Prolonged or persistent corneal edema or decompensation
- Descemet's membrane detachment
- Retinal detachment
- Worsened floaters
- Worsened dry eye
- Ptosis
- Elevated IOP
- Anisocoria/iris damage
- Late intraocular dislocation
- Need for a second surgery for lens reposition, placement, or removal of lens material

Determining a patient's visual goals is central to planning and consent for cataract surgery. Multiple standardized questionnaires are available that can direct conversations regarding visual disability, refractive goals, and IOL selection. Some questionnaires focus on grading visual impairment, such as the Catquest questionnaire, whereas others include questions defining patient goals, habits, and personality traits such as Steve Dell's Cataract and Refractive Lens Exchange Questionnaire.

Specific technologies have unique points to discuss for a complete informed consent, a few of which are listed below.

ASTIGMATISM MANAGEMENT

If a patient desires glasses independence for distance, near, or both, astigmatism management is often required for optimal outcomes. After a regular astigmatism pattern is established with topography, the magnitude of astigmatism dictates if correction with peripheral corneal relaxing incisions (performed with femtosecond laser or manually) or with a toric IOL would best.

Each method of astigmatism correction requires a unique consent.

GENERAL RISKS AND POTENTIAL COMPLICATIONS OF ASTIGMATISM CORRECTION

- Risk for residual astigmatism requiring a corneal-based refractive procedure or corrective lenses

PERIPHERAL CORNEAL RELAXING INCISIONS

- Potentially increased dry eye caused by severing of corneal nerves
- Decreased effect with time
- Risk for irregular astigmatism
- Risk for corneal perforation

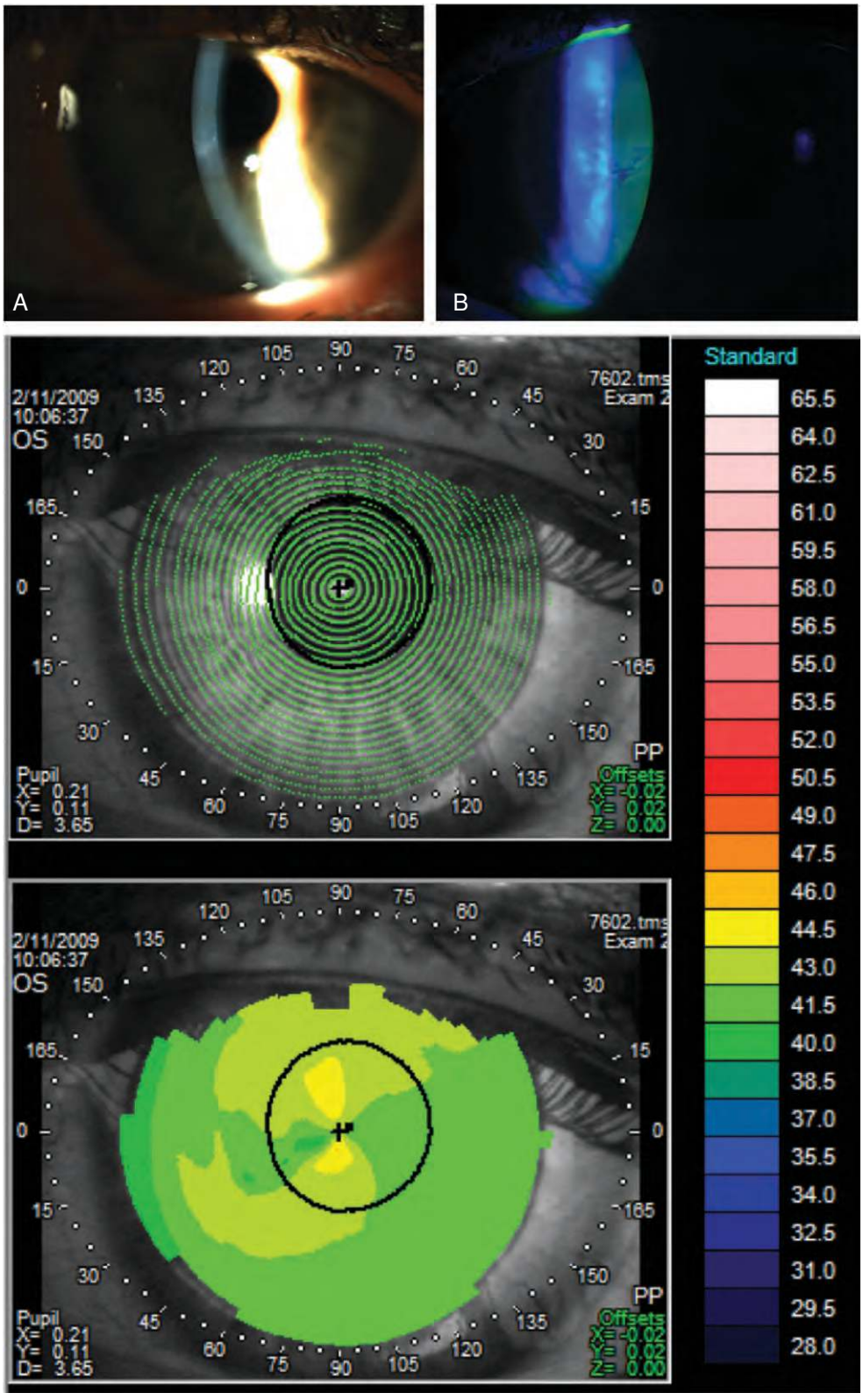

Fig. 2.11 (A) Slit lamp photograph of ABMD in the central 3 mm of the cornea. (B) Slit lamp photograph with fluorescein dye highlighting the negative stain of the ABMD in the central cornea. (C) Diagnostic image of corneal topography with placido rings showing the irregularity in topography and rings induced by the ABMD. (Photo courtesy of Stephen Pflugfelder, MD.)

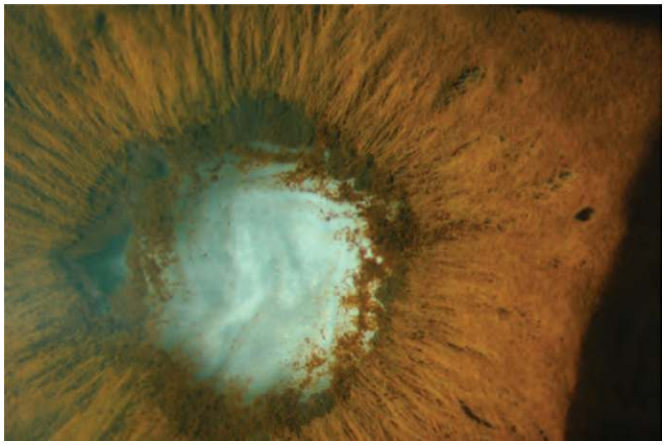

Fig. 2.12 Slit lamp image of a dense cataract with posterior synechiae limiting pupil dilation in a patient with uveitis. OVD-assisted synechiolysis and pupil expansion devices aid in cataract removal. (Courtesy Debra Goldstein, MD.)

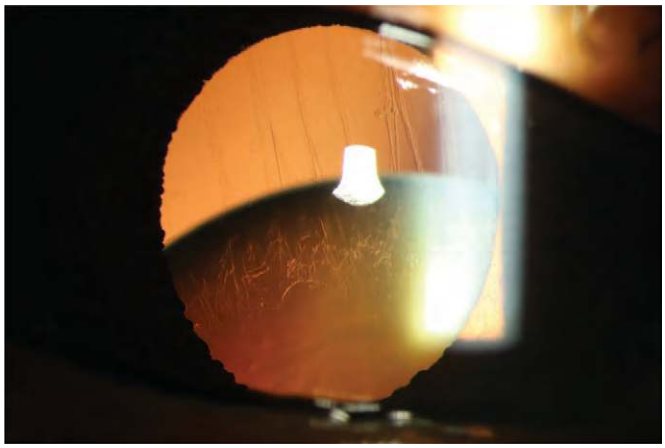

Fig. 2.13 Slit lamp image of an inferiorly displaced cataract after trauma with retroillumination. Retroillumination is often helpful to visualize zonules. (Courtesy Jessica Lam, OD, and Joe Mastellone.)

TORIC INTRAOCULAR LENS

- Risk for postoperative rotation requiring correction with lens repositioning, corneal-based refractive procedure, or corrective lenses
- Possibility that lens cannot be implanted because of zonular weakness or capsule tear requiring a corneal-based refractive procedure or corrective lenses

PRESBYOPIA CORRECTION

If a patient seeks glasses independence for both distance and near vision, a presbyopia correcting IOL may be the most suitable choice. A comprehensive examination and detailed discussion are necessary to select suitable patients and set reasonable expectations.

Optimal candidates for presbyopia-correcting IOLs include those with:

- Regular astigmatism
- Small angle kappa/Chang-Waring chord
- Good/stable tear film
- Normal corneal examination
- Minimal or no macular or optic nerve abnormalities
- Binocular vision
- Amendable personality

Unique points to include in the consent for presbyopia-correcting IOLs include:

- Multifocal/trifocal lenses: risk for halos and glare
- Extended depth of focus lenses: risk for halos, glare, and starbursts
- Decreased contrast sensitivity
- Intolerance to implant requiring explant
- Possibility that lens cannot be implanted because of zonular abnormality or capsular tear
- Some degree of corrective lenses will likely be required for some tasks, depending on the lens chosen (e.g., reading small print in low light conditions with a multifocal lens)

TIMING OF SEQUENTIAL CATARACT SURGERY

As demand for cataract surgery increases with the aging population, the logistics of providing and coordinating care becomes more challenging. Timing of cataract surgeries for patients in need of bilateral surgery has become an important topic of discussion. The more traditional sequential bilateral cataract surgery with 1 week or more between surgeries can offer refractive benefits from analysis of the first eye refractive outcome. Modifying the IOL power selection of the second eye by adjusting the selection to correct 50% of the error from the first eye has been shown to improve second eye refractive outcomes.[19] This delayed sequential surgery can be cumbersome both in cost and logistics for patients and healthcare systems because multiple postoperative visits are required for each eye. Immediate sequential bilateral cataract surgery with the second eye surgery either immediately on the same day or the next day offers benefits and challenges, some of which are listed below.

IMMEDIATELY SEQUENTIAL BILATERAL CATARACT SURGERY

Advantages

- Improved efficiency for healthcare system and patient
- Reduced wait time for surgery
- Fewer postoperative visits
- Lower risk and duration of anisometropia
- Shorter duration of postoperative limitations

Disadvantages

- Reimbursement challenges
- Absence of refractive result from first eye to adjust IOL selection for the second eye
- Potential dissatisfaction with bilateral lens choices
- Infection concerns
- Possible bilateral complication (corneal edema, toxic anterior segment syndrome)

Although there is a lack of refractive outcome data from the first eye in immediately sequential bilateral cataract surgery, a large retrospective review did not show worse postoperative refractive error or complication risk compared with traditional or delayed sequential surgery.[20]

FLOWCHART FOR EVALUATION OF A PATIENT WITH CATARACTS

Process for systematically evaluating a patient with cataracts, assessing needs, and preparing for surgery (Fig. 2.14).

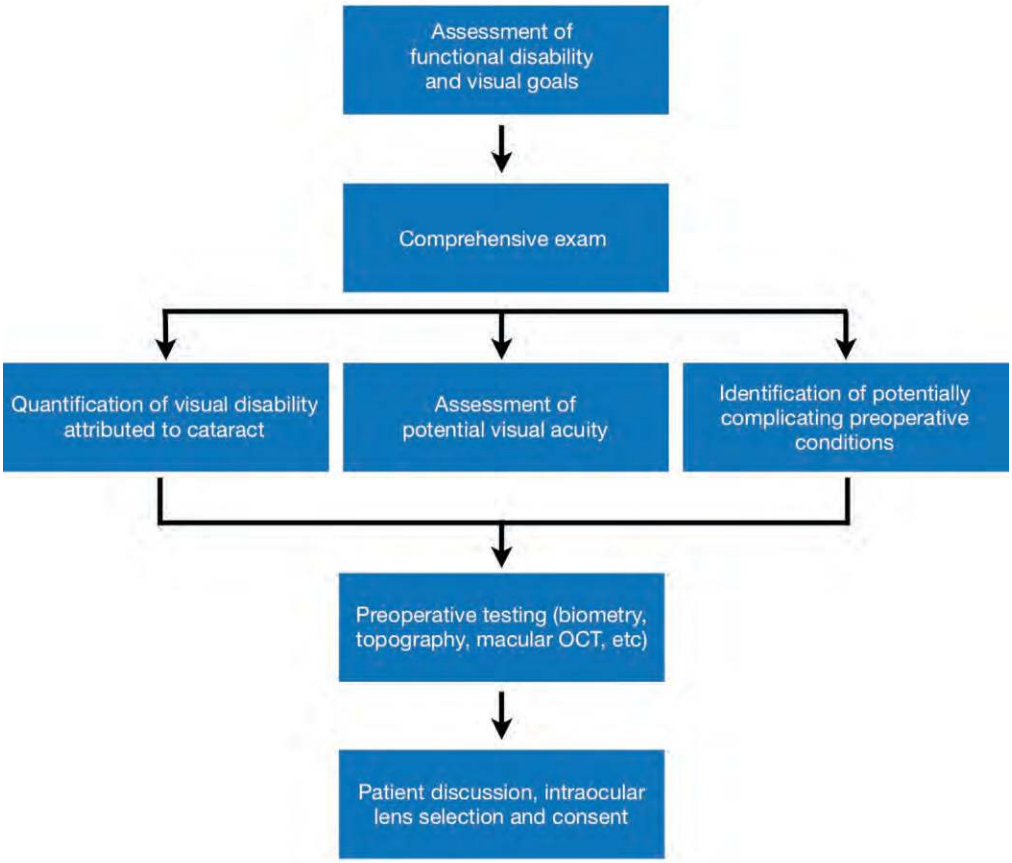

Fig. 2.14 Flowchart showing the workflow and process for evaluation of a patient with cataracts. Streamlining the thought process behind the workup and performing the algorithm on every patient helps ensure consistency and efficiency.

SUMMARY

- Quantification of visual and functional disability attributed to a cataract is necessary to establish the benefits of surgery.
- Treatment of OSD is important to achieve refractive targets.
- Identification of complicating conditions such as IFIS and zonular laxity allows for appropriate consent and preparation for surgery.
- Unique consent for advanced technology lenses is important to set expectations and select the most appropriate lens for each patient.

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3

Current Concepts in Intraocular Lens Power Calculations

Seth Michel Pantanelli

CONTENTS

KEY POINTS

- Optimize ocular comorbidities, especially the ocular surface, with best practices including contact lens holidays and a preoperative lubrication regimen.
- Scrutinize the quality of biometry measurements by looking at the raw data, and rationalize any extreme values.
- Choose an appropriate formula, check postoperative refractions, and optimize lens constants (when possible).
- Align patients' desires and expectations with achievable outcomes.

INTRODUCTION

The primary goal of cataract surgery remains the safe removal of the cataractous lens and replacement with an artificial intraocular lens (IOL), but an increasingly important secondary objective is minimization of refractive error. Although some surgeons may not find this process to be particularly stimulating, IOL power calculations are not to be underestimated. Advancements in biometry and formulas have simplified the process greatly; nonetheless, attention to detail is rewarded with exceptional refractive outcomes. In this chapter, we explore the current state of (1) biometry, (2) formulas, and (3) our understanding of how clinical variables interact with the former. Biometry will be divided into the components needed to calculate IOL power: axial length (AL), corneal power, and other variables. Formulas will be discussed by type, appropriate usage, and personalization. Clinical variables will be separated into topics including patient needs and desires, special circumstances, and problems and errors. By studying these three components, we can appreciate the conditions under which they work so well and why they fail to deliver the desired outcome in certain circumstances.

When the natural lens is removed, the resulting optical system consists of an underpowered "first lens" (the cornea) of power K, a yet-to-be-determined "second lens" (the IOL) of power P, and an image capture device (the retina) at a fixed distance (Fig. 3.1). To calculate P, one must know the vergence of light entering the optical system (R), which is zero in the case of emmetropia. The distance (X) between the two lenses affects the refraction, as does the distance (Y) between the two-lens system and the retina. X is defined as the distance between the vertex of the cornea and the principal plane of the IOL in the visual axis. Y is the distance between the principal plane of the IOL along the visual axis and the fovea. It is easy to see that X + Y is equal to the AL. Although AL can be measured preoperatively, X and Y cannot, and thus the formula X + Y = AL is not easily solved. Fortunately, there exists a relationship between preoperatively measured K, anterior chamber depth (ACD), lens thickness (LT), and X, which may also be thought of as effective lens position (ELP). Through regression analysis and theoretical modeling, the correlation between these biometry variables and ELP has been elucidated, and is the defining factor distinguishing many of the modern formulas from one another.

BIOMETRY

Obtaining biometry of the eye is synonymous with the accurate measurement of parameters that define the optical system. At a minimum, these include AL, corneal power, and ACD. Historically, these were measured by different devices (e.g., immersion ultrasound, manual keratometer), but modern biometers combine multiple technologies into one device to capture all of these variables. Table 3.1 is a nonexhaustive list of currently available devices and the technologies incorporated into each.

AXIAL LENGTH

Whether the goal of surgery is removal of the cataractous lens and replacement with an IOL or secondary IOL placement in the setting of aphakia, accurate measurement of AL is mandatory. It is the most important biometric variable to record accurately as errors in AL result in ~ 1.75 D/mm and 3.75 D/mm errors in IOL power in long and short eyes, respectively. As such, it should always be reported in hundredths

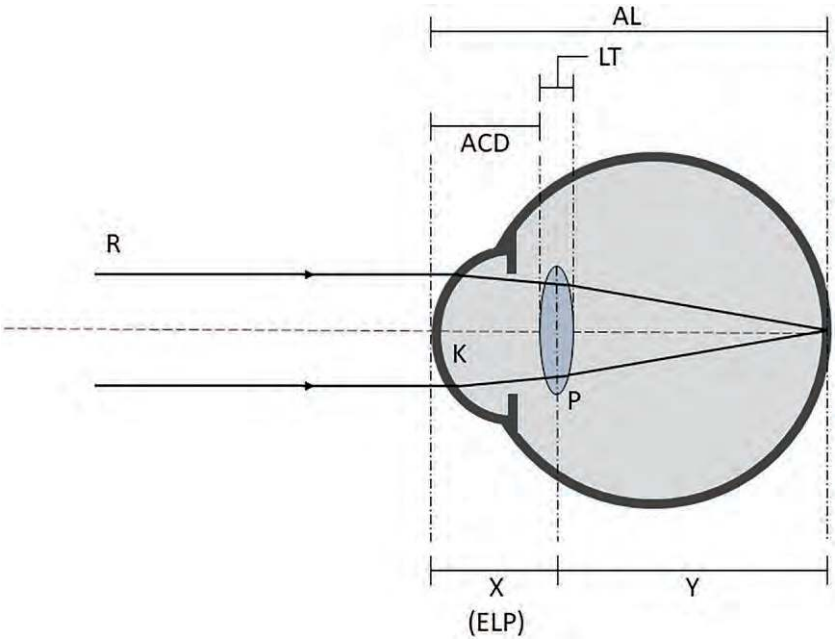

Fig. 3.1 Diagrammatic representation of measured biometric variables *(top)* and relevant optical distances *(bottom)* for determination of the intraocular lens (IOL) power *(P)*. *K* = power of cornea, measured as a radius of curvature in millimeters and reported in diopters; *R* = vergence of incoming light, which is zero when targeting emmetropia; *ACD* = anterior chamber depth, defined from the vertex of the cornea to the anterior surface of the lens capsule and measured in millimeters; *LT* = lens thickness, measured in millimeters; *AL* = axial length, measured in millimeters; *X* = distance from the vertex of the cornea to the principal plane of the IOL; *Y* = distance from the principal plane of the IOL to the retina; *ELP*, Effective lens position.

TABLE 3.1 Biometers and Incorporated Technology

		TECHNOLOGY USED TO MEASURE VARIABLE				
Device	**Manufacturer**	**AL**	**ACD**	**LT**	**Anterior K**	**Posterior K / TCP**
Anterion	Heidelberg Engineering	SS-OCT				
Argos	Movu	SS-OCT			Reflectance keratometry + SS-OCT	
Cassini	Cassini Technologies				Multicolor LED reflectance keratometry	Infrared reflectance keratometry
Galilei (G6)	Ziemer Ophthalmic Systems	OLCR	Scheimpflug imaging	OLCR	Placido-disc video keratography; Scheimpflug imaging	Scheimpflug imaging
IOLMaster (500)	Carl Zeiss Meditec	PCI	Slit-lamp based imaging		Reflectance keratometry	
IOLMaster (700)	Carl Zeiss Meditec	SS-OCT			Reflectance keratometry	SS-OCT
Lenstar (LS-900)	Haag-Streit AG	OLCR			Reflectance keratometry	
Pentacam (AXL)	Oculus	PCI	Scheimpflug imaging			
Sirius	Schwind				Placido-disc video keratography; Scheimpflug imaging	Scheimpflug imaging

AL, axial length; *ACD*, Anterior chamber depth; *K*, corneal power; *LED*, light-emitting diode; *LT*, lens thickness; *TCP*, total corneal power; *SS-OCT*, swept-source optical coherence tomography; *PCI*, partial coherence interferometry; *OLCR*, optical low-coherence reflectometry.

of a millimeter. Key considerations for obtaining accurate AL measurements are summarized in Box 3.1.

Historically, AL was measured using either contact or immersion ultrasound.[1,2] This technology, while now considered somewhat antiquated, still holds a place in the offices of cataract surgeons. There are many instances in which obtaining an AL by optical methods are not feasible, and include hyper-mature nuclear, dense posterior subcapsular (PSC), and white cataracts. Individuals that have positional limitations or those that are not capable of cooperating enough to allow for optical biometry may also be measured using A-scan ultrasound.

With immersion ultrasound, the patient should be should be supine or reclined at a 45-degree angle such that the line of sight can be oriented as close to perpendicular to the floor as possible. An open cylinder (Hansen Shell, Hansen Ophthalmic Development Lab, Coralville, IA, USA) or fixed immersion shell (Praeger Shell, ESI Inc., Plymouth, MN, USA) is secured and centered over the cornea. In the case of a fixed immersion shell, the ultrasound probe is seated at the appropriate depth. Balanced salt saline is added to the chamber until it reaches the probe tip and the device begins taking measurements. A technician may then observe the spikes and make adjustments. An experienced

technician will employ several techniques to maximize the quality of the measurements. These include measuring through an undilated pupil to improve the chances of being axial, repeating individual measurements to identify outliers, maximizing the height of spikes, and manually verifying gates (sampling points on the reflected spikes) defined by the device. Because ultrasound travels through different media with varying velocities, it is also critical that clinical parameters be correctly identified (i.e., phakic, pseudophakic, phakic IOL, or silicone oil) and the velocities set accordingly. Table 3.2 lists the known ultrasound velocities through various parts of the eye and IOL materials.[3] Fig. 3.2 highlights the importance of several of the points described herein.

Compared with ultrasound, optical biometry permits more accurate measurement of AL.[4,5] Two such technologies for doing so include

BOX 3.1 Considerations for Obtaining Accurate Axial Length Measurements

- Use optical biometry (partial coherence interferometry [PCI], optical low-coherence reflectometry [OLCR], or swept-source optical coherence tomography [SS-OCT]) over A-scan (ultrasound) measurements whenever possible.
- Confirm lens status (phakic, pseudophakic, aphakic).
- Confirm vitreous status (vitreous, silicone oil).
- Check fixation.
- Compare measurements between eyes, and rationalize discrepancies.

TABLE 3.2 Ultrasound Velocities for Various Parts of the Eye and Intraocular Lens Materials[3]

Structure	Ultrasound Velocity (at Body Temperature)
Cornea and lens	1641 m/sec
Aqueous and vitreous	1532 m/sec
Polymethylmethacrylate IOL	2660 m/sec
Silicone IOL	980 m/sec
Acrylic IOL	2026 m/sec
Glass IOL	6040 m/sec
Silicone oil	987 m/sec

IOL, Intraocular lens.

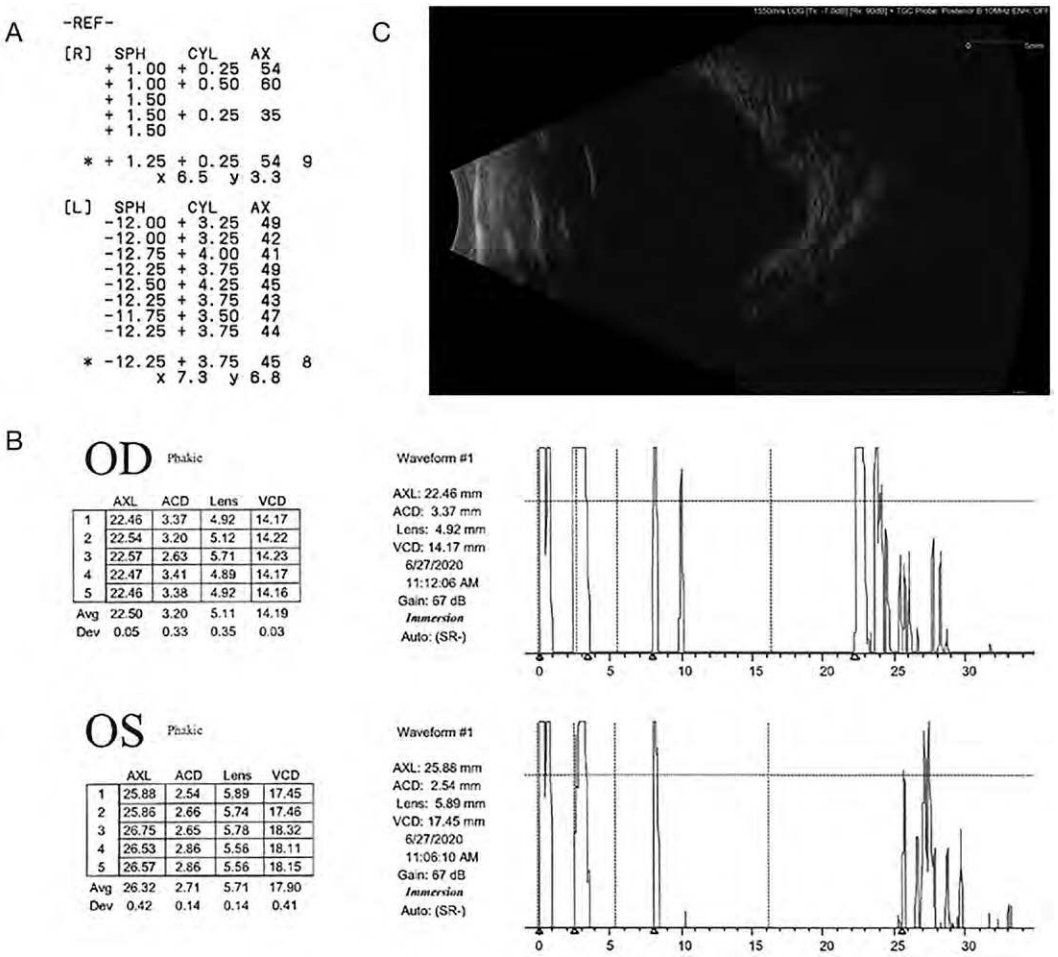

Fig. 3.2 Patient with (A) significant anisometropia as measured by an auto-refractor, (B) immersion ultrasound revealing large difference in axial length *(AXL)* between eyes, and (C) B-scan ultrasound confirming the presence of posterior staphyloma. Note that the gate defining the anterior surface of the lens in the right eye *(OD)* was incorrectly identified. Such an oversight can result in significant intraocular lens power prediction errors and should be manually checked and corrected by the technician/physician. *ACD*, Anterior chamber depth; *Avg*, average; *AXL*, axial length; *CYL*, cylinder; *Dev*, standard deviation; *OS*, left eye; *SPH*, sphere; *VCD*, Vitreous chamber depth.

partial coherence interferometry (PCI) and optical low-coherence reflectometry (OLCR), available on the IOLMaster 500 (Carl Zeiss Meditec) and Lenstar LS-900 (Haag Streit), respectively. The technologies differ with regards to their light sources and the arrangement of their respective interferometers. PCI on the IOLMaster employs the use of a multimode laser diode with a peak wavelength of 780 nm, whereas OLCR on the Lenstar uses a superluminescent diode centered at 820 nm. PCI measures the reflections from the cornea and retina in parallel using two separate beams, whereas OLCR uses a traditional Michelsen interferometer, which compares a measurement path (the patient's eye) against an internal reference path. Differences in the wavelengths do not result in any clinically meaningful differences with regards to cataract penetration or accuracy of AL measurements.[6,7] However, PCI is only able to measure a single distance, AL, whereas OLCR is capable of capturing a full A-scan of the entire eye, with distances including central corneal thickness (CCT), ACD, LT, and AL all from a single scan. This is important because PCI-based biometers must capture other biometric variables using complementary technology, and must calculate AL using a grouped index of refraction for the entire eye. On the other hand, OLCR has the capability of calculating AL by summing the individual optical path lengths while considering their respective refractive indices, although current devices still calculate the displayed AL using the single grouped index of refraction. At least two studies have reported that cataract surgery outcomes might be improved using this sum-of-segments AL, and this remains an active area of research.[8,9]

Swept-source optical coherence tomography (SS-OCT) is another technology being incorporated into optical biometers (Anterion [Haag Streit], Argos [Movu] and IOLMaster 700 [Carl Zeiss Meditec]). Like OLCR, SS-OCT brings the possibility of measuring optical path lengths between structures, with the added benefit of generating a full high-resolution B-scan (Fig. 3.3). The technology is extremely robust, and has been shown to have lower within-subject standard deviation AL (0.01 vs. 0.05 mm) and ACD (0.04 mm vs. 1.22 mm) measurements compared with OCLR.[10] Perhaps the greatest benefit of SS-OCT is its success in obtaining AL measurements in the case of dense PSC or nuclear cataracts. One study by Hirnschall et al. demonstrated 99.5% success rate with AL measurement compared with 93.6% with PCI.[11] It should be noted that the Anterion and IOLMaster 700 both calculate their displayed AL using a group refractive index, whereas the displayed AL on the Argos is calculated via the "sum-of-segments." Lastly, some SS-OCT devices allow for visualization of the foveal pit. This not only allows the technician to verify fixation during the measurement, but it may also be used as a low-fidelity screening tool to identify macular pathology, prompting a higher resolution scan when abnormalities are seen. Even though the technology is extremely robust, SS-OCT images should be inspected for correct identification of interfaces, just as we do with gates in low-fidelity A-scans.

Regardless of the technology used, the quality of the AL measurements should be scrutinized. On the IOLMaster 500, a signal to noise ratio ≥2.0 for individual and ≥50 for composite measurements is a good target. On the IOLMaster 700, Lenstar 900, and others, a standard deviation ≤20 microns is sufficient. Traditional teaching is that the two eyes should also not differ by more than 0.3 mm, but newer research by Kansal et al. suggests greater uncertainty in outcomes when the AL discrepancy between eyes is ≥0.2 mm.[12] Thus any difference of this magnitude must be rationalized. The clinician might ask whether there was loss of fixation in one or both eyes, or whether the patient has a history of scleral buckle surgery. If a precataractous refraction is available, it can be compared with the measured difference in AL to determine whether the patient's anisometropia is physiological and longstanding; for every 1 mm difference in AL, we expect a difference in the refractive spherical equivalent (SE) of ~ 2.5 D (assuming all other variables like corneal curvature and density of the cataract are equal). A true difference between ALs is a diagnosis of exclusion, and is the correct assumption only after the above has been considered.

CORNEAL POWER

The first lens in the eye is the cornea, and it provides a majority of the focusing power for the optical system. Corneal power is the second most important variable in IOL power calculations, behind AL. A 1 D error in measurement translates to ~ 0.9 D error in IOL power prediction. Although the actual index of refraction of the cornea is 1.376,[13] the keratometric index displayed on most automated keratometers is less. In the United States, 1.3375 is often used, while other countries have adopted a value of 1.3315. In both cases, these are adjusted indices of refraction that account for the contribution of the posterior cornea using the Gullstrand ratio for the anterior and posterior radii of curvature. The former (1.3375) was derived using geometric optics and

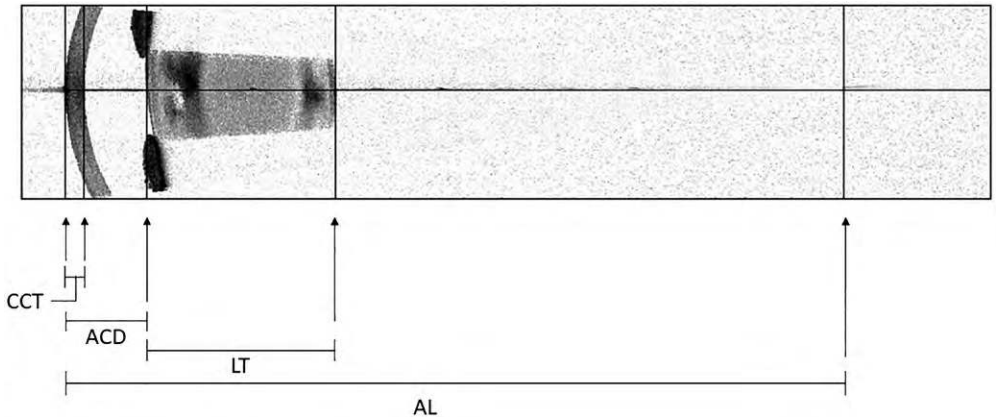

Fig. 3.3 Swept-source optical coherence tomography anterior segment image from an optical biometer (IOLMaster 700, Carl Zeiss Meditec). Note the gates the device has identified through the apex of the anterior cornea, posterior cornea, anterior lens, posterior lens, and retina. These will rarely be mis identified, but careful scrutiny can avoid a significant source of intraocular lens power calculation error. *ACD*, Anterior chamber depth; *AL*, axial length; *CCT*, central corneal thickness; *LT*, lens thickness.

vergence calculations for multiple refractive surfaces, while the latter was derived using a Gaussian thick lens formula. Key considerations for obtaining accurrate corneal power measurements are summarized in Box 3.2.

Surgeons typically think of corneal power in terms of diopters, but what is actually measured is the radius of curvature (r), reported in millimeters. Automated keratometers thus convert the measured radius of curvature (r) to diopters (D) using the equation $D = 337.5/r$. It is important to note that this equation is based on an assumed and fixed relationship between the anterior and posterior corneal curvatures. Although this assumption works well for normal and surgically naïve eyes, it is not true in eyes that have irregular corneas (i.e., keratoconus, pellucid marginal degeneration) or have a history of corneal refractive surgery (i.e., photorefractive keratectomy [PRK] or laser in situ keratomileusis [LASIK]). This is one reason why automated keratometry may not be accurate in these eyes.

Many manual and automated keratometers assess anterior radius of curvature through reflectance keratometry (IOLMaster, Carl Zeiss Meditec; Lenstar, Haag Streit) or placido-disc videokeratography (Pentacam, Oculus; Galilei, Ziemer). These methods work by photographing the reflection of multiple lights or rings projected onto the anterior surface of the cornea. For any one device, the spacing between lights or rings is known for a reference sphere of radius (x); any deviation from this can be used to determine the actual average radius of curvature (r) of the patient's cornea, the astigmatism magnitude, and axis. One corneal topographer, the Cassini (Cassini Technologies, The Hague, Netherlands), uses multicolor light-emitting diode (LED) reflectance keratometry for the anterior surface, and infrared LED reflectance keratometry to assess the posterior surface. Multiple studies have shown that many of these measures of anterior corneal curvature are highly correlated and interchangeable across devices.[14–16]

Other methods for measuring corneal power include Scheimpflug imaging and SS-OCT. The added benefit of these technologies is that they may both ascertain posterior corneal radius of curvature. This allows for calculation of total corneal power when combined with anterior corneal curvature measurements. It is critical to note, however, that total corneal power measurements may not be interchangeable across devices[17] and may not necessarily be used in lieu of traditional anterior corneal power measurements in IOL power prediction formulas. Although there may be incremental added value to total corneal power measurements for IOL power calculations in normal eyes,[18,19] it has become increasingly clear that they can be used to improve outcomes in abnormal eyes, such as those with keratoconus or a history of corneal refractive surgery.[20,21]

Because many of the methods to measure corneal curvature rely on a pristine reflected image, optimizing the ocular surface quality in anticipation of measurements is paramount. This includes treating any underlying disease like dry eye, meibomian gland dysfunction, or anterior basement membrane dystrophy (ABMD). Often, this can be achieved with over-the-counter artificial tears and/or institution of lid hygiene or warm compresses. In the case of ABMD, a superficial keratectomy should be performed, with measurements to follow 2 to 3 months later. Failing to take this important step is likely to result in either a refractive surprise or suboptimal quality of postoperative vision. Fig. 3.4 illustrates the degree to which ABMD may disrupt the placido videokeratography image taken with a corneal topographer.

BOX 3.2 Considerations for Obtaining Accurate Keratometry Measurements

- Calibrate the keratometer regularly.
- Assure that the keratometric index is set properly (usually 1.3375).
- Optimize the ocular surface.
- Contact lens holiday.
- Confirm image quality.
- Check fixation.
- Compare measurements between eyes and rationalize discrepancies.
- Check corneal topography to assess for irregularities in extremely flat, steep, or highly astigmatic eyes.
- Make compensatory adjustments in eyes that do not obey Gullstrand's eye model (post-LASIK, keratoconus).

LASIK, Laser in-situ keratomileusis.

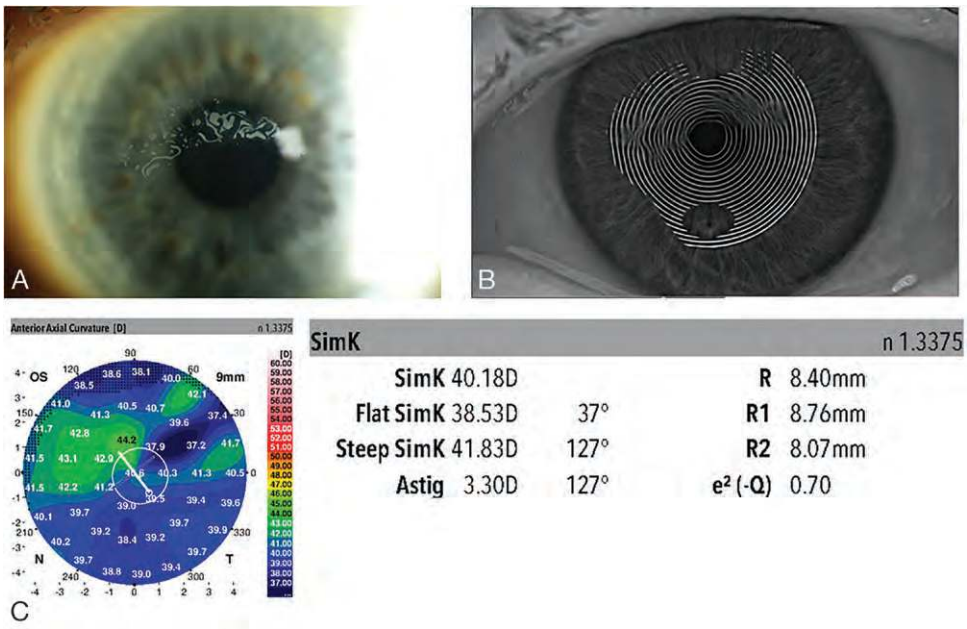

Fig. 3.4 (A) Slit lamp photograph, (B) placido videokeratography image, and (C) resulting corneal topography in a patient with central anterior basement membrane dystrophy (ABMD). The ABMD results in significant disruption in placido image quality and irregular astigmatism.

Contact lens wear is also known to effect corneal surface regularity and, as such, patients should be instructed to discontinue their use prior to measurements. A study by Meyer et al. demonstrated mean changes in SE, astigmatism magnitude, and astigmatism axis of 0.31 D (range 0.02–1.01), 0.41 D (range 0.01–1.10), and 6.3 degrees (range 0–28), respectfully, after a 14-day hiatus (the study included both soft and hard contact lenses).[22] There is no universally agreed upon advice regarding the length of the contact lens holiday, but one conservative suggestion is to discontinue soft contact lenses for 14 days and rigid gas permeable lenses for 21 days plus an additional 7 days for each decade of use or until topographic stability is verified.

Just as the gates on an A-scan ultrasound are to be confirmed to ensure accurate AL measurements, so too should the reflectance keratometry image be directly inspected for quality. Fig. 3.5 illustrates how even minor degradation in the reflectance keratometry image quality can dramatically alter the magnitude and axis of reported astigmatism. Likewise, some biometers (i.e., IOLMaster 700, Carl Zeiss Meditec) now permit one to directly visualize the foveal pit while measurements are taken, thus confirming fixation. Fig. 3.6 illustrates how the astigmatism can be altered if this criterion is not satisfied.

Astigmatism

When correction of astigmatism at the time of surgery is not planned, it need not be considered at the time of IOL power calculation. This is because the goal is to predict the postoperative SE refractive error, and the average of the two K readings is the only value used to make these predictions. The exception to this would be in cases of irregular astigmatism (i.e., keratoconus), which might alter the accuracy of SE predictions. In these cases, corneal topography and compensatory methods of IOL power calculation are warranted.

When astigmatism correction is planned, the reliability of the flat and steep keratometry values must be considered. Once again, one way to do this is to inspect the quality of the images oneself or rely on the measurement devices' internal quality metrics to warn of uncertain/unreliable values. A standard deviation within 0.3 D (R = 0.02 mm) is good for the corneal power, while 3.5 degrees is acceptable for axis. Another strategy is to measure the astigmatism with two or more devices, typically an optical biometer and a topographer. There are no universally accepted standards for how well the two devices must agree to proceed with an astigmatism correction plan, but one conservative recommendation might be an agreement within 0.5 D in magnitude and 10 degrees in axis. Higher magnitudes of astigmatism should have greater axis agreement across devices. For example, one might tolerate a disagreement of 10 degrees in the axis on a measured magnitude of 1.0 D, but this threshold would be unacceptable with a measured magnitude of 5.0 D (5 degrees would be more reasonable). The preoperative manifest refractive cylinder may serve as a third point of reference, giving the surgeon confidence in the measured value. Note that the manifest refractive cylinder would be expected to be the same or slightly higher than measured values in eyes with against-the-rule

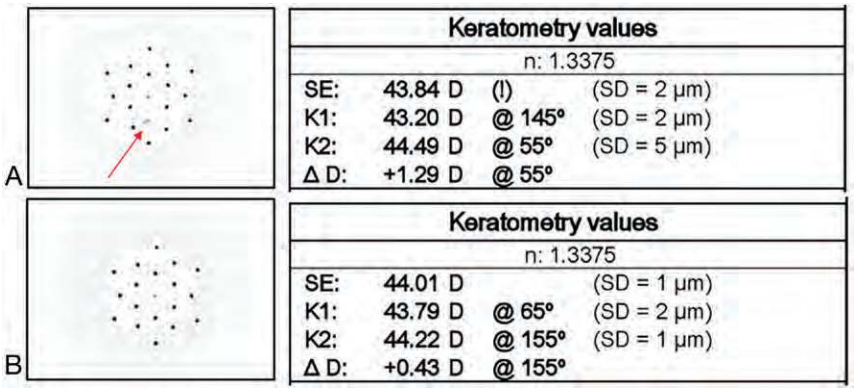

Fig. 3.5 (A) Automated reflectance keratometry image showing a single reflected spot that is smeared and (B) repeat measurement showing acceptable image quality. Note the change in astigmatism magnitude and axis of nearly 0.9 D and 100 degrees, respectively. *K1*, flat K; *K2*, steep K; *SD*, standard deviation; *SE*, spherical equivalent; *Δ*, difference between flat K and steep K.

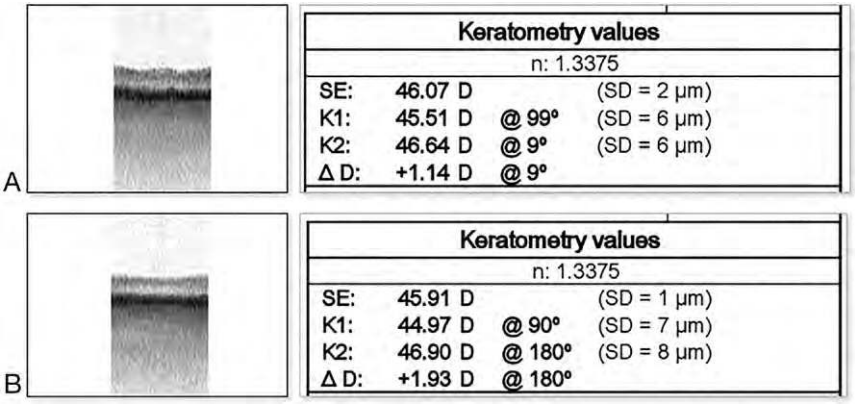

Fig. 3.6 Keratometry values (A) without and (B) with visualization of the foveal depression confirming fixation. *K1*, flat K; *K2*, steep K; *SD*, standard deviation; *SE*, spherical equivalent; *Δ*, difference between flat K and steep K.

(ATR) astigmatism and lower in those with with-the-rule (WTR) astigmatism because of the contribution from the posterior cornea and other sources of nonkeratometric astigmatism.[23,24]

OTHER VARIABLES

ACD is defined as the distance between the anterior corneal vertex (epithelium) and front surface of the crystalline lens. It is a required value for all modern formulas. The ACD is directly proportional to the location at which the IOL will ultimately rest, or the ELP, and it is thus the third most important variable in IOL power predictions. Older formulas, such as Holladay I and Sanders-Retzlaff-Kraff (SRK)/T, do not rely on ACD for ELP predictions; this is why they work well for eyes with normal anterior segment anatomies but less well for those with eccentric types.

LT refers to the preoperative thickness of the crystalline lens. It is the fourth most important variable in IOL power prediction formulas. Historically, this variable was calculated, not measured, using an age-derived LT formula.[25] However, Lam showed that the correlation between age and LT is not as linear as once implied, and that using measured over formula derived values do alter ELP and IOL power predictions.[26] It is an optionally entered value for the Barrett Universal II, Emmetropic Verifying Optical (EVO v2.0), and Kane formulas.

It should be noted that both ACD and LT can be altered by pharmacologic dilation, with multiple studies confirming an average increase in ACD and decrease in LT after instillation of 2.5% phenylephrine/1% tropicamide.[27,28] One study by Simon et al. showed that the IOL power calculated by Barrett Universal II, Olsen, Hill-RBF, and Haigis (but not Holladay I or SRK/T) increased in ~ 20% of eyes, based on postdilation versus predilation measurements.[28] This suggests that biometry measurements taken after pharmacologic dilation may lead to myopic surprises.

White-to-white (WTW), or horizontal corneal diameter, and CCT are the last of the biometric variables. WTW is a required measurement when using the Holladay II formula and is an optionally entered value for the Barrett Universal II. CCT is an optionally entered value for both the EVO and Kane formulas.

FORMULAS

Types

The first formulas for IOL power calculations were based only on the preoperative manifest refraction and are obsolete. Regression formulas like the SRK and SRK II followed but were supplanted by theoretical/vergence-based ones soon thereafter. Historically, formulas were classified by generation (1st: refraction-based; 2nd: regression-based [i.e., SRK, SRK II] 3rd: vergence-based [i.e., Holladay I, Hoffer Q, SRK/T, etc.)], but these labels have become confusing as newer formulas combined principles from several groups. Instead, it makes the most sense to classify formulas based on their underlying principles. We thus have (1) historical/refraction, (2) regression, (3) vergence, (4) ray tracing, (5) artificial intelligence, and (6) blended. Table 3.3 is a nonexhaustive list of formulas, input variables, and summary of outcomes from the primary literature. Fig. 3.7 illustrates the range over which some formulas may be expected to work well.

Astigmatism

More than one-quarter of eyes have keratometric astigmatism greater than 1.0 D, and its correction is an important additional consideration for patients seeking spectacle independence after cataract surgery.[54] Astigmatism may be reduced using a number of surgical techniques including placement of the clear corneal incision along the steep axis, performing limbal relaxing incisions, or using a toric IOL. The choice of power and alignment axis of a toric IOL depends on estimated total ocular astigmatism and the effect of the clear corneal incision (surgically induced astigmatism). Legacy calculators that only took into account anterior corneal astigmatism (ACA) and surgically induced astigmatism (SIA) produced residual astigmatism prediction errors between 0.4 and 0.6 D and are now considered obsolete.[55,56] Instead, a formula should be used that summarily incorporates anterior, posterior, and nonkeratometric contributions to total ocular astigmatism.

The overarching theme among modern toric IOL calculators is that the effect of the posterior cornea adds the equivalent of additional ATR astigmatism to the ACA. As such, eyes with ATR ACA must be overcorrected and those with WTR ACA must be undercorrected. The Baylor toric nomogram was one of the first to take this into account.[57] Since then, other formulas including the Barrett,[58] Abulafia-Koch,[59] EVO v2.0,[60] and Kane Toric[53] formulas have been introduced. A recent study by Kane et al. demonstrated near equivalence of these modern toric IOL calculators, with prediction errors within 0.5 D of 60% to 65% and a proportion of eyes with less than 0.5 D of residual astigmatism in excess of 80%.[61]

All of the above-mentioned calculators are based on regression analysis and *predicted* total ocular astigmatism. With the advent of Scheimpflug-based topographers and SS-OCT, there is great interest in *measured* total keratometric astigmatism. As of this writing, whether measured total keratometry incrementally improves toric IOL power calculations remains controversial. In one study by Skrzypecki et al., astigmatism prediction errors were similar with the Barrett Toric Calculator using measured [mean absolute error (MAE): 0.33 ± 0.15 D; centroid: 0.14 D @ 164°] vs. predicted (MAE: 0.31 ± 0.23 D; centroid: 0.13 D @ 163°) total astigmatism (IOL Master 700, Carl Zeiss Meditec).[62] In another study by Kern et al., the astigmatism prediction error was slightly reduced when using measured (centroid: 0.11 D @ 43°) vs. predicted (centroid: 0.2 D @ 74°) total corneal refractive power (Pentacam, Oculus).[63] In short, toric IOL calculations using either predicted or measured corneal astigmatism both produce excellent results.

Intraoperative Aberrometry

Intraoperative autorefraction for the estimation of IOL power was first described by Ianchulev in 2005.[64] Since then, it has been referred to by many names including intraoperative optical refractive biometry, intraoperative refractive biometry, and most recently intraoperative aberrometry (IA). Although modern formulas rely on AL, K, ACD, and a variation of the vergence formula, IA relies instead upon the preoperatively measured corneal power and intraoperatively measured vertex distance and aphakic refraction to determine the intended IOL power. Because the device must also incorporate ELP into its calculation, other preoperatively measured values such as AL are still needed. IA was conceived as a potential solution to the inaccuracies of traditional vergence formulas in eyes with a history of LASIK or PRK, and at least two studies have confirmed its usefulness in this subpopulation.[65,66]

IA has also proven useful in the alignment of toric IOLs. Woodcock et al. previously published on the results of a multicenter, randomized clinical trial comparing eyes that had a toric IOL aligned based upon either IA or preoperative biometry.[67] A higher proportion of eyes in the IA group had astigmatism of 0.5 D or less (89.2% vs. 76.6%), and the arithmetic mean magnitude of residual astigmatism was also lower (0.29 ± 0.28 D vs. 0.36 ± 0.35 D). Note that the preoperative biometry group was aligned using a legacy toric IOL calculator, and it is still unclear whether IA holds a clear advantage over modern toric IOL calculators. Nevertheless, it is an alternative technology providing surgeons with another tool in their toolbox toward excellent refractive cataract surgery outcomes.

TABLE 3.3 Intraocular Lens Power Prediction Formulas

Type	Formula	Year	Input Variables	Proportion Within 0.5 D (%)	Proportion Within 1.0 D (%)
Regression	SRK[29,30]	1981	AL, K	–	82[31] 78[32]
	SRK II[32]	1988	AL, K	48[33]	77[33] 80[32]
Vergence (2-variable)	Holladay I[34]	1988	AL, K	75.0[35] 79.1[36] 73.4[37] 60.5[38]	96.8[35] 98.6[36] 96.1[37] 91.2[38]
	SRK/T[33]	1990	AL, K	73.0[35] 75.7[36] 78.7[39] 72.1[37] 66.4[38]	96.5[35] 98.1[36] 98.0[39] 95.9[37] 93.5[38]
	T2[39]	2010	AL, K	79.6[36] 80.9[39] 88.5[40] 72.2[38]	98.8[36] 98.5[39] 99.0[40] 95.4[38]
	Hoffer Q[41]	1993	AL, K	73.0[35] 77.8[36] 73.6[37] 83.0[40] 63.0[38]	96.2[35] 97.4 [36] 95.5[37] 99.5[40] 90.6[38]
Vergence (3-variable)	Haigis[42]	2000	AL, K, ACD	77.1[35] 80.4[36] 75.5[37] 82.0[40] 68.8[38]	97.3[35] 98.7[36] 96.1[37] 98.5[40] 93.2[38]
	Ladas Super Formula[43]	2015	AL <21.5: Hoffer Q 21.5 ≤AL≥25.0: Holladay I AL >25.0: Holladay I_{WK} Negative IOLs: Haigis	79.1[36]	98.4[36]
Vergence (5-variable)	Barrett Universal II[44–46]	2010	AL, K, ACD, LT, WTW	80.8[35] 82.9[36] 75.2[37] 85.5[40] 75.2[38]	97.8[35] 99.2[36] 96.4[37] 99.0[40] 95.9[38]
	EVO v2.0[47]	2019	AL, K, ACD, LT, CCT	83.5[40] 74.6[38]	99.0[40] 95.6[38]
Vergence (7-variable)	Holladay II[48]	1995	AL, K, ACD, LT, WTW, MRx, age	75.4[35] 79.0[36] 76.0[37] 72.6[38]	97.0[35] 98.1[36] 95.5[37] 94.8[38]
Artificial Intelligence (AI)	Hill-RBF v2.0[49]	2018	AL, K, ACD, LT, WTW	75.3[37] 85.0[40] 73.4[38]	96.4[37] 99.5[40] 95.1[38]
	Hill-RBF v3.0[49]	2020		Under investigation	
Ray tracing	OCULIX[50]	2002	AL, K, ACD, CCT, IOL, design parameters	84.2[8]	99.4[8]
	Olsen (2- and 4-factor)[51,52]	2014	AL, K, ACD, LT, CCT, age	78.7[35] 83.7[36] 77.2[37] 75.9[38]	97.4[35] 99.1[36] 96.1[37] 96.1[38]
Blended (vergence, regression, and AI)	Kane[53]	2017	AL, K, ACD, LT, CCT, sex	77.9[37] 86.5[40] 77.1[38]	96.6[37] 99.0[40] 96.4[38]

ACD, anterior chamber depth; *AL*, axial length; *CCT*, central corneal thickness; *EVO*, Emmetropic Verifying Optical; *Holladay IWK*, Holladay I formula with Wang-Koch modification; *IOL*, intraocular lens; *K*, keratometry; *LT*, lens thickness; *MRx*, preoperative manifest refraction; *RBF*, radial basis function; *SRK*, Sanders-Retzlaff-Kraff; *WTW*, white-to-white.

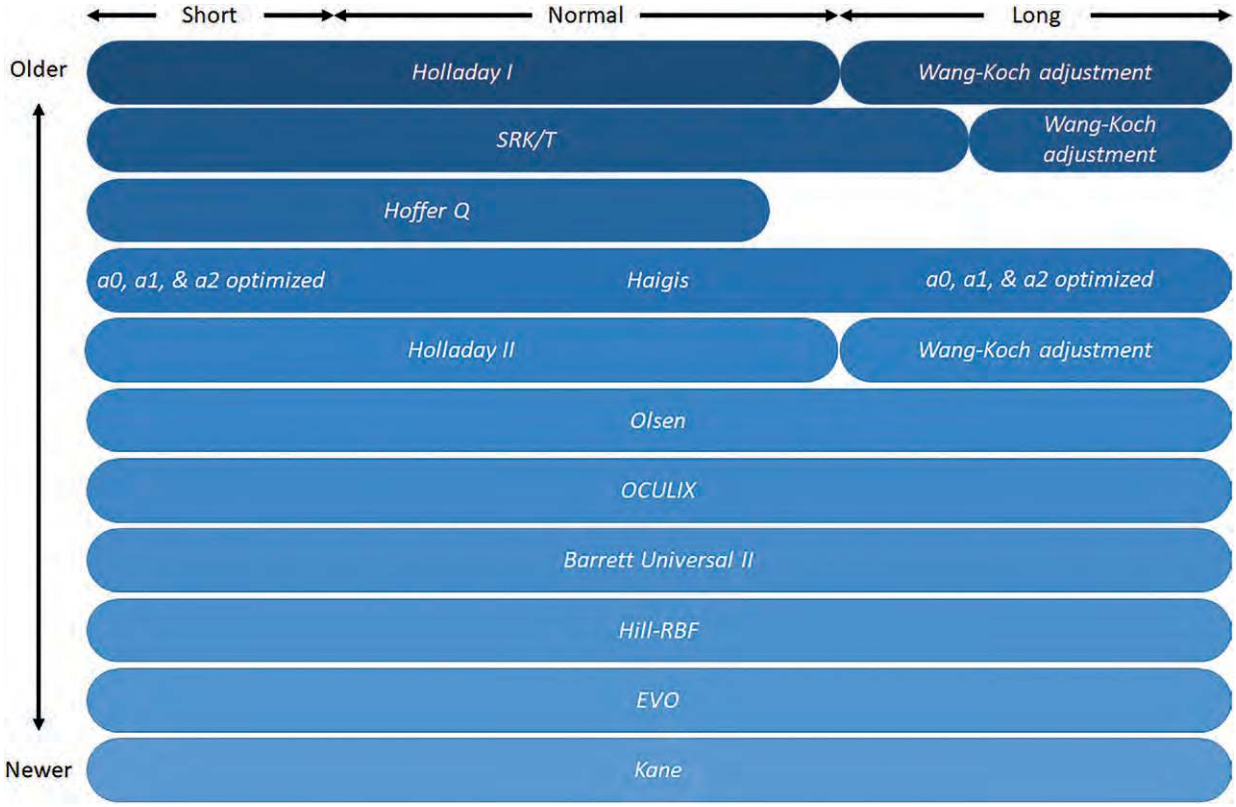

Fig. 3.7 Diagram of various intraocular lens power calculation formulas and the range of axial lengths over which they work best. *EVO*, Emmetropic Verifying Optical; *RBF*, radial basis function; *SRK*, Sanders-Retzlaff-Kraff.

BOX 3.3 Wang-Koch Axial Length Modifications

Original Wang Koch equations (for AL >25.0):[68]
- Holladay I 1-center optimized AL = 0.8289 × IOLMaster AL + 4.2663
- Haigis 1-center optimized AL = 0.9286 × IOLMaster AL + 1.562
- SRK/T 1-center optimized AL = 0.8544 × IOLMaster AL + 3.7222
- Hoffer Q 1-center optimized AL = 0.8530 × IOLMaster AL + 3.5794

Modified Wang Koch equations:[70]
- Holladay I optimized AL = 0.8170 × (measured AL) + 4.7013
- SRK/T optimized AL = 0.8453 × (measured AL) + 4.0773

Other Wang Koch equations (for AL >25.0):[69]
- Holladay I optimized AL = 0.8048 × (OLCR-AL) + 4.9195
- Holladay II optimized AL = 0.8332 × (OLCR-AL) + 4.2134

AL, Axial length; *IOL*, intraocular lens; *OLCR*, optical low-coherence reflectometry; *SRK*, Sanders-Retzlaff-Kraff.

USAGE

The dogma that the Hoffer Q, Holladay I/II, and SRK/T formulas are best for short, medium, and long eyes, respectively, carried surgeons into the early part of the 21st century and remains a reasonable practice even by today's standards. In 2011 Wang et al. published AL modifications that, when applied to various formulas, resulted in significant refractive outcome improvements in eyes with AL >25.0.[68] These formulas, frequently referred to as "Wang-Koch adjustments," were further refined and added to by the same group in 2018.[69,70] These equations are used by measuring the AL, applying the Wang-Koch adjustment and manually replacing the measured value with the optimized one in the IOL power calculation Box 3.3. The first myopic target is always chosen when employing Wang-Koch adjustments, even if it is −0.01. Newer vergence and artificial intelligence–based calculators (i.e., Barrett Universal II, EVO, Kane, Olsen) have excellent performance over the full range of ALs. This has simplified the process of IOL power calculation, and has freed surgeons from the waning practice of using different formulas for eyes with short, medium, and long ALs.

The number of existing formulas can itself be confusing and may overcomplicate IOL power calculations. Practically speaking, many of the modern formulas have similar performance, and surgeons are best advised to choose one that works well for them and be consistent in its use for all normal eyes. Appropriate usage of formulas in special groups, such as those with a history of excimer laser surgery or a diagnosis of keratoconus, are discussed elsewhere.

Most surgeons have developed their own plans for deciding on the precise target for their patients. One reasonable strategy is to consistently target mild postoperative myopia (−0.1 to −0.5 D) so that if the error is slightly hyperopic of predicted the patient will be emmetropic, and if the error is slightly myopic of predicted, they will have some level of uncorrected near vision. A second strategy is to always target the lowest magnitude SE, even if slightly positive. The rationale here is that this is the target that is statistically most likely to result in emmetropia. Both are good options, with the second strategy being preferred in the case of multifocal IOL implantation. This is because a slight hyperopic result will still provide uncorrected reading vision, and distance may easily be corrected with readily available low-powered readers. On the other hand, a slight myopic result will require prescription glasses or surface ablation for correction.

Various strategies also exist with regards to usage of toric IOL calculators. As with SE targets, one strategy is to always target the lowest possible postoperative residual astigmatism; this is the selection

most likely to result in residual refractive astigmatism less than 0.5 D. Alternatively, many surgeons advocate for targeting slight WTR astigmatism. The rationale with this strategy is that the eye will drift toward additional ATR astigmatism over time; thus targeting WTR builds in additional time in which the patient may be spectacle free.

PERSONALIZATION

Beyond choosing an appropriate formula, an important step in formula usage comes in personalization of the lens constant. When an optical biometer is set up, or when a new lens is added to its software, the lens constant that is typically entered is a default value, derived from either theoretical or pooled clinical data. Two such sources for these lens constants include the User Group for Laser Interference Biometry and IOL Con databases.[71,72] This lens constant serves as a starting point, but can be further refined by each surgeon over time.

To personalize the lens constant, one must know the preoperative predicted SE and actual postoperative manifest refractive SE for a series of eyes. Surgeons are advised to use one eye from each patient (to avoid biases associated with paired organs) and to collect data on between 150 to 250 eyes implanted with the same model IOL before performing the calculation.[73] The preoperative predicted SE is subtracted from the postoperative actual SE for each eye, and the average of these differences is referred to as mean prediction error (MPE). Once the MPE is known, it may be compensated for in one of two ways:

1. Each time a lens is selected, the MPE may be added to the predicted SE for a particular lens power and thus is assumed to be the new predicted SE.
   OR
2. The lens constant may be adjusted to deliver the corresponding change in MPE.

Both of these methods work to drive the MPE for future cases to zero. In the case of lens constant adjustment, Cooke et al. published a table and equation describing how much a lens constant should be changed to cause the desired shift in MPE (Box 3.4).[74] Alternatively, the authors of respective formulas (i.e., Warren Hill [Hill-RBF], Graham Barrett [Barrett Universal II], Tun Kuan Yeo [EVO], and Jack Kane [Kane]) might be directly contacted for help with lens constant optimization for their specific formula. When performing adjustments using either of the two above-mentioned methods, it is critical that the examining lane length be considered, with an ideal length being no less than 4 meters, but preferably closer to 6. Manifest refractions obtained in extremely short lanes (i.e., 8 feet) will result in highly positive MPEs and erroneous personalization of lens constants.

SIA results from the creation of incisions through which the cataract surgery is performed. As a general rule, SIA increases with incision size and may range between 0 and 0.5 D for widths between 1.8 and 3.0 mm.[75] The clear corneal incision flattens the cornea along the axis upon which it is made but steepens it an equal amount at an axis 90 degrees away (referred to as coupling), resulting in a mean change in the SE of zero. Thus SIA need not be considered in IOL power calculations that do not involve the correction of astigmatism. On the other hand, SIA plays a small but important role in toricity and axis of alignment in toric IOL calculations. As a starting point, surgeons might consider using an SIA magnitude between 0.12 and 0.3 D when performing phacoemulsification through a 2.4 mm incision. A surgeon's SIA can later be personalized by collecting preoperative and postoperative biometry on a series of patients and using Warren Hill's SIA Calculator.[76]

BOX 3.4 Equation for Optimizing Lens Constants

Change in lens constant = MPE/1.3357
*This formula should not be used for SRK/T or Haigis optimizations.

MPE, Mean prediction error; *SRK*, Sanders-Retzlaff-Kraff.

CLINICAL VARIABLES

Patient Needs and Desires

The discussion regarding a refractive target is compulsory. Although the vast majority will opt for a target of emmetropia, myopes and patients familiar with mono vision are two populations in which an alternate target might be considered. A myope will never be happy as a hyperope; thus a target of slight myopia might be best even when emmetropia is desired. On the other hand, some myopes are happy to have the ability to remove their glasses to read a book or restaurant menu and are content with being left with a postoperative refractive target between −2.0 and −2.5 D. Patients with natural mono vision or significant experience with it through the use of contact lenses are excellent candidates for sequential cataract surgery with distance and near targets, respectively. Patients without prior mono vision experience but inquiring about it should be counseled with caution. In the author's experience, an in-depth preoperative discussion on the intricacies of living with mono vision does not prevent the need for a postoperative explanation of why one eye is blurry at distance. In these patients, a preoperative mono vision contact lens trial is advised.

Another encountered circumstance is that of the patient with unilateral cataract and large ametropia. If the singular cataract is operated upon, and if emmetropia is targeted, the patient may suffer from anisometropia, headaches, lack of binocularity, and imbalance. The discussion on how to manage this situation is best broached preoperatively, before it occurs. Options include (1) removing the cataract and targeting an ametropic SE that is within 2.5 D of the contralateral eye; (2) removing the cataract and targeting emmetropia, with the understanding that the contralateral eye may need a contact lens to achieve binocularity; or (3) removing the cataract and targeting emmetropia, with the plan to treat the impending anisometropia with sequential removal of the noncataractous lens. Surgeons must be mindful that the same risk exists with treatment of astigmatism, and that a surgical plan should aim to deliver astigmatic anisometropia of less than 1.5 D between eyes.

SPECIAL CIRCUMSTANCES

Inevitably, surgeons will find themselves in the position of needing to place a posterior chamber IOL in the sulcus. A one-piece acrylic IOL should never be placed in the sulcus because its thickness is likely to cause iris chaffing, uveitis-glaucoma-hyphema syndrome, and glaucoma long term. Instead, a three-piece lens is the most appropriate choice. Warren Hill has published an excellent table that appropriately adjusts the IOL power for the sulcus (Table 3.4).[77] His table assumes that the original calculation was carried out for placement within the

TABLE 3.4 Calculating Bag Versus Sulcus Intraocular Lens Power

Power at the Capsular Bag (D)	Subtract from Bag Power (D)
+28.5 to +30.00	−1.50
+17.5 to +28.0	−1.00
+9.5 to +17.0	−0.50
+5.0 to +9.0	No change

capsular bag, that the position of the IOL is being shifted from the plane of the capsular bag to the plane of the ciliary sulcus (i.e., this would not apply to sulcus implantation with optic capture), and that the IOL design is biconvex. This is typically a 0.5 mm anterior change in the ELP with a resulting decrease in IOL power. The amount that needs to be subtracted is proportional to the power of the optic. If the IOL haptics are placed in the sulcus and the optic is captured behind the capsulorhexis, no adjustment from the intracapsular IOL power is necessary.

Another infrequent circumstance is the need to choose an IOL power in the setting of previous trauma, where accurate keratometry measurements are not possible. The surgeon may choose to use average keratometry readings from the alternate eye, or use an average SimK reading obtained with a corneal topographer. An option of last resort is to simply speculate the approximate corneal power, with the understanding that corneal scars typically cause local flattening. Obviously, the patient needs to be counseled about the uncertain refractive result in these situations.

Last, IOL power calculations may be affected by concurrently planned keratoplasty procedures. For cataract surgery combined with penetrating keratoplasty (PK), there is no way of knowing the postoperative corneal refractive power. It is thus recommended that these two procedures be staged with the PK being performed first and the cataract surgery 6 months later, whenever possible. This avoids large degrees of ametropia. However, if the triple procedure is planned, one may use 44.0 D as a manually entered, "best guess" for the corneal refractive power in IOL power calculations, combined with other measured variables. In the case of Descemet stripping automated endothelial keratoplasty, consensus is that the refractive target should be adjusted by −0.8 to −1.25 D; in the case of Descemet membrane endothelial keratoplasty, this is reduced to between −0.5 and −1.0 D.[78–80]

POSTOPERATIVE PROBLEMS AND ERRORS

It is inevitable that all surgeons will find themselves in front of a patient with a postoperative refractive surprise. These can be stressful encounters, but both the patient's and surgeon's anxiety can be mitigated by a clear strategy for deducing the source of the error and fixing it. These steps should include checking (1) clinical variables that could have affected the quality of the biometry (i.e., presence of a scleral buckle or severe dry eye); (2) that the IOL implanted was the IOL intended; (3) the manifest-refraction; (4) the IOL position relative to the capsulorrhexis; (5) the orientation of the IOL (i.e., reverse "S" in the case of most asymmetric biconvex IOLs); and (6) the actual versus intended axis of alignment in the case of toric IOLs. If, after checking the above, the reason for the refractive surprise is still undetermined, a diagnosis of exclusion is that the patient's anatomy is unique and not accurately accounted for by modern formulas.

Options for management of the refractive surprise include conservative measures such as glasses or contact lenses, surface ablation, and IOL exchange. In the case of IOL exchange, performing the procedure within 6 weeks of the initial surgery will make for an easier and safer surgery. The power of the new IOL can be determined by looking at the original biometry and evaluating how much the refractive error is likely to change for each step up or down in IOL power. For example, in the case of a 1.0 D hyperopic surprise and biometry that suggests a 0.30 D change in the refractive error for each 0.5 D increase in IOL power, the surgeon might choose to exchange the implanted IOL with one that is 1.5 D higher in power.

When a refractive surprise has occurred after the first of two eyes are operated upon, a key question is how to appropriately manage IOL power selection for the second eye. At least one study suggests that the second eye's target should not be adjusted.[81] However, there is also a significant body of literature to indicate otherwise. One study from Aristodemou et al. showed that when the first eye's prediction error was greater than 0.5 D, applying a correction factor equal to 50% of the error from the first eye to the second eye's calculation resulted in an improvement in the proportion of second eyes obtaining an SE within 0.5 D of predicted from 56% to 75%.[82] A second study by Turnbull and Barrett confirmed this finding for the Hoffer Q, Holladay I, and SRK/T formulas but suggested that the correction factor might be closer to 0.3 D for the Barrett Universal II.[83] These "fudge factors" should be used only when the eyes are believed to be similar; unilateral amblyopia, axial anisometropia, or a history of scleral buckle or LASIK would be contraindications to their use.

FUTURE WORK

At first glance, one might conclude that advances in biometry and formulas have made the exercise of choosing the appropriate IOL power an easy task. To some extent, this is true: we can now anticipate a satisfactory refractive target in more than 80% of operated upon eyes when best practices are followed. Despite this statistic and the tremendous progress in the accuracy of biometry and IOL power calculations, there is more work to do. We might expect incremental improvements in normal eyes with broad adoption of formulas that incorporate total corneal power, segmented AL, and consideration for precise geometry of the implanted IOL. IOL manufacturers might also increase the availability of IOLs with tighter manufacturing tolerances and smaller dioptric power increments (i.e., 0.25 D).[84] In eyes with unique anatomy, where classical vergence formulas fail, more widespread use of ray tracing or artificial intelligence might also translate to increases in accuracy. Until then, postoperative adjustment of corneal power with surface ablation or IOL power through the use of light-adjustable IOLs will remain the best means of refining outcomes.

SUMMARY

IOL power calculations begin with optimization of the ocular surface in anticipation of optical biometry. Measurement of AL, corneal power, ACD, and other variables must be followed by scrutiny of the quality of those measurements. Checking for fixation and evaluation of the reflectance keratometry image are details not to be overlooked. Good quality measurements, combined with use of a modern formula will lead to a satisfactory refractive result a vast majority of the time. Even then we can only appreciate these results and further refine them by following up on our surgical plan with postoperative refractions, personalization of lens constants, and careful consideration of our patients' needs and desires.

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4

Intraocular Lens Calculations After Refractive Surgery

Ravi Shah, Li Wang, Douglas D. Koch, and Mitchell P. Weikert

CONTENTS

INTRODUCTION

Although corneal refractive surgery (CRS) produces excellent visual outcomes, it creates several difficulties in accurately calculating intraocular lens (IOL) power.[1] This chapter discusses the problems induced by CRS, solutions to those problems, and tools that exist for IOL power calculations in these challenging cases, including web-based IOL power calculation, an optical coherence tomography (OCT)–based IOL power formula, intraoperative measurements, and postoperative lens adjustment.

PROBLEMS INDUCED BY CORNEAL REFRACTIVE SURGERY

The two main causes of error in IOL power calculations in postrefractive surgery eyes are incorrect corneal power estimation from topography and/or tomography and incorrect estimation of effective lens position (ELP) as calculated by many IOL power calculation formulas.

Challenges in accurately determining corneal power include the following:

- Standard keratometry and simulated keratometry readings from standard biometers only measure small zones in the paracentral cornea, ignoring the more central region altered by ablation.
- Standard keratometry and corneal topography measure only the anterior corneal surface and estimate the curvature of the posterior corneal surface. These devices use a standardized corneal refractive index, which is 1.3375 in most devices (USA), to convert the anterior corneal measurement to an estimation of total corneal refractive power. LASIK and PRK alter the ratio of anterior to posterior corneal curvature, therefore the use of the standard corneal refractive index (1.3375) is no longer valid. Using a Dual Scheimpflug Analyzer (Galilei, Ziemer Ophthalmics AG, Port, Switzerland), the mean corneal refractive indices were found to be 1.3278 in normal eyes, 1.3246 in eyes with previous myopic LASIK/PRK, and 1.3302 in eyes with previous hyperopic LASIK/PRK.[2]
- Approaches for dealing with the errors in corneal refractive power estimation will be discussed in detail in the next section.

Issues in estimating the ELP include the following:

- Except for the Holladay II, Haigis, and Barrett formulas, the other third- and fourth- generation IOL formulas use measured corneal power to predict the ELP. After myopic LASIK/PRK, the flattened K values cause these formulas to predict a falsely shallow ELP, thereby leading to insufficient IOL power. This yields the classic postoperative hyperopic surprise.
- Aramberri proposed the double-K method[3] to help solve this problem. It uses the pre-CRS average K value for the estimation of ELP and the postoperative average K value for calculation of IOL power in the standard vergence formula.
- This approach had been previously developed by Holladay in the Holladay 2 formula in the Holladay IOL Consultant software program. Using the Holladay IOL Consultant, one can enter pre-LASIK/PRK K values to predict the ELP. If previous data are not available, one can check the "previous RK/PRK/LASIK" box, which will instruct the formula to use the default corneal power of 43.86 D for its ELP calculation.
- Studies have shown that the double-K method improves the accuracy of IOL power calculation in postrefractive eyes.[3–5] Nomograms proposed in one study can be used to adjust the IOL power when the modified corneal powers are used for these formulas.[6]
- The magnitude of the ELP-related error varies according to the particular formula, the amount of refractive correction, and the axial length (AL) (Fig. 4.1).[6,7]

Additionally, higher-order aberrations (HOAs) are alterations or distortions in the focus of light that are the fo in not correctable by simple spherocylindrical lenses. This often degrades quality of vision. Root-mean-square (RMS) is a measure of total HOAs. It is well known that HOAs and RMS increase after myopic and hyperopic corrections in refractive surgery.[8] The burden is especially weighted for decentered ablations and spherical aberration, a fourth-order aberration.[9] For all of these reasons, it is extraordinarily important to counsel postrefractive patients on the difficulty of refractive accuracy after cataract surgery. Despite the advances in biometry, power calculation formulas, and IOL technology, refractive surprises still occur, and patients should be aware of the potential need for additional surgery or IOL exchange.

SOLUTIONS TO PROBLEMS INDUCED BY CORNEAL REFRACTIVE SURGERY

Numerous techniques have been devised and proposed to improve the accuracy of IOL power calculation in eyes following CRS (Table 4.1). These can be divided into three categories:

1. Ignore current corneal measurements, and use pre-LASIK/PRK data and post-LASIK/PRK refraction.
2. Use current corneal measurements combined with regression formulas based on LASIK/PRK-induced refractive change to modify either:
   a. the measured anterior corneal power or
   b. the calculated IOL power.
3. Use only measurements obtained when the patient presents for cataract surgery, and
   a. modify measured anterior corneal power based on regression formulas or
   b. directly measure both anterior and posterior corneal curvatures.

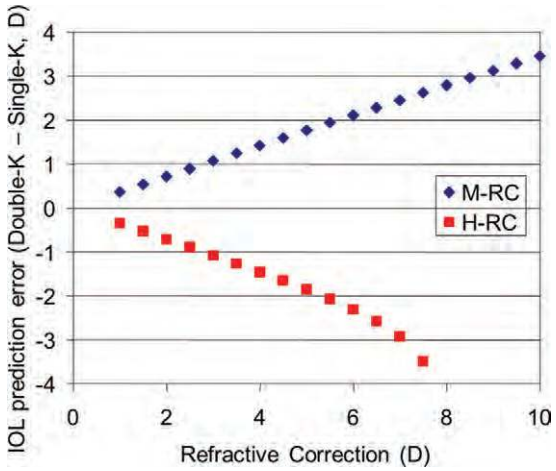

Fig. 4.1 IOL power prediction errors related to the ELP estimation (Double-K – Standard-K) using the SRK/T formula in eyes following myopic and hyperopic refractive surgery (M-RC and H-RC) as a function of the amount of refractive correction.

Use Pre-LASIK/PRK Data

The three methods that ignore current corneal measurements are (1) the Clinical History Method, (2) the Feiz-Mannis Method,[10] and (3) the Corneal Bypass Method.[11] These formulas require accurate preoperative keratometry, manifest refraction (MR), and a stable, updated MR obtained before cataract-induced refractive changes. Using the preoperative keratometry and the surgically induced change in MR, IOL power is calculated. Because of dependence on the accuracy of historical data and the difficulty in getting reliable refraction data before cataract development, and therefore disappointingly inconsistent outcomes, methods using historical data are less accurate compared with other methods.[12]

Use Current Measurements with Regression Formulas Based on LASIK/PRK-Induced Refractive Change and Modify Them

Modification to Measured Anterior Corneal Power

Below are several methods that modify current corneal power measurements based on regression analysis derived with the change in MR induced by refractive surgery. One advantage of these methods is that they use corneal data obtained at the time the patient presents for cataract surgery evaluation. They also avoid the one-to-one diopter error found in approaches that rely entirely on historical data by multiplying the change in MR by some fraction, typically less than 0.3.

- **Adjusted EyeSys effective refractive power (EffRP)**: The EffRP from the EyeSys topographer (EyeSys Vision Inc., Houston, TX, USA) is the mean corneal power over the central 3-mm zone, accounting for the Stiles-Crawford effect. Briefly, the Stiles-Crawford effect explains how light entering near the edge of the pupil produces a diminished

TABLE 4.1 Methods for intraocular lens Power Calculation in Eyes After Corneal Refractive Surgery

Method	Strength	Weakness	Technique
Ignore current corneal measurements and use Pre-LASIK/PRK data	• Reliable if accurate pre-LASIK/PRK data is available	• Dependent on the accuracy of pre-LASIK/PRK data • One-to-one diopter error if any historical data is incorrect • Difficult to get historical data • Less accurate compared with other methods	• Clinical history • Feiz-Mannis • Corneal bypass
Use current corneal measurements and modify them	• Avoid one-to-one error found in approaches relying entirely on historical data	• Amount of refractive correction required for modification based on ΔMR	• Adjusted EffRP • Adjusted atlas values • Adjusted K • Adjusted keratometry • Adjusted ACCP • Wang-Koch-Maloney • Shammas method • Haigis-L • Galilei TCP
Use current corneal measurements to calculate IOL power and modify the IOL power	• Avoid one-to-one error found in approaches relying entirely on historical data	• Requires amount of refractive correction (ΔMR)	• Masket formula • Modified Masket formula
Measure actual anterior and posterior corneal curvatures to calculate true total corneal power	• No prior data needed • True total corneal power calculated	• Certain adjustments to total corneal power still needed to achieve accurate IOL power calculation	• Slit-scanning system • Scheimpflug imaging devices • OCT systems

cone photoreceptor response compared with light of equal intensity entering the center of the pupil. Subsequently, peripheral zones of the pupil suffer from optical aberration. Optimal, diffraction-limited optics exist only for pupils approximately 3 mm in diameter. Hamed et al. proposed the Adjusted EffRP, which is modified as follows:[13,14]

- Adjusted EffRP in post**myopic** LASIK/PRK = EffRP – 0.152 × (ΔMR) – 0.05
- Adjusted EffRP in post**hyperopic** LASIK/PRK = EffRP + 0.162 (ΔMR) – 0.279

The EffRP value is taken from the EyeSys device and input into the web-based tool; this is explained in greater detail below. This web-based tool applies the above modifications to the keratometry values prior to using them in a variety of formulas.

- Adjusted values from the Atlas topographer (Zeiss, Oberkochen, Germany):
  - *Adjusted Atlas Ring Values*: The average of the Atlas 0-, 1-, 2-, and 3-mm annular rings (AnnCP) from the Atlas topographer is modified by another fraction of the ΔMR. With this method, the accuracy of the IOL power calculation in eyes after hyperopic LASIK/PRK is significantly improved.[14]
  - Adjusted AnnCP in postmyopic LASIK/PRK = AnnCP – 0.2 × (ΔMR),
  - Adjusted AnnCP in posthyperopic LASIK/PRK = AnnCP + 0.191 × (ΔMR) – 0.396

The AnnCP value is taken from the Atlas device and input into the web-based tool; this is explained in greater detail below. This web-based tool applies the above modifications to the keratometry values prior to using them in a variety of formulas.

- *Adjusted Atlas Zone Value*: With this method, the 4-mm zone value obtained from the Atlas 9000 topographer (Zeiss, Oberkochen, Germany) is altered by subtracting 0.2 times the ΔMR.
- *Adjusted average central corneal power (ACCP):* ACCP from the TMS topographer (Tomey, Nagoya, Japan) is the measured power within the central 3-mm zone. Awwad et al.[15] reported that this method accurately predicted the corneal refractive power after myopic LASIK:
  - Adjusted ACCP in post**myopic** LASIK/PRK = ACCP – 0.16 × (ΔMR)

The ACCP value is taken from the TMS device and input into the web-based tool; this is explained in greater detail below. This web-based tool applies the above modifications to the keratometry values prior to using them in a variety of formulas.

- **Barrett True-K Formula:** The Barrett True-K formula was developed by Dr. Graham Barrett from Australia. The True-K is obtained by modifying the measured K values and the amount of refractive correction induced by CRS. See below for further discussion on this formula and its various iterations.

Modification to Calculated Intraocular Lens Power

- **Masket Formula**: With this method,[16] the IOL power is calculated using the IOLMaster's keratometry readings and the SRK/T formula, and then adjusted by 32.6% of the refractive correction:
  - Adjustment of IOL = ([MR] × 0.326) + 0.101
- **Modified Masket Formula**: The Masket formula was later modified by Hill (presented at ASCRS 2006) to adjust the IOL by 43.9% of the refractive correction and a smaller constant was added afterward.
  - Adjustment of IOL = ([ΔMR] × 0.4385) + 0.0295

Of note, all the above formulas still require reliable refraction data prior to cataract development, and the accuracy of their outcomes is dependent on the accuracy of that historical data. The Barrett True-K No History and OCT-based formulas presented below do not require any historical data and therefore are not dependent on the accuracy of these data.

Use Only Current Corneal Measurements

Modification to Measured Anterior Corneal Power Based on Regression Formulas

- **Wang-Koch-Maloney**: The Atlas 4-mm zone value obtained from the Zeiss Atlas topographer is converted to anterior corneal power by multiplying it by 376.0/337.5, or 1.114. An assumed posterior corneal power of 5.59 D is then subtracted from this product:
  - Adjusted corneal power = (Atlas 4-mm zone × 1.114) – 5.59
- **Shammas Method**: Using regression analysis, this method estimates the postrefractive corneal power by adjusting the measured post-LASIK/PRK keratometry readings (Kpost):[17]
  - Adjusted corneal power = (1.14 × Kpost) – 6.8
- **Haigis-L**: This formula uses a regression equation to correct the post-LASIK corneal radius obtained from the IOLMaster based on corneal powers calculated from historical data:[18]
  - Corrected corneal radius = 331.5/(–5.1625 × post-LASIK corneal radius with IOLMaster + 82.2603 – 0.35). IOL power is then calculated using the Haigis formula.
- **Galilei total corneal power (TCP) Method**: The TCP obtained from the Galilei (Ziemer, Port, Switzerland) is the TCP averaged over the central 4-mm zone calculated by ray tracing through the anterior and posterior corneal surfaces using the Snell's law. This method is based on a regression equation between the TCP values and the corneal powers derived from the historical method (unpublished):
  - Adjusted corneal power in myopic LASIK eyes = (1.057 × TCP) – 1.8348

The adjusted corneal powers above are all input into the web-based tool; this is explained in greater detail below. This web-based tool applies the above modifications to the keratometry values prior to utilizing them in a variety of formulas.

Directly Measure Anterior and Posterior Corneal Curvature

The two major technologies that measure both anterior and posterior corneal surfaces are Scheimpflug imaging devices and OCT systems, both of which are commercially available. The Pentacam (OCULUS, Wetzlar, Germany) and Galilei Scheimpflug imaging devices have shown promising results for the reproducibility of posterior corneal surface measurements.[19–21] In addition, Tang et al. reported that the reproducibility of the TCP measurements with the RTVue OCT (Optovue, Fremont, CA, USA) system was 0.26 D for the post-LASIK eyes.[22] Once the anterior and posterior corneal curvatures have been measured, the TCP can be calculated using two methods: the Gaussian optics thick-lens formula and the ray tracing method.[2]

The Gaussian thick-lens formula calculates the Gaussian equivalent power by assuming para-axial imaging and combining two refractive surfaces separated by the central corneal thickness:

$$GEP = F1 + F2 - \left(d/n\right)\left(F1 * F2\right)$$

where F1 = anterior corneal power, F2 = posterior corneal power, d = pachymetry and n = index of refraction (1.376). For example, the Equivalent K-readings displayed on the Holladay Report of the Pentacam is calculated using the Gaussian optics thick-lens formula.

The ray tracing method propagates incoming parallel rays and uses Snell's law to refract these rays through the anterior and posterior corneal surfaces. The Galilei calculates the TCP using ray tracing. Power is determined by n/f, where f is the calculated focal length, which is referenced to the anterior corneal surface (TCP2) or posterior corneal surface (TCPIOL), and n is the index of refraction of the aqueous (n = 1.336). In a prior study[2] it was determined that, by ignoring the refraction of rays passing through the anterior corneal surface, the Gaussian thick-lens formula overestimates the effective minus power of the posterior surface and introduces errors in the calculation of TCP. Ray tracing has additional applications in power calculations.

Canovas et al.[23] performed custom ray tracing to analyze the equivalent refractive index (ERI) on IOL power prediction in patients undergoing cataract surgery who previously received myopic LASIK. The sample size was only 25 patients, but the effect of introducing average ERI in the ray tracing IOL power calculation improved prediction error to within ± 0.5 D compared with the Haigis-L formula (84% vs. 52%). The ray-tracing procedure included anterior curvature, and the ERI was calculated using para-axial optics.

Although TCP values can be obtained from devices that measure the posterior corneal surface, studies have shown that certain adjustments are still needed to achieve accurate IOL power calculation in eyes with prior CRS. More studies are needed to improve the accuracy of corneal power measurements and to develop new IOL power calculation formulas in these eyes.

- **Barrett True-K No History**: As previously stated, the True-K is obtained by modifying the measured K values and the amount of refractive correction induced by CRS. It also works when the amount of refractive correction is not available. This is the No History version of the formula. For IOL power calculation, the Universal II formula, which is a theoretical formula, is used.[24, 25] Details regarding the design of the True-K and Universal II formulas are not published.
- **OCT-Based IOL Power Calculation**: OCT is a noncontact imaging technology that can measure both anterior and posterior corneal powers with high axial resolution. Even in the presence of opacities, the high axial resolution of OCT (3–17 μm in commercial instruments) allows clear delineation of corneal boundaries.[26] Tang and colleagues began OCT corneal power measurements using time-domain technology.[27] With the advance from time-domain to Fourier-domain OCT, the speed of OCT corneal mapping became much faster, and repeatability of corneal power measurements improved dramatically. Using the RTVue (Optovue Inc, Fremont, CA, USA), Tang and colleagues[22] developed an OCT-based IOL calculation formula. Based on the anterior and posterior corneal powers and the central corneal thickness, the net corneal power (NCP) was calculated using the Gaussian thick-lens formula. Then, for IOL power calculation, the NCP was converted to an effective corneal power (ECP) based on linear regression analysis:
  - ECP in post**myopic** LASIK/PRK = 1.0208 × NCP – 1.6622
  - ECP in post**hyperopic** LASIK/PRK = 1.11 × NCP – 5.736

The OCT-based IOL formula uses an optical vergence model of the eye (i.e., the paraxial approximation of Gaussian optics). The ELP is predicted using a regression-derived formula based on anterior chamber depth (ACD)-constant, posterior corneal power, and AL of the eye. The OCT-based IOL formula uses five preoperative biometric measurements: AL and ACD from a partial coherence interferometer and NCP, posterior corneal power, and central corneal thickness from the OCT. This formula has been integrated into the web-based postrefractive IOL calculator (Fig. 4.2A).

TOOLS FOR INTRAOCULAR LENS POWER CALCULATION

Web-Based Postrefractive Intraocular Lens Calculator at ASCRS.org

It is complicated and time consuming to perform calculations using the various methods discussed previously. In 2007 Hill, Wang, and Koch developed a web-based IOL power calculator (http://iolcalc.ascrs.org). The calculator is updated regularly and has over a million usages per year.

This calculator has three modules: (1) prior myopic LASIK/PRK, (2) prior hyperopic LASIK/PRK, and (3) prior RK (see Fig. 4.2B). When one uses the IOL calculator for eyes with prior laser refractive surgery, all available data is entered: pre- and post-LASIK/PRK data and biometric data. By clicking the "Calculate" button, the results are shown in the bottom. Depending on the availability of historical data, the IOL calculator categorizes the various calculation methods into two groups: (1) methods using ΔMR and corneal measurements at the time of cataract surgery and (2) methods using no prior data. Methods using Pre-LASIK/PRK Ks and ΔMR were initially included but were removed several years ago because of inaccurate results. The IOL power is calculated using the double-K Holladay 1 formula, Shammas-PL, or Haigis-L method. In the double-K Holladay 1 formula, pre-LASIK/PRK keratometry values are used to estimate the ELP. If pre-LASIK/PRK keratometry is not available, 43.86 D is used. In addition to displaying the average and range of IOL powers from all available methods, the average IOL power is also listed for methods using ΔMR only and methods using no prior data. Pop-up windows are included to explain each method in detail.

In post-RK eyes, unlike post-LASIK/PRK eyes, the posterior corneal curvature also changes, typically increasing the Gullstrand ratio (ratio of the radii of posterior to anterior curvature) above normal levels. Table 4.2 lists mean Gullstrand ratios that have been found using the dual-Scheimpflug analyzer in normal, postmyopic, and posthyperopic LASIK and post-RK corneas. Because of the typically wide variation in corneal power, for post-RK eyes using an average corneal power over the central 2 to 4 mm is recommended. In the ASCRS postrefractive surgery calculator, one can enter the average corneal powers from the Atlas for the 1-, 2-, 3-, and 4-mm AnnCP, the Atlas 4-mm zone value, the EffRP from the EyeSys, and the TCP from Galilei. Presumably, other topographers that provide average values over the central 2 to 4 mm can also be used. Compensation for potential error in ELP is still required by using double-K version of IOL formulas; the double-K Holladay 1 formula is used by the ASCRS online calculator.

Barrett True-K and True-K No History Formulas

The Barrett suite of formulas has been incorporated in the Postrefractive IOL Calculator at ascrs.org (see Fig. 4.2A) and can also be accessed from the APACRS websites (www.apacrs.org) (Figs. 4.3A-B).

Optical Coherence Tomography–Based Intraocular Lens Formula

This formula can be downloaded at www.coollab.net. Currently, this OCT-based IOL formula is also included in the ASCRS IOL calculator, so users can perform and view the results of all their calculations in one place.

INTRAOPERATIVE MEASUREMENTS

Intraoperative refractive biometry (IRB) was proposed by Ianchulev et al.[28] This method performs aphakic retinoscopy after removal of the cataract and before implantation of the IOL. IOL power is adjusted

A

B

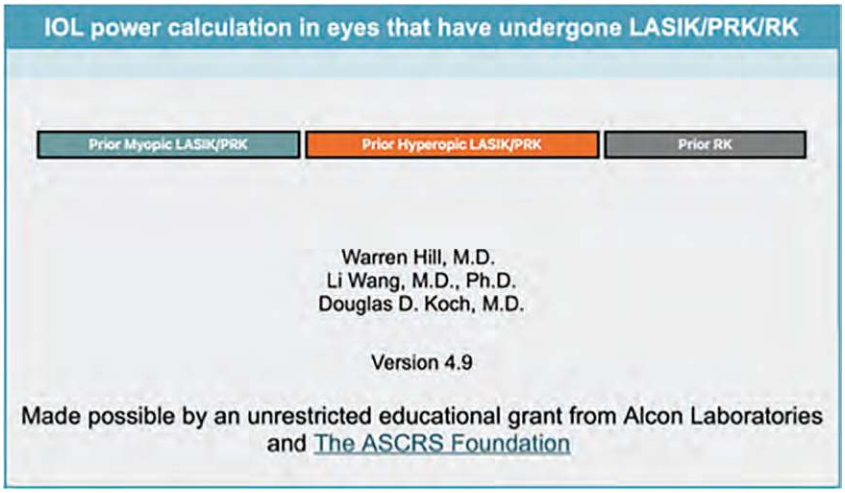

Fig. 4.2 Postrefractive IOL calculator at ASCRS (www.ascrs.org). A, Data entry and results sections for eyes with myopic LASIK/PRK. B, Three modules for eyes with prior myopic LASIK/PRK, prior hyperopic LASIK/PRK, and prior RK.

based on the intraoperative refraction. This is more commonly referred to as intraoperative aberrometry.

The Optiwave Refractive Analysis (ORA) System (Alcon, Fort Worth, TX, USA) measures the aphakic refraction intraoperatively after cataract extraction. Using a proprietary algorithm that estimates the ELP, this system has the integrated capability to calculate the IOL power based on the aphakic spherical equivalent and the patient's preoperatively measured AL and Ks.

The ELP cannot be measured with IRB and must be estimated. Factors that might affect the accuracy of intraoperative biometry include intraocular pressure, patient fixation, increased corneal thickness, surface abnormalities, wound hydration, and external pressure from the lid speculum.

TABLE 4.2 Gullstrand Ratios of Different Types of Corneas

Normal (virgin) corneas (n = 94)	0.82
Myopic LASIK/PRK (n = 236)	0.77
Hyperopic LASIK/PRK (n = 115)	0.86
RK (n = 42)	0.94

COMPARATIVE DATA FOR THE MODERN FORMULAS INCLUDING INTRAOPERATIVE MEASUREMENTS

- Wang et al. showed higher IOL predictive accuracy in **No History methods** compared with methods requiring prerefractive data.[12]
- A large metaanalysis of **postmyopic refractive patients** showed a higher predictive accuracy using the ASCRS average compared with Haigis-L, Shammas-PL, and Wang-Koch-Maloney.[29]

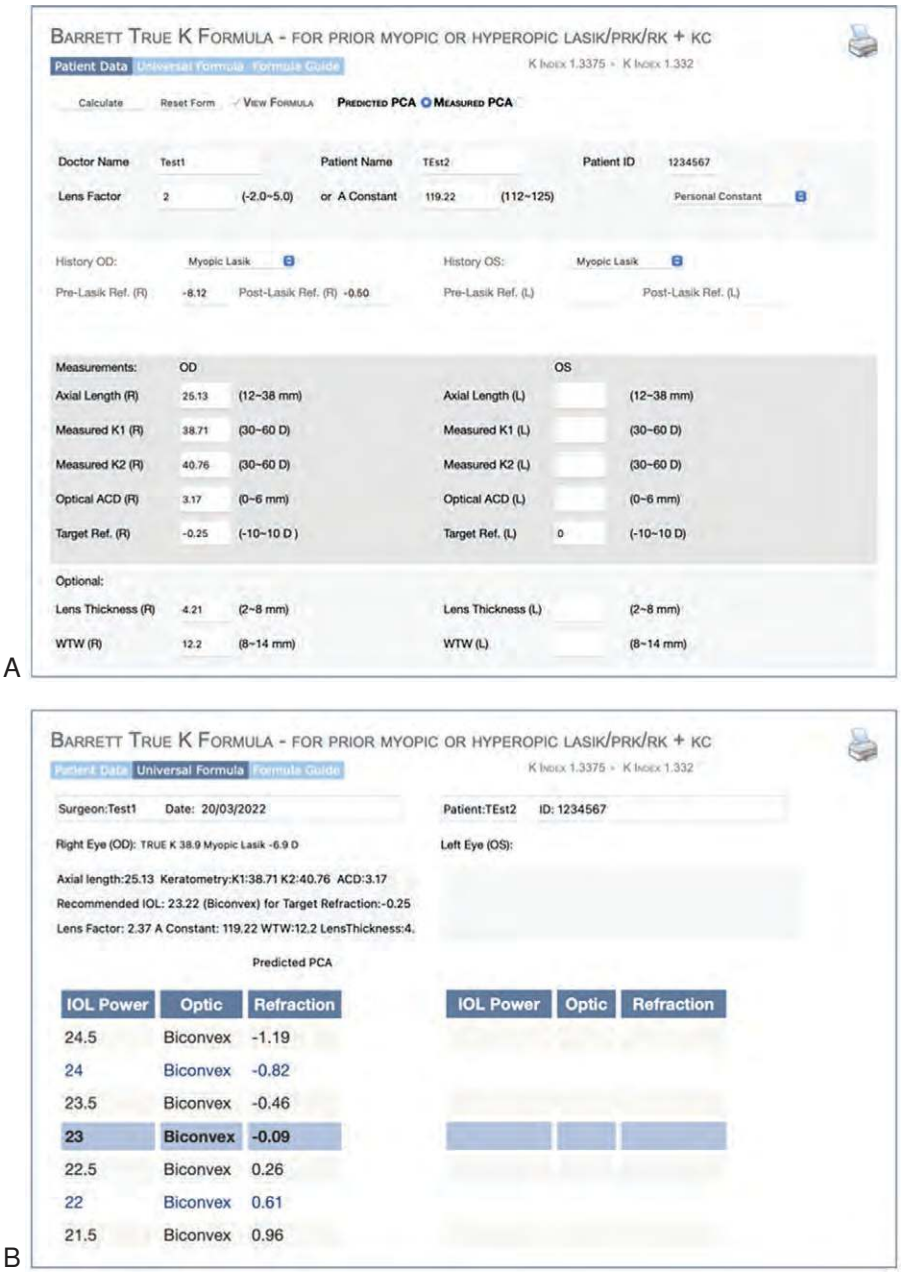

Fig. 4.3 Barrett True-K formula for eyes with prior myopic or hyperopic LASIK/PRK (www.apacrs.org). A, Data entry section; B, IOL power output section.

- For **posthyperopic refractive patients** undergoing cataract surgery, two small-sample studies have found no significant difference in mean absolute IOL prediction errors for the formulas compared.[30,31] This indicates that the currently available tools for this type of patient are comparable.
- **Post-RK eyes** have poor accuracy because of variability in anterior and posterior corneal curvature. Given that 20% to 50% of RK eyes have a gradual hyperopic shift, it is recommended to target −0.75 to −1.00 in IOL power calculations for these eyes.[32–34]
- Data for the **Barrett True-K formula** are quite positive overall, yielding a smaller median absolute refraction prediction error and a greater percentage of eyes within ± 0.50 D of predicted error than several formulas it was compared against.[29,35]
- The **OCT-based IOL formula** has been validated and shown to produce similar refractive prediction errors or even higher predictive accuracy than the Haigis-L, Shammas, and Wang-Koch-Maloney formulas for post myopic laser vision correction eyes.[29,36–39] This formula has also been modified to be used in pre-RK eyes with a reduction in hyperopic surprises.[40]
- In a large-sample study, Ianchulev and colleagues[41] determined ORA achieved the greatest predictive accuracy compared with the Haigis-L and Shammas methods. In a smaller sample study, there was no statistically significant difference between ORA, OCT, and Haigis-L, indicating that ORA and OCT are newer methods with promising results.[42]
- Yoo et al.[43] described a regression-based formula using anterior segment three-dimensional OCT from a femtosecond laser imaging

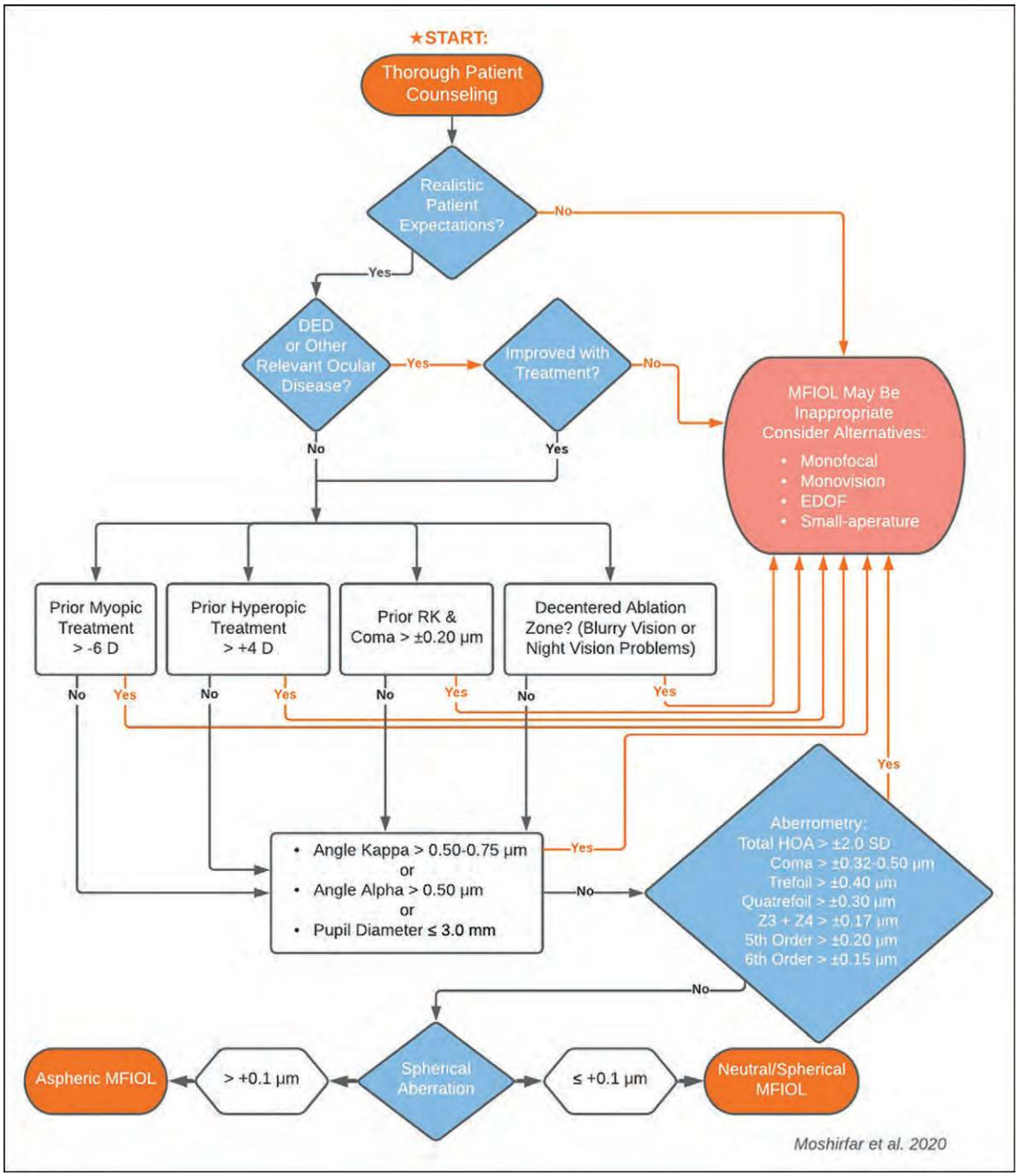

Fig. 4.4 Flowchart of premium intraocular lens use in postrefractive patients.

system with a superior refractive accuracy compared with other formulas including the Barrett Universal II. Although this formula has yet to be tested in postrefractive patients, it could potentially solve the ELP source of error.

PREMIUM INTRAOCULAR LENS USE IN POSTREFRACTIVE PATIENTS

Presbyopia-correcting lenses are becoming increasingly used across the world and have been around for several years now. There is a vast array of options including bifocal, trifocal, and extended depth of focus IOLs. In addition to some photic phenomena including glare, halos, spiderwebs, and starbursts, contrast sensitivity tends to decline in patients with these IOLs. However, for many patients desiring spectacle independence, these IOLs provide a new alternative. The concerns are of course refractive accuracy and quality of vision. Four studies of multifocal IOLs with power calculated using the Holladay post-LASIK formula, the Barrett True-K No history formula, Potvin-Hill formula, or an average of several formulas reported that the percentages of eyes within 0.5 D of target ranged from 47.6% to 100%.[44–47] Although these studies show that premium IOLs are not contraindicated in patients with prior refractive surgery, a comprehensive study evaluating the relationship between corneal HOAs and visual outcomes with various premium IOLs is very much needed. These would include detailed reporting on side effects and contrast sensitivity to assist clinicians in patient selection and informed consent. Fig. 4.4 is a flowchart that describes the considerations for using premium IOLs in postrefractive patients, and Moshirfar and colleagues have put together an excellent review to aid in choosing suitable candidates for this purpose.[48]

Postoperative Intraocular Lens Adjustment

The light-adjustable lens (LAL; RxSight, Inc., Aliso Viejo, CA, USA) enables residual spherical and cylindrical errors to be corrected or adjusted after the postoperative refraction has stabilized.

Brierley[49] evaluated whether postoperative refractive power adjustment of an LAL improves refractive outcomes in patients who have undergone prior LASIK or PRK. In 34 eyes of 21 cataract patients with a history of myopic CRS, the final MR spherical equivalent relative to target refraction was within ± 0.25 D in 74% of eyes, within ± 0.50 D in 97% of eyes, and within ± 1.00 D in 100% of eyes. Mean absolute error was 0.19 D ± 0.20 D.

The "Holy Grail" in this field may be an adjustable and easily exchangeable IOL, which could facilitate correction of residual spherical astigmatic refractive errors and residual HOAs. Ideally, such an IOL could be modified multiple times to adapt to the patient's changing visual needs and to compensate for aging changes of the cornea. Not yet approved by the Food and Drug Administration, the Juvene fluid filled accommodating IOL uses modular technology. Reportedly, the fluid-filled component allows the still-functioning ciliary muscle and zonules to subtly change the ELP in the capsular bag to simulate accommodation. The modular IOL component allows for IOL exchanges with relative ease.[50]

Additionally, femtosecond laser technology is exploring in vivo IOL power adjustments.[51] This could lead to other modifiable parameters such as adding or removing toricity or multifocality to IOLs in vivo. Other approved options for postoperative adjustment include LASIK, PRK, and IOL exchange. The selection of procedures depends on multiple factors, including the magnitude and type of refractive error, the status of the IOL and capsular support, corneal health, and patient preferences.

TABLE 4.3 Authors' Strategy for Intraocular Lens Power Calculation in Eyes After Corneal Refractive Surgery

Preoperative measurements	• RTVue OCT scans • Galilei measurement • Atlas corneal topography • IOLMaster • Lenstar
Patient consultation	• Warn patients of IOL power calculation inaccuracy and possible additional surgery, as well as its associated cost.
IOL power calculation	• Enter all available data, and run IOL calculator at ASCRS, which includes OCT-based IOL power and Barrett True-K formulas.
IOL power selection	• Rely more on methods that use current data from ASCRS IOL calculator. • Select the IOL power based on the consensus of multiple methods from ASCRS calculator, with more weight on OCT-based IOL power formula and Barrett True-K formula. • Have two more IOLs ready on the operation table that are 0.5 D lower and 0.5 D higher than the IOL power selected preoperatively.
Intraoperative measurement	• Use Optiwave Refractive Analysis (ORA) System to confirm the IOL power selected preoperatively. • If ORA suggestion is different from the IOL power selected preoperatively, use the IOL that is 0.5 D higher or 0.5 D lower than the IOL power selected preoperatively.

SUMMARY

Although the methodology for accurately calculating IOL power in eyes with previous CRS has improved dramatically in recent years, refractive surprises still occur, especially in RK eyes. In current practice, multiple formulas should be used, and those that use current data (i.e., corneal topography [Table 4.3]) should be heavily weighted. Patients should always be warned of IOL power calculation inaccuracy and possible additional surgery with its associated cost. As for now, the OCT-based formula and Barrett True-K No History perform the best in postrefractive eyes. Luckily, formulas are constantly evolving, and new formulas are being used for standard IOL refractive error calculations, such as the Hill-RBF and Kane formulas. Using new algorithms and technology, these formulas have yet to be tested in the postrefractive realm, and their results remain to be seen. The most prudent strategy for the surgeon may be to obtain IOL calculations using several different methods and to select the IOL power based on the consensus of multiple methods.[6,7,52] Future advances are needed in all areas, including methods of measuring corneal power, predicting ELP, and calculating the lens power.

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PART II

Intraocular Lenses

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5

Principles of Intraocular Lens Design and Biomaterials

Liliana Werner and Catherine J. Culp

CONTENTS

KEY POINTS

- IOLs can be fixated to different sites after cataract surgery; the design of the lens has to be adapted for each site.
- The field of presbyopia-correcting IOLs is evolving fast, with numerous trifocal and extended-depth-of-focus lenses now available, and different accommodating lenses are being developed.
- A square posterior optic edge is the most important IOL-related factor to prevent PCO, although evidences suggest that IOLs keeping the capsular bag open and expanded, allowing for continuous aqueous humor flux, maintain better overall bag clarity.

INTRODUCTION

Intraocular lenses (IOLs) have been developed to replace the refractive power of the natural crystalline lens removed during cataract surgery. There has been a continuous evolution in this field since the first IOL implantation done by Harold Ridley, owing to advancements in manufacturing and surgical techniques, with the most recent innovations occurring in the area of presbyopia-correcting lenses. Awareness of the characteristics of different IOL designs and materials will assist surgeons in the selection of the ideal IOL for each particular eye, and this chapter aims to provide an overview of these characteristics.

THE EVOLUTION OF THE INTRAOCULAR LENS

Apple and associates have classified the development of IOLs into six generations, based primarily on site of IOL fixation (Fig. 5.1).[1] Each step forward represented an advance in both surgical technique and IOL design and quality.

- **Generation I** Ridley's first implant (1949–1950), was manufactured by Rayner and was a biconvex disc designed for implantation in the posterior chamber after extracapsular capsular extraction. The two major problems with this lens design were posterior capsule opacification (PCO) and IOL malposition/decentration, this latter caused by the excessive weight of the implant, the lack of fixation haptic elements, and performance of irregular anterior capsulotomies.
- **Generation II** (circa 1952–1962) was represented by early anterior chamber IOLs implanted after intracapsular cataract extraction. These lenses had excessive anterior vaulting of the entire pseudophakos causing inappropriate contact with the corneal endothelium. Corneal problems persisted well into Generations III and IV with many IOL designs.
- **Generation III** (circa 1953–1973), iris-fixated IOLs were designed to fixate the IOL further posterior from the cornea. However, physical contact of IOL haptics, especially metal haptics, with uveal tissue often caused inflammation and its sequelae, including corneal decompensation, cystoid macular edema, and inflammatory membrane formation. At this time, Binkhorst modified his early four-loop iris clip lens, creating the two-loop iridocapsular lens, so the optical component remained in front of the iris but the haptics were inserted into the capsular bag after extracapsular extraction, which had largely been abandoned as a surgical technique since Ridley's first implant.
- **Generation IV** (circa 1963–1992) represents a move back to the anterior chamber. Several pioneers developed rigid IOL designs, while others experimented with more flexible designs. The lenses with closed loops fixated into the anterior chamber angle of the late 1970s to early 1980s were associated with significant inflammation secondary to a "cheese cutter" effect. Flexible anterior chamber IOLs with open loops and Choyce-style footplate fixation elements formed the basis for the modern successful open loop anterior chamber IOLs used today. At the site of touch of Choyce-style footplates within the angle recess there is usually formation of a fibrous membrane that effectively separates the IOL from direct contact with the adjacent anterior chamber recess tissue.
- **Generations V and VI** (circa 1977 to present) form the basis for modern foldable IOL surgery after phacoemulsification via a small incision.[1] These two generations are subdivided into two subgroups each, ranging from Generation V-a, the early years of extracapsular extraction with posterior chamber IOL implantation (circa 1977–1982), to Generation V-b, the important transitional period toward the modern capsular surgery techniques (circa 1982–1987), culminating in the two subgroups of Generation VI (circa 1987–1992). Generation V-a was characterized by a general lack of modern surgical techniques, namely, no viscoelastic, can-opener anterior capsulotomy, no

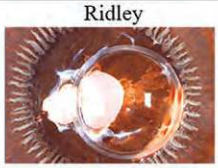
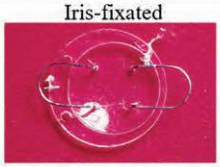
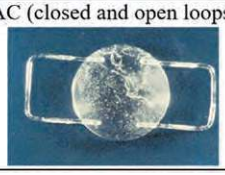
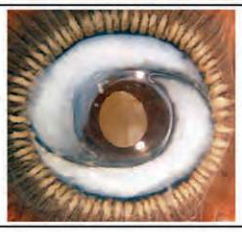
Generation	IOL type
I (1949-1950)	Ridley 
II (1952-1962)	Early AC 
III (1953-1973)	Iris-fixated 
IV (1963-1992)	AC (closed and open loops) 
V (1977-1987)	Early PC; Out-of-the-bag or asymmetric fixation 
VI-a (1987-1992)	Rigid PC; Better manufacture/ surgical techniques 
VI-b (1992-present)	Foldable PC; Small incision cataract surgery 

Fig. 5.1 Summary of the classification of the development of intraocular lenses (IOLs) and photographs of a representative lens from each generation. Generation I: Eye implanted with a Ridley IOL, which is decentered. Generation II: Schreck early anterior chamber (AC) IOL. Generation III: Iris-fixated IOL. Generation IV: Early closed-loop AC IOL. Generation V: Eye implanted with a three-piece PMMA posterior chamber (PC) IOL exhibiting asymmetric fixation. Generation VIa: Eye with a single-piece PMMA IOL symmetrically fixated within the capsular bag. Generation VIb: Eye with a single-piece hydrophobic acrylic IOL symmetrically fixated within the bag. Photographs of Generations I to IV from: Apple DJ, Ram J, Foster A, Peng Q. Elimination of Cataract Blindness: A Global Perspective Entering the New Millennium. Surv Ophthalmol. 2000 Nov;45 Suppl 1:S1–196.

hydrodissection, manual extracapsular extraction, and malfixation of haptics of the early posterior chamber IOLs, which were often poorly designed and manufactured. Most fixation of these lenses throughout Generation V was uveal or asymmetric (one or both haptics out of the capsular bag). Complications such as IOL decentration and uveal tissue chafing with its consequences (transillumination defects, pigmentary dispersion, uveitis-glaucoma-hyphema syndrome) were common. Successful transition toward symmetric in-the-bag fixation defines the transition from Generation V (precapsular surgery era) to Generation VI (capsular surgery era). The lens capsular bag is a basement membrane that separates the pseudophakos from the adjacent delicate tissues of the iris and ciliary body, a principle learned during experiences with anterior chamber lenses (Generation IV), as well as later experiences with sulcus fixated lenses (Generation V). Generation VI-a was the period when high-quality capsular surgery using mostly rigid lenses inserted via large incisions was common (circa 1987–1992). Generation VI-b (circa 1992 to present) is the era of small-incision phacoemulsification surgery with implantation of foldable IOL designs.

INTRAOCULAR LENS CONSTRUCTION AND SITES OF FIXATION

In general terms, when the entire IOL is manufactured from the same material, the lens is described as a single-piece design. Multipiece lenses (usually described as three-piece lenses) have the haptic components made from a material different from the optic. IOLs are overall described as developed for implantation in the anterior or posterior chambers, according to the site of fixation.[1,2]

Anterior Chamber

- ***Angle:*** Anterior chamber (AC) lenses are currently reserved for cases without appropriate capsular support, when there is a normal iris and a deep chamber (See Fig 6.1a). The diameter of the optical component is usually 5.5 mm, with a total diameter generally between 12 to 14 mm, and an anterior optic vaulting. The overall size of the lens is selected according to the anterior chamber diameter of the eye (e.g., measuring the white-to-white distance and adding 1 mm).
- ***Iris:*** Iris-fixated AC IOLs are usually one-piece rigid PMMA lenses with an iris-claw design (see Fig. 5.2).[3]

Posterior Chamber

Posterior chamber (PC) IOLs can be fixated within the capsular bag, the ciliary sulcus, or at the capsulotomy edge (see Fig. 5.1, Generations V and VI).[2]

- ***Capsular bag:*** The capsular bag is the ideal fixation site for PC lenses. IOLs should be designed to conform to different bag sizes, remaining stable postoperatively in the presence of fibrosis and contraction. PC lenses designed for fixation within the capsular bag are manufactured in a large variety of single-piece or multipiece

Fig. 5.2 Artisan Aphakia (model 205; courtesy Ophtec BV). From: Werner L. For the AAO "The IOL Issue" Intraocular Lenses: Overview of Designs, Materials, and Pathophysiology. Ophthalmology. 2020 Jun 30;S0161–6420(20)30626-6. doi: 10.1016/j.ophtha.2020.06.055. Online ahead of print.

designs. Single-piece lenses may be open loop designs or overall plate lenses.[1,2] More recently, special IOLs designed to be fixated in the capsular bag emerged, which include open-bag lenses, fluid-filled lenses, and modular lenses (Fig. 5.3A–C).

- **Open-bag IOLs**: Traditionally, PC IOLs that are designed for in-the-bag fixation are recommended to be inserted through a capsulorrhexis with a smaller diameter than the optic, so the periphery of the optic will be covered by the residual anterior capsule. This will favor the "shrink wrapping" of the IOL by the bag, enhancing the contact between posterior optic surface and posterior capsule with better PCO prevention. However, there is increasing evidence that IOLs designed to keep the capsular bag open and expanded, allowing for continuous flux of aqueous humor within the bag, are associated with better overall bag clarity.[4,5]
- **Fluid-filled IOLs**: Different fluid-driven IOLs, designed to mimic the eye's mechanism of accommodation, are currently being developed or already under clinical investigation. An example is the FluidVision (PowerVision, Inc.), a new single-piece hydrophobic acrylic deformable accommodating lens. Its design features hollow optic and haptic components filled with index-matched silicone oil. During efforts for accommodation, the silicone oil is driven from the haptics into the optic, which increases the optic's surface curvature, resulting in higher optic power.[6]
- **Modular IOLs**: IOLs can be designed in two separate pieces that are connected after injection into the eye. These modular IOL systems are usually composed of a base component implanted within the capsular bag and an optic component that clips or docks to the base. Such systems permit easier and safer surgical exchange of the optic component, allowing correction of residual refractive errors or those resulting from postoperative anatomic changes. They also, in theory, grant the patient access to yet-to-be-developed optical technologies.[7]

- ***Ciliary sulcus:*** In cases of posterior capsule complications during surgery, with adequate residual capsule support, an IOL can be fixated in the ciliary sulcus.[8] To avoid uveitis-glaucoma-hyphema syndrome from excessive interaction of lenses with the posterior iris surface and other uveal tissues, the design of the PC lens placed in the sulcus should have sufficient posterior iris clearance, which can be obtained with a posterior optic-haptic angulation. A three-piece PC IOL has the advantage of thin, posteriorly angulated, C-shaped haptics that enhance posterior iris clearance and minimize uveal interaction. The anterior optic surface and edges should be smooth and round to minimize iris chafing in case of iris contact. The overall IOL diameter must be sufficiently long to enhance centration and allow for stable fixation in the sulcus (minimum of 13.0 mm). Posterior optic capture through the capsulorrhexis can be performed in the presence of a well-centered capsulorrhexis with a diameter slightly smaller than that of the optic, in which case peripheral contact between the haptic and the ciliary sulcus is not necessary for stable fixation and centration. If the residual capsular support is not sufficient, a lens can still be fixated in the ciliary sulcus and additional support can be provided by suturing the IOL loops to the sclera or the iris. More recently introduced sutureless intrascleral fixation techniques allow fixation of three-piece IOL haptics into scleral tunnels parallel to the limbus, without IOL suture-related complications.[9]
    - Incorrect IOL power remains one of the most important causes of IOL explantation, and supplementary (add-on; piggyback) IOL implantation has been used to deal with this complication. There is also renewed interest in the piggyback IOL procedure because of the potential to implant a low-power multifocal lens to provide spectacle freedom to pseudophakic patients, or other specialized IOLs (pinhole implant for irregular astigmatism, supplementary IOL for macular degeneration).[10–12] Another indication is to manage progressive refractive changes in pediatric eyes. The surgical trauma of piggyback implantation is significantly less than explantation/exchange of an in-the-bag IOL, especially if done long-term postoperatively. Supplementary IOLs are usually placed in the sulcus while the primary IOL is in the bag, which avoids growth of proliferative material between the lenses (interlenticular opacification [ILO]).[10] In addition to the overall characteristics delineated above, these lenses should ideally be manufactured from a soft biocompatible material, allowing for small incision insertion and provide appropriate clearance with the in-the-bag IOL, decreasing likelihood of induced refractive error and optical aberrations. The latter can be done by incorporating an anterior convex surface with a posterior concave surface.
- ***Capsulotomy:*** The "bag-in-the-lens" (BIL), developed by Dr. Tassignon in Belgium, changes the relationship between the IOL

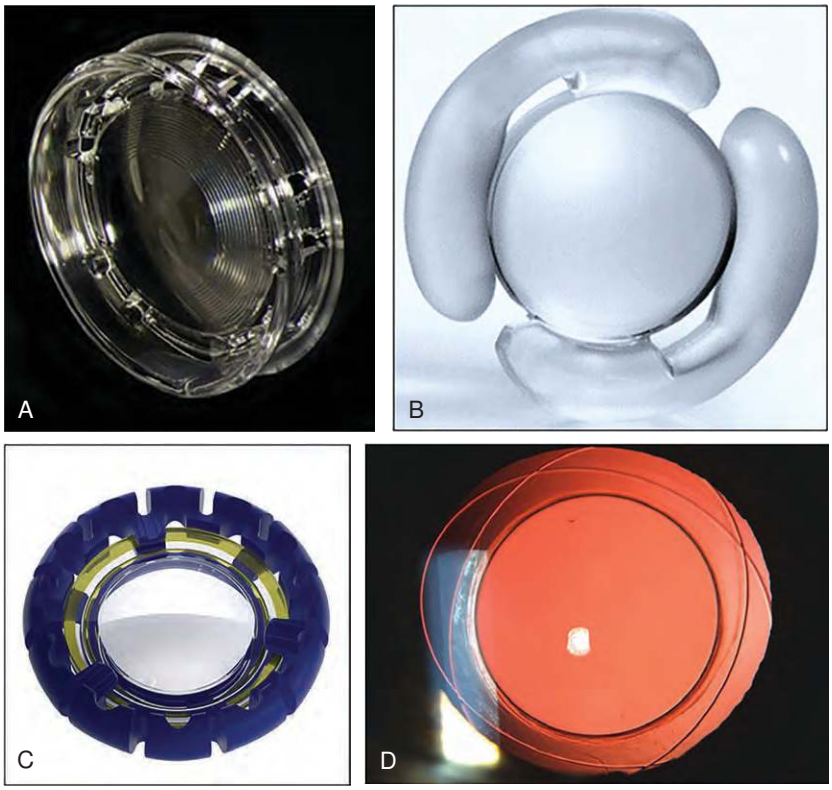


Fig. 5.3 Photographs and drawings showing special IOL designs and a capsulotomy-fixated lens. (A) Zephyr open-bag lens (Anew Optics). (B) FluidVision fluid-filled accommodating lens (Powervision). (C) Juvene modular fluid-filled accommodating lens (LensGen). (D) Bag-in-the-lens (Morcher; courtesy M.J. Tassignon, MD, Belgium). B and C from: Werner L. For the AAO "The IOL Issue" Intraocular Lenses: Overview of Designs, Materials, and Pathophysiology. Ophthalmology. 2020 Jun 30;S0161–6420(20)30626-6. doi: 10.1016/j.ophtha.2020.06.055. Online ahead of print.

and the capsular bag, eliminating the contact between the lens and the inner surface of the latter (see Fig. 5.3D). It involves performing anterior and posterior capsulorrhexis of the same size and stretching both capsular openings in the groove around the optic of the lens. This limits the residual lens epithelial cells (LECs) to the remaining space of the capsular bag, preventing PCO.[13]

- The advent of femtosecond laser-assisted cataract surgery, with the ability to create capsulotomies of consistent sizes, renewed the interest in capsulotomy-fixated IOLs, which potentially offer benefits in predictability and stability of IOL centration and tilt, control of capsular phimosis, elimination of negative dysphotopsia, and rotational and refractive predictability and stability. New IOLs designed to be used in conjunction with laser cataract surgery have a haptic system with two large and two small flaps to clamp the lens into the capsulotomy.[14]
- Other grooved, capsulotomy-centered IOLs are antidysphotoptic lenses with an annular groove on the periphery of the anterior optic surface to receive the anterior capsulotomy, while the rest of the lens remains inside of the capsular bag. They were designed based on the theory that placing the optic anteriorly to the anterior capsule will reduce, eliminate, or prevent negative dysphotopsia.[15]

INTRAOCULAR LENS OPTICS

Beyond the basic function of adding spherical refractive power to the eye after cataract surgery, different properties have been included in the IOL optic design over the past decades. At a basic IOL optic classification level, monofocal IOLs have a fixed focus for one distance, while multifocal IOLs distribute the light to different foci. These later can be refractive, diffractive, or a combination of both designs.[16] Presbyopia-correcting IOLs can be divided into multifocal lenses (bifocal, trifocal), extended depth-of-focus (EDOF) IOLs, and accommodative IOLs (monofocal lenses with special designs to allow for anterior optic movement or optic shape changes upon efforts for accommodation).[17–19] EDOF lenses create a single-elongated focal point to enhance the depth of focus (Fig. 5.4). They are frequently combined with a light-splitting optic technology such as a multifocal optic. Non–light-splitting presbyopia-correcting EDOF optics include small aperture optics.[20] Toric IOLs have different powers in different meridians of the lens to correct astigmatism and are available in combination with presbyopia-correcting IOL optics described above.[21]

The eye, like any other optical system, suffers from a number of specific optical aberrations. Low-order aberrations (myopia, hyperopia, and regular astigmatism) have a greater impact on vision. However, high-order aberrations, such as spherical aberration, also play an important role. This generally reduces retinal image contrast and affects visual quality, especially under mesopic conditions. The average spherical aberration of the anterior cornea surface is positive, remaining stable throughout life. The natural crystalline lens compensates for this positive spherical aberration, inducing a negative spherical aberration. However, with the development of cataracts, the spherical aberration of the crystalline lens changes over time from negative to positive. Because implantation of traditional spherical IOLs may also increase the spherical positive aberration, aspheric IOLs with anterior and/or posterior prolate surfaces were developed. Aspherical lenses may be

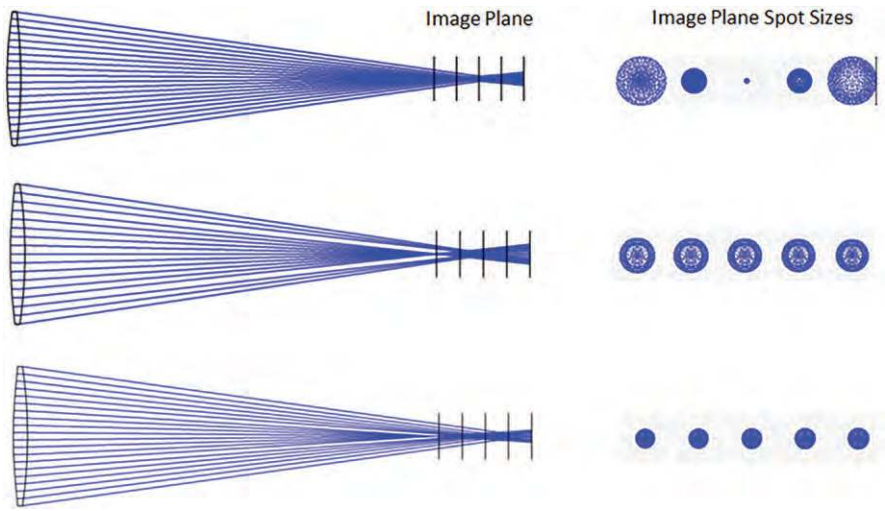


Fig. 5.4 Modeling of image formation at various focal distances using ZEMAX ray trace program for a monofocal IOL (top), a trifocal IOL (middle), and an extended-depth of focus IOL (bottom). Courtesy Kamal Das, PhD, Alcon Vision, LLC.

neutral or induce different amounts of negative spherical aberration to compensate for the cornea's positive spherical aberration. Aspheric technology has also been applied to multifocal IOL technology to decrease undesirable optical phenomena associated with those lenses, such as glare, halos, and loss of contrast sensitivity.[22]

INTRAOCULAR LENS MATERIALS

Optic

Biomaterials (polymers) used for the manufacture of IOL optics can be divided into two major groups, namely, acrylic and silicone. Acrylic lenses have a carbon backbone, and material variations are achieved by varying the sidechains. Acrylic IOLs can be further divided into rigid, e.g. poly(methyl methacrylate) (PMMA), and foldable, hydrophobic, or hydrophilic acrylic materials.[1,2]

Each currently available foldable acrylic lens design is manufactured from a different copolymer acrylic, with different refractive index, glass transition temperature (the temperature above which the polymer exhibits flexible properties), water content, mechanical properties, and so forth. Standard hydrophobic acrylic lenses (and silicone lenses) have a very low water content, generally lower than 0.5%. Hydrophobic acrylic IOLs appear to have the largest share of the market worldwide. Because of the potential concern of hydration-related inhomogeneities such as glistenings (fluid-filled microvacuoles within the IOL when in an aqueous environment), recent years have seen the increasing development and availability of hydrophobic acrylic lenses with higher water contents, ranging from 1.5% to approximately 4%, that still meet the criteria for this class, and they are considered glistenings free.[2]

Most of the currently available hydrophilic acrylic lenses are manufactured from copolymers acrylic with water contents ranging from 18% to 38%. The Collamer material (Staar Surgical) can also be included in this category because it is composed of a proprietary copolymer of a hydrophilic acrylic material and porcine collagen, with a water content of 34%.[2]

The first silicone material used in the manufacture of IOLs was poly(dimethyl siloxane), which has a refractive index of 1.41. Latest generations of silicone materials have higher refractive indexes. Although foldable acrylics display glass transition temperatures at around room temperature, the glass transition temperature of silicones can be significantly below room temperature. Another differentiating property is the refractive index, which is higher with acrylics (1.47 or greater) so these lenses are usually thinner than silicone lenses for the same refractive power.[2]

The surface properties of a polymer can be modified to ensure that it will be better adapted to its final use. An example is the heparin-surface-modification of PMMA IOLs to increase the lens' biocompatibility and decrease inflammatory reactions, particularly in the pediatric population. More recently, a treatment with ultraviolet–ozone has been applied to the posterior surface of lenses manufactured by Hoya to enhance the attachment between the posterior optic surface and the posterior capsule and help prevent postoperative PCO.[23]

Filters

In our natural environments, the most offending portions of the electromagnetic spectrum are ultraviolet (UV) radiation (200–400 nm) and the blue-light portion of the visible spectrum (400–500 nm), which is composed of violet light (400–440 nm) and blue light (440–500 nm). Important elements of the IOL optic component are represented by the ultraviolet-absorbing compounds (chromophores). These are incorporated to the IOL optic to protect the retina from ultraviolet (UV) radiation in the 300 to 400 nm range, a protection normally provided by the crystalline lens. Two classes of ultraviolet-absorbing chromophores are used in general for the manufacture of pseudophakic IOLs, namely benzotriazole and benzophenone.[2] Yellow acrylic IOLs containing a blue light-filtering chromophore (besides the standard chromophore for protection against UV radiation) are also available in the market, as are orange-tinted IOLs, which filter blue-green light.[24] The addition of a covalently bonded yellow dye results in an IOL UV/visible light transmittance curve that mimics the protection provided by the natural, precataractous adult human crystalline lens. There is indirect evidence showing that this may result in a reduction of the risk for macular degeneration, or its progression. Other manufacturers adopt the approach of a violet light-filtering chromophore (Fig. 5.5).[25] This is based on studies indicating that UV radiation and violet light can cause significant phototoxicity but contribute little to rod-mediated visual function, while blue light is vital for scotopic vision. Furthermore, the response of nonvisual retinal ganglion photoreceptors to bright, properly timed light exposures help ensure effective circadian photoentrainment and optimum diurnal physiologic processes. The spectral

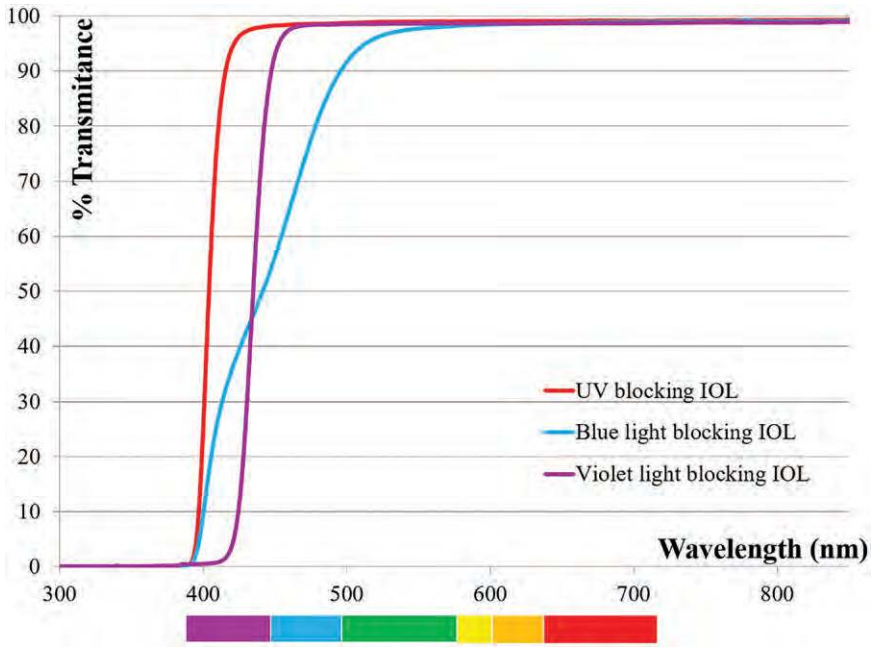


Fig. 5.5 Light transmittance spectra between 850 nm and 300 nm for an IOL with UV filter (AcrySof SA60AT, Alcon Vision, LLC), an IOL with UV and blue-light filters (AcrySof SN60WF, Alcon Vision, LLC), and an IOL with UV and violet-light filters (Tecnis Optiblue, Johnson & Johnson Vision). The visible spectrum corresponds to wavelengths from about 400 to 700 nanometers (bar below graph showing approximate wavelengths). The wavelengths below and above these limits correspond to ultraviolet light and infrared light, respectively.

sensitivity of circadian photoreception peaks in the blue part of the spectrum at approximately 460 nm. Therefore there has been an argument about whether IOLs should transmit blue light for optimum scotopic vision and circadian photoreception. Another important point is that short-wavelength lighting enhances light scattering, chromatic aberration, and fluorescence and that contrast and visual clarity in human vision and in photography are improved when cutoff filters are used to eliminate environmental light with wavelengths shorter than 450 nm (violet light).[25]

Special IOL materials include those with photochromic and light adjustable properties. The hydrophobic acrylic photochromic lens (Medennium) has an UV-near blue absorption curve similar to blue-filtering yellow IOLs when exposed to UV light, while it behaves as a standard UV absorbing IOL in an indoor or night environment. Therefore the lens optic changes from colorless to yellow when exposed to UV light and back to colorless in indoor environments. A silicone light adjustable lens (RxSight) contains macromers and photoinitiators, in addition to the silicone matrix polymer and standard chromophore for UV protection. The photosensitive silicone subunits (macromers) move within the lens optic upon fine tuning with a low intensity beam of near-UV light, which allows the refractive power of the lens to be adjusted noninvasively after implantation. Biocompatibility studies in rabbit eyes were performed before clinical implantation of these two new materials, which were found to induce reactions similar to standard IOLs.[2]

Haptics

Materials currently used for the manufacture of the loop or haptic components of multipiece lenses include PMMA, polypropylene (Prolene), polyimide (Elastimide), polyvinylidene fluoride (PVDF), and polyethersulfone (PES). Fixation of flexible-looped IOLs is achieved by exerting centripetal pressure on the surrounding ocular tissues. The two factors that contribute to the ability of IOL loops to maintain their original symmetric configuration are loop rigidity (resistance to external forces that act to bend the loops centrally), and loop memory (ability to reexpand laterally to original size and configuration). IOL loops should have enough flexibility to allow easy insertion and accommodation to the circular shape of the eye and appropriate rigidity to resist external forces related to capsular bag contraction from capsular fibrosis. There is a tendency to abandon Prolene as a loop material because of its greater flexibility that makes it less resistant to contraction forces within the capsular bag in the postoperative period, which may lead to IOL decentration.[1,2]

There is usually some angle between the optic component and the loops of three-piece PC lenses to make the optic component more posteriorly located. With in-the-bag fixation, the posterior angulation will enhance the contact between the posterior optic surface and the posterior capsule, enhancing PCO prevention by the optic barrier effect. For three-piece IOLs placed in the ciliary sulcus, this posterior angulation will allow for sufficient posterior iris clearance.

IOL stability is largely dependent on the mechanical design of the haptics. For IOLs fixated within the capsular bag, postoperative bag shrinkage caused by fibrosis may lead to axial displacement, with ensuing refractive shifts, among other complications. Single-piece IOLs with open loops are usually designs with planar haptics (0-degree angle), or step-vaulted designs with haptics that are offset from the optical plane. In IOLs with a planar haptic design, the haptics extend radially from the optic edge along the optical plane. There is a smooth transition at the junctions and, if PCO occurs, it has the tendency to start at those sites. In IOLs with a step-vaulted haptic design, the haptics extend radially from the optic edge but are shifted anteriorly from the optical plane to allow for a posterior step feature at the optic-haptic junction, which would allow for better PCO prevention. However, step-vaulted and angulated haptics are mechanically biased toward posterior axial deflection, which may result in more posterior IOL axial displacement in cases of significant postoperative capsular bag contraction.[26]

INTRAOCULAR LENS PATHOLOGY

Uveal Biocompatibility

Uveal biocompatibility is defined by the inflammatory response of the eye toward the IOL. Cataract surgery with IOL implantation breaks down the blood-aqueous barrier, causing immediate release of proteins and cells into the anterior chamber. Protein adsorption on the IOL's surface is the first phenomenon observed. It depends on factors such as the surface energy of the IOL biomaterial and its chemical structure. This phenomenon will influence subsequent cell interaction in the interface material-tissue, observed in the following minutes or hours. The complement system is activated by the alternative pathway, attracting polymorphonuclear leukocytes and monocytes, which are the origin of the macrophages and giant cells that constitute a foreign-body reaction against the IOL. Specular microscopy shows that inflammatory cell deposits are a normal occurrence on the lens surface for up to 1 year after surgery. This cellular response consists of two distinct processes: a response with small round and fibroblast-like cells, which peaks by 1 month, and a later giant cell response, which peaks at 3 months. Giant cells then degenerate and detach from the IOL surface, and only an acellular proteinaceous membrane surrounds the IOL, isolating it from the surrounding ocular tissues. Variations on the intensity and duration of each cell response (small cells or giant cells) may be found according to the IOL biomaterial evaluated. However, this cellular reaction is generally of low grade and clinically insignificant.[2,27]

Capsular Biocompatibility

Capsular biocompatibility is defined by the degree of LEC proliferation after IOL implantation. The epithelium of the natural crystalline lens consists of a sheet of anterior epithelial cells ("A" cells) that are in continuity with the cells of the equatorial lens bow ("E" cells; Fig. 5.6). "E" cells comprise the germinal cells that undergo mitosis as they peel off from the equator. They constantly form new lens fibers during normal lens growth. Although both the anterior and equatorial LECs stem from a continuous cell line and remain in continuity, they are usually divided into two functional groups. The "A" cells, when disturbed, tend to remain in place and not migrate. They are prone to a transformation into fibrous-like tissue (pseudofibrous metaplasia). In contrast, the "E" cells tend to migrate posteriorly along the posterior capsule, and instead of a fibrotic transformation, they tend to form large, balloon-like bladder cells also known as Elschnig pearls. These are the cell types involved in the different forms of postoperative opacification of the capsular bag, including anterior capsule opacification (ACO), posterior capsule opacification (PCO), and interlenticular opacification (ILO).[1,2,27]

- ***Anterior capsule opacification:*** Significant fibrosis and ACO may lead to anterior capsular shrinkage and constriction of the anterior capsulotomy opening (capsulorrhexis contraction syndrome or capsular phimosis). It may also prevent appropriate functioning of accommodating IOLs, generally designed to present a forward movement of the optic upon efforts for accommodation. ACO is more common with silicone IOLs, especially plate designs, because of the larger area of contact between these lenses and the anterior capsule (Fig. 5.7). However, there are no significant differences in ACO between hydrophobic acrylic and the latest generation of silicone lenses. ACO may eventually be prevented by the use of an IOL that does not contact the inner surface of the anterior capsule. Capsular polishing during surgery may also decrease ACO and capsulorrhexis aperture contraction postoperatively.[2,27]
- ***Posterior capsule opacification:*** Secondary cataract or PCO is the most common postoperative complication of cataract surgery (see Fig. 5.7). The "Sandwich" theory states that a hydrophobic acrylic IOL with bioadhesive surface would allow only a monolayer of LECs to attach to the capsule and the lens, preventing further cell proliferation and capsular bag opacification. We performed immunohistochemical studies on the protein adhesion to different IOLs implanted in human eyes obtained postmortem, which confirmed greater amounts of fibronectin (protein mediating adhesion) on the surfaces a hydrophobic acrylic lens (AcrySof, Alcon).[2,27] The surface of an IOL may also be modified to enhance its adhesion to the capsule through

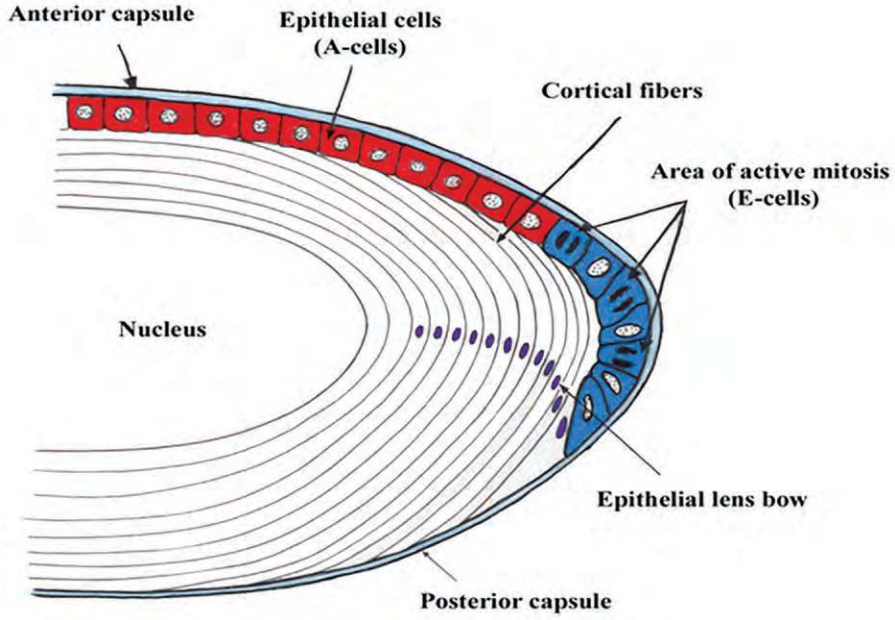


Fig. 5.6 Schematic drawing representing the histology of the crystalline lens. From: Werner L, Apple DJ, Mamalis N. Pathology of Cataract Surgery and Intraocular Lenses. In: Steinert RF, ed. Cataract Surgery, 3rd Edition. Philadelphia, PA: WB Saunders Co. Elsevier; 2010, Chapter 42, pp. 501–529.

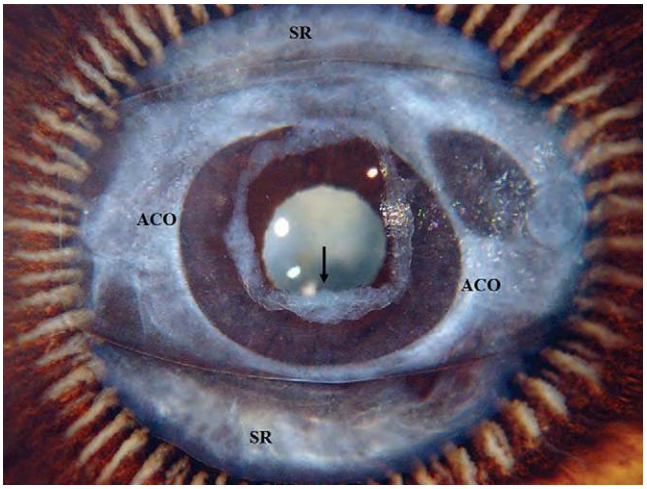


Fig. 5.7 Gross photographs of a human eye obtained postmortem, taken from the posterior or Miyake-Apple view. The eye contains a single-piece plate silicone lens implanted in the bag. There is Soemmering's ring formation (SR), anterior capsule opacification (ACO) in the area of contact between the anterior capsule and the IOL anterior surface, and a posterior capsulotomy (arrow) performed because of posterior capsule opacification formation.

TABLE 5.1 Surgery- and Intraocular Lens (IOL)-Related Factors for Prevention of Posterior Capsule Opacification (PCO)*

Six Factors for PCO Prevention	
Surgery-Related Factors	**IOL-Related Factors**
1. Hydrodissection-enhanced cortical clean-up	4. Biocompatible IOL to reduce stimulation of cellular proliferation
2. In-the-bag IOL fixation	5. Contact between the IOL optic and the posterior capsule
3. Capsulorrhexis smaller than the diameter of the IOL optic	6. IOL with a square, truncated optic edge.

*From: Werner L, Apple DJ, Mamalis N. Pathology of Cataract Surgery and Intraocular Lenses. In: Steinert RF, ed. Cataract Surgery, 3rd Edition. Philadelphia, PA: WB Saunders Co. Elsevier; 2010, Chapter 42, pp. 501–529.

surface modifications, like with the ultraviolet–ozone applied to the posterior surface of lenses manufactured by Hoya.[23]

- Experimental and clinical studies helped define three surgery-related and three IOL-related factors that help prevent PCO (Table 5.1).[1,27] The most important IOL-related factor for PCO prevention is the presence of a square posterior optic edge. This IOL design feature has generally been incorporated into modern foldable IOL designs, but evaluation of the microstructure of the edges of currently available foldable IOLs using scanning electron microscopy found that all square edges in the market are not equally square. As a group, hydrophilic acrylic lenses have less square edges than hydrophobic acrylic and silicone lenses. Animal and clinical studies demonstrated that the square posterior optic edge should also be present for 360 degrees around the lens optic, for maximal prevention of PCO. In some single-piece designs, the optic-haptic junctions show a smooth transition where the optic edge effect is lost, which may represent initial sites for PCO formation.[2,27]

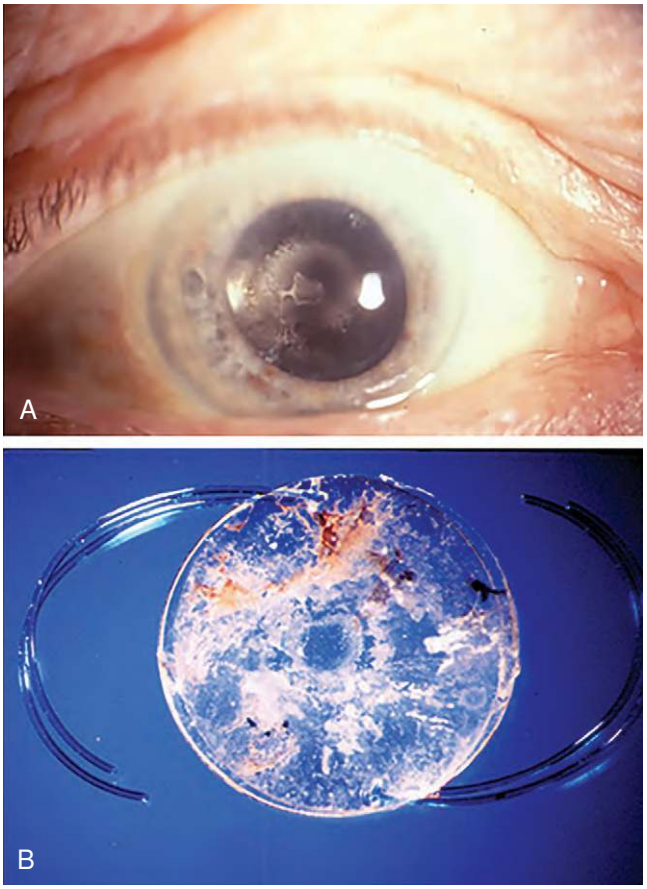


Fig. 5.8 Interlenticular opacification between two three-piece hydrophobic acrylic lenses implanted within the bag. (A) Clinical photograph. (B) Gross photograph of the explanted lenses. From: Werner L, Apple DJ, Mamalis N. Pathology of Cataract Surgery and Intraocular Lenses. In: Steinert RF, ed. Cataract Surgery, 3rd Edition. Philadelphia, PA: WB Saunders Co. Elsevier; 2010, Chapter 42, pp. 501–529.

- ***Interlenticular opacification:*** Interlenticular opacification (ILO) occurs in the interface between two IOLs (Fig. 5.8). A second IOL may be added to a pseudophakic eye for different reasons, such as to correct a residual refractive error or to add multifocality in an eye implanted with a monofocal lens. ILO is derived from retained/regenerative cortex and pearls, which is similar to the pathogenesis of the pearl form of PCO. To date, all cases of ILO analyzed in our laboratory seem to be related to implanting two hydrophobic acrylic IOLs (AcrySof, Alcon) in the capsular bag through a small capsulorrhexis with 360-degree overlapping of the anterior IOL's optic edge. When these lenses are implanted in the capsular bag through a small capsulorrhexis, the bioadhesion of the anterior surface of the front lens to the anterior capsule edge and of the posterior surface of the back lens to the posterior capsule prevents the migration of the cells from the equatorial bow onto the posterior capsule, which is then directed to the interlenticular space. In this scenario, the two IOLs are sequestered together with aqueous and LECs in a hermetically closed microenvironment. In addition, the adhesive nature of the IOL surface seems to render the opacifying material very difficult to remove by any surgical means.[1,2,27]
  - ILO can be prevented by implanting the anterior IOL in the sulcus with the posterior IOL in the bag. The capsulorrhexis margin will adhere to the anterior surface of the posterior IOL and the

material and cells within the equatorial fornix will be sequestered.[2,27] However, clinical evidences suggest that in this case, the IOL fixated in the sulcus should have a smooth rounded anterior optic edge and thin haptics to minimize its interaction with the posterior iris surface and prevent complications such as pigmentary dispersion syndrome.[10]

- ***Lens epithelial cell ongrowth***: "A" cells at the capsulorrhexis edge may proliferate onto the anterior surface of some IOLs, a phenomenon referred to as LEC ongrowth or outgrowth. This usually has no influence on the visual function. Elongated LECs with dendritic expansions are seen growing toward the center of the anterior optic surface, usually in association with protein deposition. The phenomenon appears to be material dependent, and has been observed in the past with some hydrophilic acrylic lenses and, more recently, with some hydrophobic acrylic lenses.[2,28]

IOL Opacification

Although constituting a relatively rare complication, IOL materials may exhibit opacification shortly or long-term after implantation.[2,27] Different processes leading to IOL opacification may include slowly progressive degradation of the lens biomaterial by long-term UV exposure, influx of water in hydrophobic materials (hydrophobic acrylic and silicone), formation of deposits/precipitates on or within the IOL, or IOL coating by substances such as silicone oil and ophthalmic ointment (Fig. 5.9).

Snowflake degeneration is a slowly progressive opacification observed in three-piece PMMA lenses manufactured by injection molding. It appears to be a result of long-term UV light exposure. Affected lenses have spherical lesions interpreted as foci of degenerated PMMA clustered in the central and midperipheral portions of the optic. As the peripheral optic may be protected against UV exposure by the iris, snowflake lesions are generally not observed in the optic periphery. This condition has so far not been observed with modern PMMA lenses, manufactured through techniques other than injection molding.

Hydration-related phenomena in hydrophobic acrylic lenses include glistenings and subsurface nanoglistenings.[29] Glistenings are fluid-filled microvacuoles (1–20 microns in diameter) that form within the IOL optic when in an aqueous environment. The absorbed water is usually not visible because it is in the form of water vapor within the polymer network. If the lens is placed in warm water and then the temperature is lowered, the water inside the polymer becomes oversaturated. The water surplus gathers inside voids within the polymer network, forming glistenings. Because there is a significant difference in the refractive index of water droplets (1.33) and the bulk of the IOL polymer (e.g., 1.555 for AcrySof lenses), the light is refracted and scattered at the water-polymer interfaces, leading to a sparkling appearance of the fluid-filled vacuoles (thus the term glistenings).

Subsurface nanoglistenings are a result of phase separation of water (from the aqueous humor) at the IOL subsurface. They may cause light scattering seen as a "whitening" appearance of the lens surface when the light is directed at the IOL at an angle of incidence of 30 degrees or greater during slit lamp examination or during image capture at an angle of 45 degrees with Scheimpflug photography. As with glistenings, subsurface nanoglistenings have also been particularly studied and described in IOLs made of the AcrySof material (Alcon). Both glistenings and subsurface nanoglistenings have the potential to increase light scattering but have been rarely reported as causes of IOL explantation.

Different factors may lead to increased influx of water in silicone IOLs, which are normally highly hydrophobic. Preoperative contamination of three-piece silicone IOLs inside of their vapor permeable packages by local spraying of cleaning and insecticide agents led to early postoperative opacification (optic cloudiness observed a few hours after implantation). Late postoperative brownish discoloration and central haze of silicone lenses was reported in the early 1990s, rarely requiring explantation. The haze was apparently caused by light

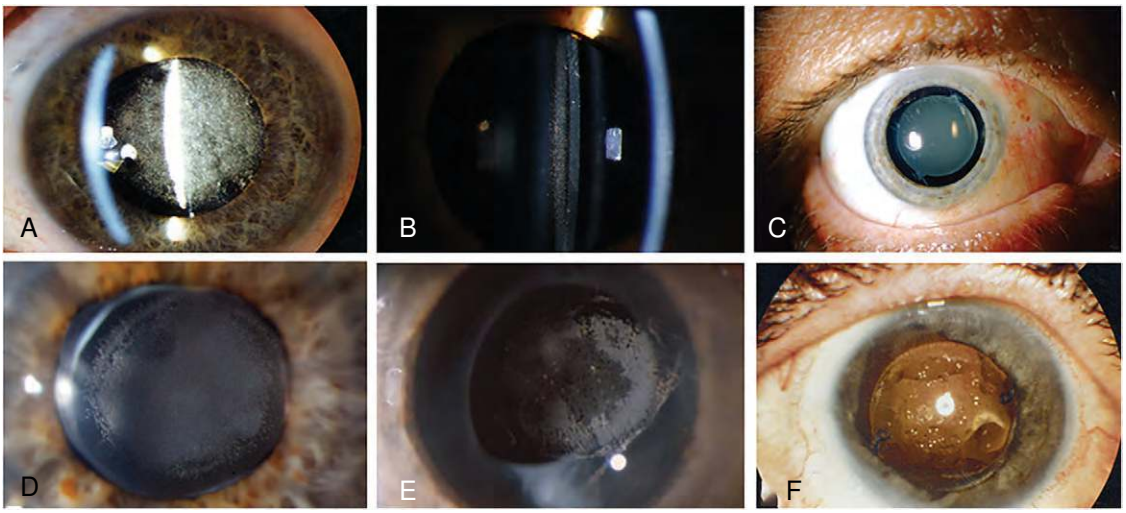


Fig. 5.9 Clinical photographs showing conditions leading to IOL opacification. (A) Snowflake degeneration of a PMMA lens. (B) Glistenings on a hydrophobic acrylic lens. (C) Early opacification of a three-piece silicone lens. (D) Round, localized anterior surface/subsurface calcification of a hydrophilic acrylic lens. (E) Calcification on the posterior surface of a plate silicone lens, which has been partially cleared with Nd:YAG laser application. (F) Adhesion of silicone oil to the surface of a three-piece silicone lens. A, C, E, and F from: Werner L, Apple DJ, Mamalis N. Pathology of Cataract Surgery and Intraocular Lenses. In: Steinert RF, ed. Cataract Surgery, 3rd Edition. Philadelphia, PA: WB Saunders Co. Elsevier; 2010, Chapter 42, pp. 501–529. D from: Werner L, Wilbanks G, Nieuwendaal CP, Dhital A, Waite A, Schmidinger G, Lee WB, Mamalis N. Localized opacification of hydrophilic acrylic intraocular lenses after procedures using intracameral injection of air or gas. J Cataract Refract Surg. 2015 Jan;41(1):199–207.

scatter from water vapor diffusing into the silicone when immersed in an aqueous medium, resulting from an anomaly of the curing process or incomplete extraction of large polymers during manufacturing.

Formation of deposits/precipitates on the IOL surface and/or within its substance is in general related to calcification, a complication usually associated with hydrophilic acrylic lenses. Analyses of explanted lenses showed that it is often difficult to determine the time optic opacification occurs, but lenses are, on average, explanted during the second year post implantation. The opacification is not associated with anterior segment inflammatory reaction, and Nd:YAG laser is ineffective in removing the calcified deposits. Calcification of hydrophilic acrylic lenses appears to be a multifactorial problem, with possible contributing factors including IOL manufacture variables, IOL packaging containing silicone compounds, surgical techniques and adjuvants, and patient metabolic conditions (e.g., diabetes). Explantation/exchange of the opacified/calcified IOL is to date the only possible treatment.

A specific pattern of calcification in a round configuration localized to the anterior surface/subsurface of the central/paracentral optic area of different hydrophilic acrylic IOLs has been described after secondary anterior segment procedures using intracameral injection of air/gas,[30] and after secondary posterior segment procedures.[31] This suggests an inflammatory or metabolic change in the aqueous humor caused by repeated intraocular procedures as the cause of this secondary IOL calcification. Indeed, the calcification always occurs where the aqueous humor contacts the anterior IOL surface. Silicone lenses may also exhibit calcification on the posterior optic surface in eyes with asteroid hyalosis. The deposits may be at least partially removed by Nd:YAG laser application, but generally, there is a fast reaccumulation of the deposits after posterior capsulotomy.

Opacification of silicone lenses in the late postoperative period was also observed in relation to deposition of material on the lens surfaces. Patients with vitreoretinal problems that require use of silicone oil should not be implanted with silicone lenses because the oil will attach to the lens surfaces. Toxic anterior segment syndrome (TASS) has been related to tight eye patching after applying antibiotic/steroid ointment and pilocarpine gel in patients who underwent uneventful phacoemulsification via clear corneal incisions with implantation of three-piece silicone lenses. The ointment gained access to the anterior chamber, coated the IOL surfaces, and caused significant damage to anterior chamber tissues. These cases highlight the importance of appropriate wound construction and integrity, and the risks of tight eye patching after placement of ointment.[2,27]

SUMMARY

A variety of new pseudophakic IOL designs, manufactured from different biomaterials, is continuously being made available to cataract surgeons worldwide, owing to advancements in manufacture and surgical techniques. They are expected to remain biocompatible and transparent in the intraocular environment for a long time. The overview provided in this chapter shows that these amazing implantable devices are being used with increasing efficiency not only to restore the refractive power of the eye after cataract surgery but also to provide added features and benefits to patients.

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Polymethyl Methacrylate Posterior- and Anterior-Chamber Intraocular Lenses

Jonathan B. Rubenstein and Sarah E. Carballo

CONTENTS

KEY POINTS

- Polymethyl methacrylate (PMMA) intraocular lenses (IOLs) are an important tool in a cataract surgeon's repertoire in the setting of abnormal capsular/zonular anatomy.
- PMMA IOLs require special considerations and surgical technique for placement in either the anterior or the posterior chamber.
- Precise surgical placement is key to avoid common complications of anterior-chamber intraocular lens (ACIOL) implants or sutured posterior-chamber intraocular lens (PCIOL) implants.

INTRODUCTION

Historically, the original intraocular lens (IOL) implants were made of polymethyl methacrylate (PMMA). Discovered after inert shards of PMMA were removed from the eyes of World War II Air Force pilots, the first IOL implant made of PMMA was successfully implanted by Sir Harold Ridley in London in 1949. PMMA implants were then the primary form of IOL implant from the 1950s to the 1980s.

PMMA is a rigid and hydrophobic material with a refractive index of 1.49. PMMA IOLs typically have an optic diameter of 6 mm, a length of 12.5 to 13.5 mm, and are nonfoldable. As such, they require a large incision size. This material provides excellent biocompatibility, a hydrophobic surface, and outstanding optical performance. However, when the phacoemulsification technique for cataract surgery developed and continued to improve in efficiency, foldable acrylic and silicone IOLs became the preferred material for lens implants because of their ability to fit through the smaller incisions. Because of this, PMMA lenses have largely fallen out of favor as the standard choice for posterior chamber lens implantation associated with phacoemulsification. They do, however, still remain an important tool for cataract and anterior segment surgeons in a variety of clinical settings. Examples of the common PMMA lenses used today include the following:

- **Anterior-chamber intraocular lens (ACIOL) implant:** MTA3U0/MTA4U0/MTA5U0 (Alcon), S122UV/L12UV (Bausch & Lomb)
- **Posterior-chamber intraocular lens (PCIOL) implant:** CZ70BD (Alcon), P359UV (Bausch & Lomb), EZE-60/EZE-55 (Bausch & Lomb)

The indications, preoperative considerations, surgical techniques, and potential complications of both anterior chamber and posterior chamber placement of PMMA IOLs are discussed in this section.

INDICATIONS

There are a number of scenarios that might lead a surgeon to require the use of a PMMA IOL. The most common PMMA lens implants used today are ACIOLs or scleral-fixated PCIOs. The common indications for these lenses are outlined below.

Lack Of Capsular/Zonular Support

If there is a lack of capsular or zonular support for a primary in-the-bag PCIOL or sulcus IOL, PMMA PCIOLs can be used via suture fixation to the sclera in the PCIOLs or ACIOLs lenses can be placed in the anterior chamber.

Secondary Lens Implantation

PMMA IOLs are often used in IOL exchange or placement of an IOL in aphakia.

In Association with Penetrating Keratoplasty

ACIOLs and capsular bag placed or sulcus-fixated PMMA PCIOLs can provide structural integrity during open sky surgery.

Patient Selection

Anterior-Chamber Intraocular Lens Implants

PMMA ACIOLs can be placed in patients with normal corneas and quiet anterior segments with normal angle anatomy. Earlier models of the ACIOL were more rigid with a closed loop often leading to postoperative complications such as chronic iritis, glaucoma, and corneal endothelial cell decompensation. Current models typically have more a flexible and open loop with a supporting base at the end of each

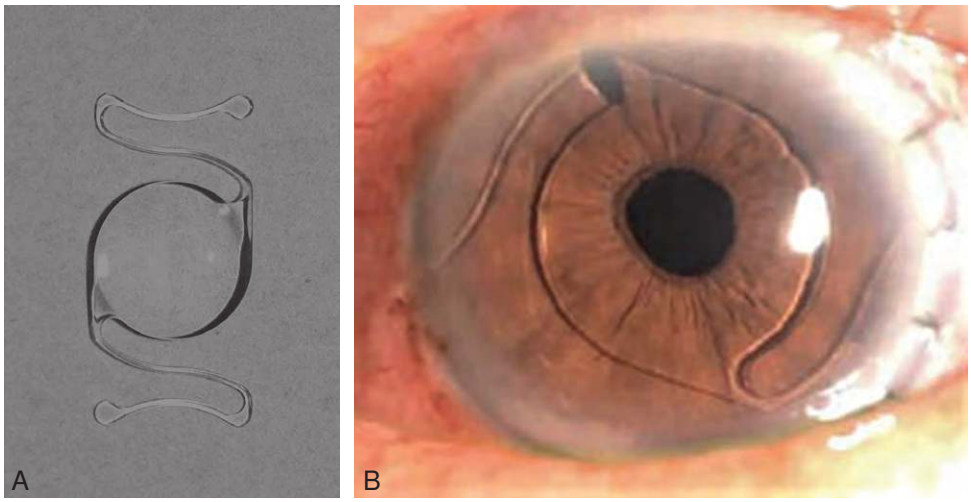

Fig. 6.1 Contemporary ACIOL with open loop (A). Well placed, well centered ACIOL (B).

haptic (Fig. 6.1). This allows for the lens to be flexibly supported by the scleral spur without disruption of the iris, ideally resulting in fewer complications.[1]

Any type of shallow angle, corneal endothelial dysfunction, or preexisting iridocorneal pathology such as peripheral anterior synechiae (in the setting of prior trauma or inflammation, for example) should be considered a contraindication to ACIOL placement. Their use is also highly discouraged in open angle glaucoma, narrow angle glaucoma, pigment dispersion syndrome, chronic inflammation, or uveitis-glaucoma-hyphema (UGH) syndrome. Given the risk for the eventual development of these and similar complications with placement of an ACIOL, some recommend avoiding ACIOLs all together in patients younger than 50 years old.[2]

Posterior-Chamber Intraocular Lens Implants

PMMA PCIOLs can be placed primarily in the bag, placed in the sulcus, or used as a scleral-fixated lens when normal posterior chamber anatomy is not available. In patients requiring sutured scleral-fixated IOLs, hydrophobic PMMA IOLs with eyelets are favored over hydrophilic acrylic IOLs with eyelets in those patients who are at an increased risk for requiring repair of retinal detachment or endothelial keratoplasty in the future (Fig. 6.2). This is because of reports of calcification of hydrophilic acrylic IOLs after procedures involving the injection of intraocular air or gas.[3]

Scleral-fixated IOL should be avoided in patients with a history of scleritis or scleromalacia, or in high myopes with very thin sclera.

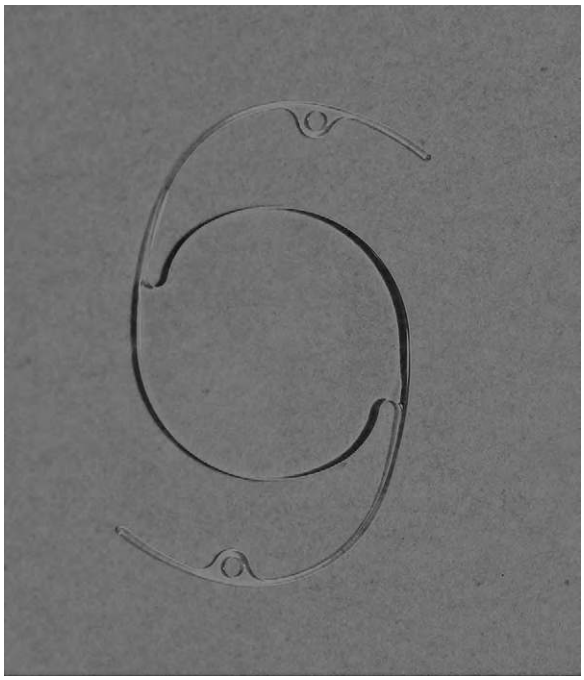

Fig. 6.2 Rigid hydrophobic PMMA IOL. Note eyelets near along edge of haptics.

PREOPERATIVE MANAGEMENT

PMMA ACIOL

When planning to place an PMMA ACIOL, special attention should be paid to the assessment of angle anatomy and corneal endothelial cell function in the preoperative setting. The preoperative examination should include the following:

- Gonioscopy to ensure adequate angle depth and normal angle anatomy
- Careful slit lamp examination to rule out corneal endothelial pathology
- Ultrasound pachymetry
- Specular microscopy possibly indicated for endothelial cell count if uncertain/borderline clinical findings exist
- Ultrasound biomicroscopy considered for precise measurement of anterior chamber anatomy, including depth and width

The surgeon should obtain careful horizontal white-to-white (WTW) measurements for proper ACIOL selection. This measurement helps ensure proper size and fit within the anterior chamber. The most common formula for sizing is WTW + 1 mm. Given the variability of limbal anatomy, however, there is data to support the more widespread use of ultrasound biomicroscopy for more accurate anterior chamber measurements before ACIOL use.[4,5]

In terms of IOL power selection, it should be noted that ACIOL power tends to be 3 to 4 D less than that of an in-the-bag IOL secondary to its anterior location.

PMMA PCIOL

When planning to place a suture fixated PMMA PCIOL, the preoperative examination should include consideration of all potential surgical interventions. This includes a strategic examination of the sclera as one plans for proposed suture placement. Specifically look for the presence of a glaucoma filter or tube shunt or existing areas of scleral thinning. Suture exits are typically placed 2 to 3 mm posterior to the limbus. The planned effective lens position will also be affected by the location of the scleral fixation sutures, and this may affect the postoperative refractive error.

In many eyes requiring a suture fixated lens implant, associated anterior chamber reconstruction may be required. Special attention should be paid to the following:

- Prescence of an existing lens implant
  - Anterior vs. posterior and position
  - Techniques to remove the lens implant
- Iris/pupil anatomy
  - Need for iris repair? Best approach?
  - Need for pupil expansion device, ring vs. hooks?
- Presence of synechiae: anterior and/or posterior, clock hour location and management
- Presence of vitreous in the anterior chamber/need for an anterior or pars plana vitrectomy
- Extent of capsular/zonular defects: best way to support the new lens implant

SURGICAL PROCEDURE

PMMA ACIOL Surgical Steps

Once lens extraction has been completed or if the patient is already aphakic, the following surgical steps should be followed for successful placement of an ACIOL (Video 6.1).

- ***Step 1:*** Create incision, which should be 6.5 to 7 mm in length, often with a scleral tunnel incision to promote good wound closure and decrease irregular astigmatism.[6]
- ***Step 2:*** Instill either Miostat (carbachol 0.01%) or Miochol (acetylcholine chloride 1%) to constrict the pupil and pull the iris out of angle and create a taught iris diaphragm.
- ***Step 3:*** Create a peripheral iridotomy to prevent iris bombe or pupillary block (can use micro scissors through the large wound or an anterior vitrector).
- ***Step 4:*** Insert ACIOL, often assisted by a lens glide (Sheet's glide), ensure the proper placement of all footplates at the scleral spur, and check for any signs of iris incarceration.
- ***Step 5:*** Rotate ACIOL 90 degrees away from the wound to keep the footplates from abutting the wound and away from any peripheral iridotomies.
- ***Step 6:*** Lift the lens footplates anteriorly to release iris contact, and assure adequate angle fixation without iris tuck peripherally.
- ***Step 7:*** Consider intraoperative gonioscopy if adequate position of ACIOL is in question.
- ***Step 8:*** Close the incision with multiple interrupted or running suture.

Scleral-Fixated PMMA PCIOL Surgical Steps

There are a wide range of techniques available to surgeons for scleral fixation of a PMMA IOL. Surgical steps can vary based on the desired suture position, suture material (always nonabsorbable), and the method of burying the sutured material. These techniques vary based on surgeon preference or patient anatomy. They are briefly outlined below (Video 6.2).

- ***Step 1:*** Complete lens removal if not already done.
- ***Step 2:*** Meticulous capsular cleanup and anterior or pars plana vitrectomy to clear both anterior chamber and sulcus of remaining capsular material or anterior vitreous base.
- ***Step 3:*** Insertion of an anterior chamber maintainer if not open sky.
- ***Step 4:*** Insertion and fixation of PMMA IOL.
  - *Ab externo suture fixation*
    - Sutures are passed from the outside to the inside of the eye.
    - Uses conjunctival flaps, scleral flaps, tunnels, or grooves.
    - Suture material is often either 9-0 polypropylene (Prolene) or polytetrafluoroethylene (Gore-Tex), which is off-label for intraocular use.
    - Needles can be straight (STC-6) or curved (CIF-4 or CTC-6L).
    - Hollow 27 - or 30 -G needles may be used as docking guides to ensure exit at a predetermined site.
    - Gore-Tex maybe passed without a needle using micro forceps through a sclerotomy to grasp the suture material.
  - *Ab interno suture fixation*
    - Suture passed from inside to outside the eye.
    - 9-0 Prolene suture is most commonly used.
    - The suture needle can be inserted into a 25-, 26-, or 27-G hollow needle and then externalized to avoid a blind pass through the sulcus.
  - The location of the suture fixation sites can also vary based on surgeon preference. Their placement in relation to the limbus can be either radial or tangential (Fig. 6.3).
- ***Step 5:*** Bury the suture material:
  - Within scleral flaps/pockets
  - Beneath a conjunctival flap covering completely buried knots
  - Through creation of a Hoffman pocket
- ***Step 6:*** Complete any other concurrent anterior segment reconstruction necessary.
- ***Step 7:*** Close the scleral or corneal incision with multiple interrupted or running sutures. Assure that the conjunctiva is reapproximated and covering the sutured material appropriately.

SURGICAL PEARLS

- For ACIOL: Key factors for success are proper IOL sizing and ensuring proper angle placement without iris tuck (checking for a round pupil after miotic agent).
- For PCIOL: Location of scleral fixation points includes a radial vs. a tangential pattern, but regardless of fixation pattern, suture material *must* be well buried or covered.

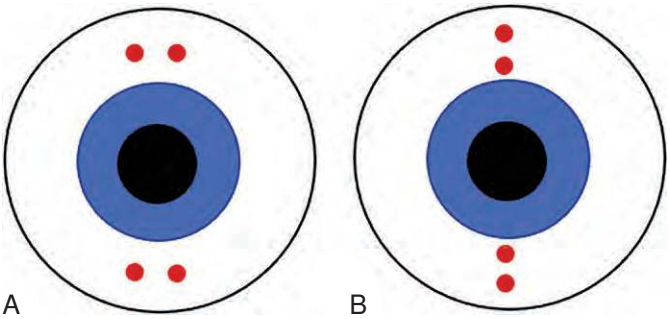

Fig. 6.3 (A) Demonstrates tangential scleral fixation sites 2 mm apart and each 3 mm posterior to limbus. (B) Demonstrates radial scleral fixation sites each 1 mm then 3 mm posterior to limbus and 180 degrees away from each other.

POTENTIAL COMPLICATIONS

There are a number of potential complications that can occur in both types of PMMA IOL implantation, ranging from early (intraoperatively or in immediate postoperative period) to late. These complications can range from mild (refractive changes) to more serious (chronic inflammation or infection). Improper sizing of ACIOLs can lead to many of the after complications.[7] This section outlines these potential complications.

Early Complications

- **Effective Lens Position and/or Tilt:** Even with careful surgical planning, scleral-fixated PCIOLs may vary in effective lens position. This may lead to decreased refractive predictability. Suture placement and tension must be precise to limit the amount of lens tilt and/or decentration of a sutured IOL.
  - In ACIOLs, malposition may be due to unequal placement in the angle or improper lens sizing
  - In PCIOLs, malposition may be caused by the following:
    - Uneven suture tension translating to IOL decentration
    - Suture fixation sites being too near or too far from the limbus, resulting in IOL placement more anterior or posterior in the sulcus and producing either a hyperopic or myopic surprise
    - Asymmetric anterior/posterior location of suture sites causing one pole of the lens implant to sit more anteriorly leading to IOL tilt
    - Suture fixation sites not being exactly 180 degrees apart causing IOL tilt along its axis and significant astigmatism at the IOL plane
    - Obstruction of the lens position by residual capsular/lens material, Soemmering ring, or vitreous), invoking IOL tilt along the anterior-posterior axis
  - The above abnormalities of IOL position can appear intraoperatively (with the opportunity to correct it in real time) or as a late complication because of suture erosion/breakage (potentially requiring secondary intervention).
- **Synechiae/Iris Tuck:** Improper placement or sizing of an ACIOL can cause iris tuck and pupil ovalization, which can be seen intraoperatively. If not noticed and addressed at the time of surgery, this can lead to formation of synechiae.
- **Intraocular hemorrhage:** Passage of sutures through uveal tissue as in a scleral-fixated PCIOL or manipulation of ACIOL in the angle can both prompt intraocular hemorrhage.[8] This bleeding is usually controlled intraoperatively in most cases but may require closer monitoring for clearance/sequelae (like elevated intraocular pressure [IOP]) and can cause decreased visibility intraoperatively and in clinical examinations during the postoperative period.
- **Retinal Detachment:** Passage of suture through the scleral wall increases the risk for retinal tear or detachment more than typical cataract surgery. To mitigate this risk, careful placement of suture fixation sites should be performed with every case with care to stay in the anatomic area of the ciliary sulcus. In addition, adequate vitrectomy should be performed in all scleral-fixated IOL cases to limit the risk for vitreous traction and eliminate the risk for vitreous incarceration in the haptics or fixation sutures.
- **Suprachoroidal hemorrhage:** There is an increased risk for intraoperative suprachoroidal hemorrhages with scleral-fixated IOLs because of the often complex nature of these cases, which may require longer case times, larger incision sizes, and more relative hypotony.

Late Complications

- **Cystoid Macular Edema (CME):** PMMA IOLs are typically reserved for complex eyes/surgeries and their placement is inherently more inflammatory (whether ACIOL or scleral-fixated PCIOL). This can lead to CME in the weeks to months after surgery. Often, these eyes already have preexisting CME secondary to chronic inflammation from a complex primary cataract extraction or dislocated primary IOL. In these cases, the preexisting CME should be managed aggressively preoperatively before secondary IOL placement.
- **Pigment Dispersion/UGH Syndrome:** As discussed previously, poor positioning of ACIOL, incorrect sizing of ACIOL, or placement of an ACIOL in an angle that is too narrow increases the risk for iris chaffing and secondary inflammation. Improperly placed PCIOLs whether scleral fixated or placed in the sulcus can also create contact with the ciliary body causing a chronic inflammatory reaction.
- **Induced Astigmatism:** Because PMMA implants are large and inflexible, they require a large incision with an average wound size of 7 mm with subsequent suture closure. Large incisions are more likely to induce postoperative astigmatism secondary to late wound relaxation and corneal flattening in the axis of the wound. Techniques to reduce induced astigmatism include scleral tunnel versus corneal incisions, operating on the steep axis, and postoperative corneal relaxing incisions created once the induced astigmatism stabilizes.
- **Corneal Decompensation:** Endothelial cell loss leading to corneal edema or pseudophakic bullous keratopathy can occur in both ACIOLs and PCIOLs. Preoperative low endothelial cell[1] counts are an obvious risk factor and surgery should be avoided unless concurrent endothelial or penetrating keratoplasty is planned. Chronic IOL-induced inflammation leading to decreased endothelial cell function can also be seen with either type of IOL placement, though the long-term risk from ACIOLs is higher given their anatomic location.
- **Suture Erosion or Breakage:** A potential late complication of all sutured IOLs is external erosion or breakage of the suture material. Suture breakage usually occurs at the point of contact between the suture material and the PMMA loop at the haptic-optic junction. Friction between the suture and the PMMA is the proposed mechanism. Finer suture materials like 10-0 Prolene have a higher risk for breakage compared with materials such as 9-0 Prolene and Gore-Tex. Sutures may become exposed in up to 11% of cases. This can provide an opportunity for ocular surface irritation and localized noninfectious or infectious scleritis. Bacterial entry, late endophthalmitis, and possible dislocation of the IOL may occur.

POSTOPERATIVE MANAGEMENT

After either anterior chamber or posterior chamber implantation of a PMMA IOL, patients should follow a typical postoperative course with clinical visits on day 1, week 1, and month 1. If the case was excessively complicated, the postoperative course may be more intensive. In the setting of ACIOL or scleral-fixated IOL surgery, there should be vigilant monitoring of IOP, anterior chamber inflammatory reaction, and IOL position and stability at each postoperative visit. This may include gonioscopy in the setting of ACIOLs and a dilated retinal examination in all patients when the view allows. If the view is poor, B-scan ultrasonography should be used to assess for retinal pathologies. Long-term follow up should always include careful examination for signs of suture erosion in the setting of sutured PCIOLs.

SUMMARY

Although the primary lens implant used today is a foldable acrylic or silicone IOL, there is still a place for the rigid, one-piece PMMA IOL in the modern day cataract surgeon's toolbox.

- ACIOL is still useful when placed properly, especially in elderly patients.
- Sutured PMMA PCIOL works well in combination with anterior segment reconstruction.
- Precise surgical planning and placement is key to avoid common complications of ACIOL or sutured PCIOL.

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Video 6.1: PMMA ACIOL Surgical Steps

- Step 1: Create incision, which should be 6.5 to 7 mm in length, often with a scleral tunnel incision to promote good wound closure and decrease irregular astigmatism.
- Step 2: Instill either Miostat (carbachol 0.01%) or Miochol (acetylcholine chloride 1%) to constrict the pupil and pull the iris out of angle and create a taught iris diaphragm.
- Step 3: Create a peripheral iridotomy to prevent iris bombe or pupillary block (can use micro scissors through the large wound or an anterior vitrector).
- Step 4: Insert ACIOL, often assisted by a lens glide (Sheet's glide), ensure the proper placement of all footplates at the scleral spur, and check for any signs of iris incarceration.
- Step 5: Rotate ACIOL 90 degrees away from the wound to keep the footplates from abutting the wound and away from any peripheral iridotomies.
- Step 6: Lift the lens footplates anteriorly to release iris contact, and assure adequate angle fixation without iris tuck peripherally.
- Step 7: Consider intraoperative gonioscopy if adequate position of ACIOL is in question.
- Step 8: Close the incision with multiple interrupted or running suture.

Video 6.2: Scleral-Fixated PMMA PCIOL Surgical Steps

- Step 1: Complete lens removal if not already done
- Step 2: Meticulous capsular cleanup and anterior or pars plana vitrectomy to clear both anterior chamber and sulcus of remaining capsular material or anterior vitreous base
- Step 3: Insertion of an anterior chamber maintainer if not open sky
- Step 4: Insert and fixate PMMA IOL

7

Posterior Chamber Intraocular Lenses

Oliver Findl and Stefan Palkovits

CONTENTS

KEY POINTS

- Materials used in posterior chamber lenses
- Biocompatibility, edge design, posterior capsule opacification, and photic phenomena
- Impact of aspheric optics
- Iris and scleral fixation of posterior chamber lenses

INTRODUCTION

In modern cataract surgery, after opacified lens removal, an artificial intraocular lens (IOL) is inserted into the eye. In routine cataract surgery, the majority of IOLs are implanted into the posterior chamber. The capsular bag is the preferred location to hold the IOL. Nevertheless, in case of complications such as posterior capsule rupture, the implantation of the IOL in the ciliary sulcus or an alternative approach to fixate the IOL, such as iris or scleral fixation, with or without sutures is used.

The introduction of IOL implantation was a huge milestone in the development of modern cataract surgery and one of the major advances in ophthalmology in the 20th century. In 1949 Harold Ridley first implanted an IOL into the human eye, which was made out of polymethyl methacrylate (PMMA).[1] Ridley chose PMMA when he observed that parts of the windshield of fighter planes during World War II were inert in the human eye after penetrating trauma, which led him to replace the natural lens with an artificial plastic one. He was the first to implant an artificial IOL, which sets the basis of modern cataract surgery (Fig. 7.1). Nevertheless, during the first decades, cataract surgeons had several problems after surgery, such as corneal decompensation, complications caused by large incisions, IOL luxation, and inflammatory reactions to the material. As PMMA lenses are rigid and therefore not foldable, their implantation required large corneal incisions.

In the 1970s Charles Kelmann introduced phacoemulsification, which allowed the removal of crystalline lens through smaller incisions. With this development, a demand for foldable IOLs occurred and newer materials such as silicone were used. Since then, significant developments were made with the IOL material and design.

Intraocular Lens Material and Biocompatibility

Today, four major IOL materials are used: PMMA, hydrophobic acrylate, hydrophilic acrylate, and silicone. The three acrylic materials have the same acrylic polymer backbone but differ in the composition of the backbone's sidechains, which is responsible for the material's features, such as rigidity, water content, or biocompatibility. Physical features are summarized in Table 7.1. The biocompatibility is an important feature of every artificial material implanted into the human body. It describes how well the body tolerates the foreign body, which is very crucial when using implants in the human eye because even a low reaction can lead to decreased vision or other serious complications.

Scales published criteria for an ideal material for implants as early as 1953: the material should be a biocompatible material, that is, chemically inert; physically stable; noncarcinogenic; nonallergenic; capable of fabrication in the required form; and not cause a foreign body reaction.[3]

Desired properties of an ideal IOL include the following:

- Biocompatible material
- Chemically inert
- Physically stable
- Good memory of IOL haptics
- Easily implanted through a small incision
- Clear optic

The ideal IOL material has combined advantages for the patient and for the surgeon. The surgeon wants an IOL that can be implanted easily through a small incision and has a good haptic to keep the IOL in place and a clear optic to ensure good vision. The inflammatory reaction, like the presence of cells on the anterior or posterior surface of the IOL, should be minimal. In the past, adverse reactions of IOL material such as calcification of the IOL surface led to patient complaints and explantation of the IOL frequently.

Amon categorized biocompatibility into uveal and capsular.[4] Uveal biocompatibility describes the reaction of the iris, ciliary body, and anterior choroid to the IOL, showing an increased inflammation in the anterior segment due the breakdown of the blood aqueous barrier and the formation of giant cells, monocytes, and macrophages on the IOL surface. The possible reasons for this are issues during the manufacturing process, incomplete polymerization, and contamination.

Capsular biocompatibility, on the other hand, refers to the reaction of the capsule to the IOL, such as anterior and posterior capsular opacification (PCO). Consequently, for a long-lasting clear capsule, a good capsular biocompatibility is needed.

IOL biocompatibility is affected by several parameters, such as the patient's age, surgeon's skill and technique, and coexisting disease. The IOL material also has a significant impact on the biocompatibility. In recent years the surface of IOLs were modified to get the best out of two worlds and to combine the advantages of different materials.[5]

Today modern IOLs may be categorized in two major groups: hydrophilic and hydrophobic materials. This feature, showing to what extent the IOL repels water, is responsible for most of the factors mentioned previously. The contact angle measures the extent of hydrophobicity.[2] A large contact angle means high hydrophobicity and therefore a high tendency to repel water. Fig. 7.2 illustrates the measurement of the contact angle in hydrophilic and hydrophobic materials.

Polymethyl Methacrylate

PMMA was the first IOL material used in cataract surgery. It is a polyacrylic derivative, also known as Plexiglas or Perspex. It is rigid at room temperature and therefore not foldable. Moreover, it is hydrophobic with a contact angle of 65 to 71 degrees and hardly absorbs any water. Its refractive index is approximately 1.49.[2] Because PMMA IOLs are not foldable, a large wound must be created for IOL implantation; thus these lenses are less commonly used today and have been widely replaced by foldable IOLs. Nevertheless, they play an important role in areas where manual extracapsular cataract extraction is performed, and a large wound is routinely created. Furthermore, specific IOL like the anterior chamber lenses or the Artisan lens (iris-claw lens) are made out of this material because of its rigidity and stability.

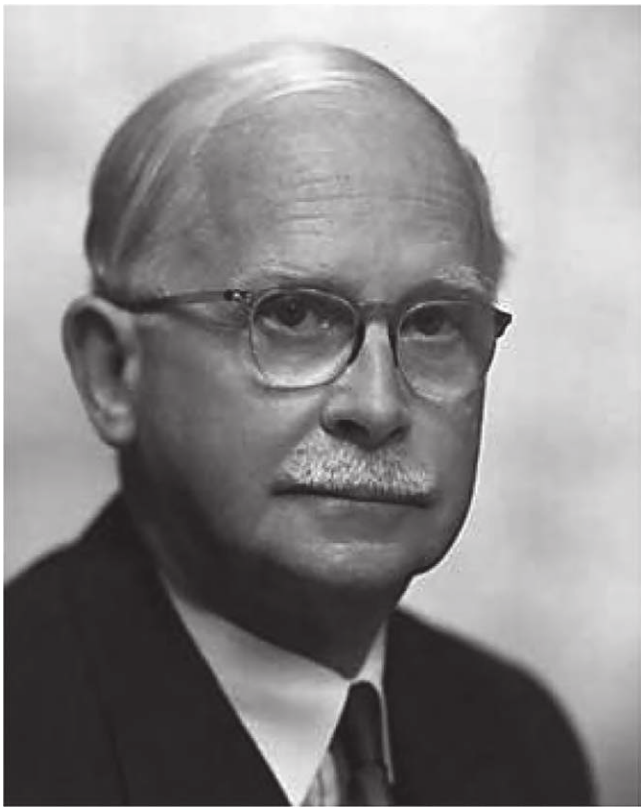

Fig. 7.1 Harold Ridley.

Silicone Polymers

Silicone IOLs were introduced in the mid-1980s after Charles Kelman introduced phacoemulsification. Silicone is a hydrophobic material (<0.4% water content), usually foldable, making its implantation via a small incision possible. The first foldable IOL was a silicone plate haptic. In general, modern silicone IOLs have good capsular and uveal biocompatibilities.[6] Early problems with silicone IOLs were the discoloration and surface calcification in certain ocular pathologies.[7,8] These lenses then needed to be exchanged.[9] However, with better production and storage procedures, these problems occurred less often.

Silicone lenses may not be the best choice after retinal detachment surgery with silicone oil as a tamponade or in patients who will likely undergo retinal detachment surgery such as those with high myopia. A posterior capsulotomy is often necessary in patients after vitrectomy, and silicone oil then comes into contact with the silicone IOL. After silicone oil removal, small drops of silicone oil may remain on the posterior surface of the IOL, which reduces optical quality.

Hydrophilic Foldable Acrylic Intraocular Lenses

The hallmark of hydrophilic IOLs is their high water content. In contrast to PMMA, hydrophilic acrylic lenses have a hydroxyl group in the sidechain of the acrylic polymer that increases water attraction. Most often and originally, poly 2-hydroxyethyl methacrylic acid was used, which has a water content of up to 38%. Therefore these IOLs have to be stored in solution. The refractive index of hydrophilic acrylate is 1.40, slightly lower than hydrophobic materials. Hence these lenses tend to be thicker than the hydrophobic counterpart.

Hydrophilic IOLs have an excellent biocompatibility. However, PCO occurred more frequently with these lenses compared with hydrophobic materials, so yttrium aluminum garnet (YAG) capsulotomy had to be performed more often (Fig. 7.3).[10,11]

Another rare problem is the calcification of the IOL surface and within the lens, which is categorized into primary calcification caused by manufacturing or storage issues and secondary calcification caused by further procedures or systemic conditions. This problem was recently seen in lenses from different manufacturers, and the risk for its development was higher after the use of intraocular gas during endothelial keratoplasty.[12–15] Calcification was also seen after posterior segment surgery[16,17] and after multiple intraocular procedures, resulting in chronic inflammatory reaction. In a recent publication, Neuhann et al. found that the main cause of IOL explanation (76.5%) was opacification of the IOL. In 13.5% the reason was IOL dislocation. The majority of lenses were hydrophilic (83.5%), of which 62% had a hydrophobic

TABLE 7.1 Physical Properties of Different IOL Materials[2]

Material	Eq. Hygroscopy (%)	Cont. Angle	Tensile Str. (MPa)	*n*	T_g (°C)
PMMA	0.4–0.8	65–71 degrees	47–70	1.49	105–113
Silicone	0.38	97–120 degrees	5.9–8.2	1.43	(–120)–(–90)
Hydrophilic acrylics	18–38	20–70 degrees	0.4–0.6	1.40–1.43	10–20
Hydrophobic acrylics	0.1–0.5	72–88 degrees	No data	1.47–1.56	5–16
Standard new hydrophobic acrylics (approx. values)	4–5	69–79 degrees	4–6	1.54	27–29

Cont., Contact; *Eq.*, Equilibrium; *MPa*, Megapascals; *PMMA*, polymethyl methacrylate; *Tg*, glass transition temperature.

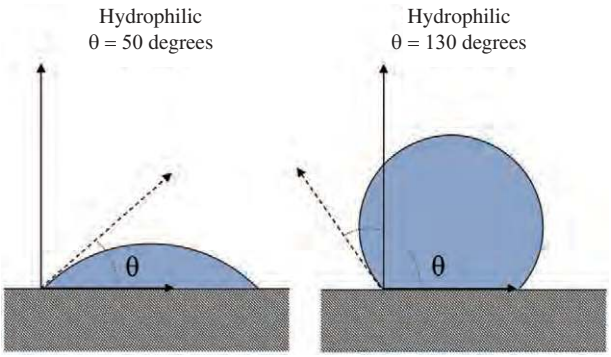

Fig. 7.2 Illustration of the contact angle. Water drop is placed on a surface, and contact angle (θ) is measured. *Left*, Shallow contact angle in hydrophilic materials. *Right,* Large contact angle in hydrophobic materials.

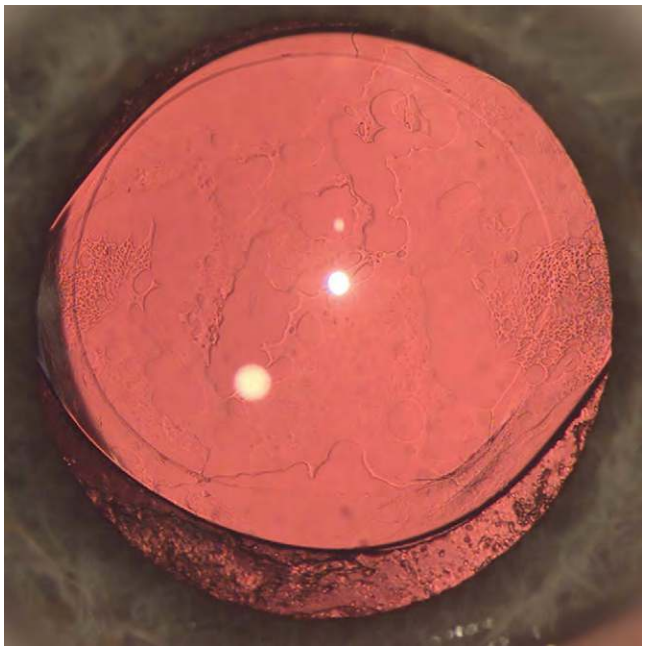

Fig. 7.3 Mild regeneratory posterior capsular opacification. Honeycomb in an eye with a hydrophilic IOL.

surface modification.[18] Electron microscopy was used to illustrate calcium deposits on the surface of a hydrophilic IOL (Fig. 7.4).[19]

Hydrophobic Foldable Acrylic Intraocular Lenses

After the introduction of the Acrysof three-piece IOL (Alcon, Fort Worth, TX, USA) in 1993, hydrophobic acrylate became the most popular IOL material. Because this material is also foldable, the implantation through a small incision is possible. After implantation, the IOL regains its original shape in a short period of time, which shows that it has a high memory, stabilizing itself over time. This group of materials has a high refractive index, which, in turn, reduces the IOL thickness, further increasing the foldability of the IOLs. In addition, the lens can be produced with a sharp posterior edge, reducing the rate of PCO. The water content of these materials is very low (<1%).

One disadvantage of these materials is the occurrence of intralenticular changes called *glistenings*. Glistening refers to small pockets within the network of folded polymers filled with water. During polymerization, a perfect folding of the polymer to eliminate all pockets is hardly possible. After the implantation of the IOL, the change from dry to fluid

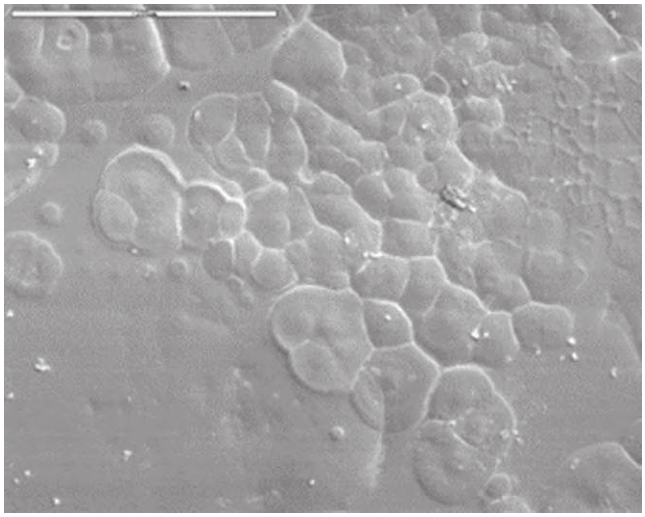

Fig. 7.4 Scanning electron micrograph of calcification on the surface of a hydrophilic IOL in an animal model. (Courtesy Rakhi Jain, PhD.)

surroundings may allow the hydration of these small pockets that occurs slowly, and glistening may increase in size and number over time.[2]

The rate of PCO with hydrophobic acrylic IOLs has been shown to be lower than with hydrophilic acrylic IOLs because of, first, the material itself and, second, the manufacturing. Cutting a hydrophobic material results in a sharp edge, whereas cutting a hydrophilic material with the consequent hydration leads to a lesser sharp edge. In a recent meta-analysis, hydrophobic acrylic IOL had the lowest PCO and neodymium-YAG (Nd:YAG) capsulotomy rates.[20] One other explanation is the stronger adherence of hydrophobic acrylate to the posterior capsule, closing the gap between the IOL and the capsule, which makes the migration of lens epithelial cells (LECs) less likely.[21]

One drawback of a sharp edge design in combination with a higher refractive index is the increased incidence of positive dysphotopsia (PD), resulting in edge-glare, which is caused by reflections.

Intraocular Lens Adjustment Postoperatively

Several different approaches were taken to adjust IOL power postoperatively.[22] One technique is the light-adjustable lens (LAL). The LAL is a silicone three-piece IOL with PMMA haptics. After implantation and healing of the wounds, irradiation using ultraviolet (UV) light (365 nm) can be used to change IOL refractive power, which is enabled by photosensitive macromers incorporated into the silicone material using a specific light delivery device in an outpatient setting. During irradiation, these photosensitive macromers polymerize, form silicone polymers, and induce a shape change of the IOL. By altering the irradiated area (optical center vs. periphery), the IOL refraction can be modified predictably. Once the target power is reached, the entire IOL is irradiated ("lock-in"), which prevents further changes caused by light.[23]

In accordance with the Food Drug Administration Summary of Safety and Effectiveness Data, LALs allow a spherical correction up to 2.0 D (−2.0 D to +2.0 D). Cylindrical corrections can be made from 0.75 to 2.0 D.[24]

Until the IOL is locked, the patient must wear UV-light protecting glasses as sunlight may initiate polymerization. Also, correcting astigmatism was performed with high accuracy. The LAL was also implanted in patients after refractive corneal procedures, such as photorefractive keratectomy and laser in situ keratomileusis. In these patients, biometry, especially keratometry, as well as IOL power calculation, is challenging, making the postoperative adjustment interesting.

In another approach, a femtosecond laser is used to change IOL power postoperatively. The concept behind this technology is called *refractive-index shaping*. IOL power is changed via a chemical reaction triggered by the femtosecond laser, making the material more hydrophilic and, in turn, reducing the refractive index. This procedure is not yet commercially available. Previous studies investigated this technology in rabbits. The change in refraction can be performed with high precision within 0.1 D of the target without any significant alteration of optical quality.[25] Furthermore, even the addition or removal of multifocality of an already implanted IOL can be achieved using refractive-index modification.[26,27]

The laser treatment did not alter the biocompatibility of the IOL nor induce any inflammatory reactions.[28] In general, every hydrophilic and hydrophobic acrylic IOL may potentially be treated using the femtosecond laser to change IOL power, making this approach an interesting one because the treatment is highly accurate, can be performed within a single procedure, and can be repeated if necessary.

Surface Modification

Several techniques were published to modify the surface of IOL, such as surface coating, surface grafted modification, plasma surface modification, photochemical immobilization, and layer-by-layer self-assembly.[5] All the modifications intend to improve biocompatibility or reduce the occurrence of complications and craft the "perfect" IOL, increasing the advantages and reducing the disadvantages of different IOL materials. Newer materials and compounds are added or the preexisting material is modified, for the enhancement of certain properties of IOL.

One example, the heparin surface-modified–PMMA (HSM-PMMA) lens, was introduced in the late 1970s. The heparin coating was incorporated to reduce the molecular adhesion to the IOL surface, therefore increasing biocompatibility. Krall et al. found no difference in PCO rate in the HSM-PMMA lens compared with the unmodified version.[29] However, in a 12-year prospective trial, PCO rates were higher in these lenses than in silicone and hydrophobic acrylic IOLs.[30]

Capsular Biocompatibility and Edge Design

Capsular biocompatibility describes the interaction of the IOL material with the capsular bag. PCO and anterior capsule opacification are common reactions after IOL insertion into the capsular bag. In both cases, LECs proliferate and migrate along the capsule. In the case of PCO, LECs originate from the equator of the capsule and form an opaque layer between the IOL and the posterior capsule, leading to a reduced visual function, which is still the most common side effect after cataract extraction (see Fig. 7.2). PCO development is dependent on several factors, such as surgical technique, IOL material, and IOL design. Whereas IOL material is an important factor, the posterior IOL edge design is the most critical factor. The design of the edges of the optic and haptic, especially the posterior edge of the optic, is also dependent on the material used, showing that the edge in "square-shaped" hydrophilic IOLs is not as sharp as in hydrophobic or silicone IOLs.

Nishi et al. were the first to describe that proliferation and migration of LECs stop at the sharp edge of the IOL posterior surface; on the other hand, round edges are a much lesser effective barrier to LEC migration (Fig. 7.5).[31]

A Cochrane review compared the PCO rates in sharp-edged versus round-edged IOLs.[32] The review favors sharp-edged IOL. Furthermore, a 360-degree coverage of the optic by the anterior capsule appears critical in ensuring a more effective barrier at the optic edge,[33] which is essential in exerting the pressure on the IOL to keep it in close contact with the posterior capsule. If there is a small gap between the posterior surface of the IOL and the posterior capsule, LEC might migrate into this gap (Fig. 7.6). Comparison of PCO development 3 years after implantation of the round-edged version (AR40e) in one eye vs. the sharp-edged version (AR40) in the other eye is shown in Fig. 7.7.

A previous study found the relationship between the anterior and posterior capsules as an important prognostic factor for PCO development.[34] The design and material of the IOL (including the haptic design) influenced the capsular bend and the configuration of the anterior and posterior capsule at the optic edge. A configuration in which the posterior capsule is wrapped around the IOL edge appears to result in the lowest risk of developing PCO (Fig. 7.8).

Recommendations to prevent PCO occurence[33] include the following:

- Good cortical cleanup
- In-the-bag placement of the IOL
- Capsulorrhexis covering the edge of the IOL optic
- Tight adhesion between the capsule and the IOL
- Sharp posterior optic edge

Dysphotopsia

After understanding how sharp optic edges prevent PCO, this edge configuration was incorporated in most IOLs. However, because of this design change, a new phenomenon arose: dysphotopsia. Dysphotopsia is divided into bright arcs and streaks of light, so-called *PD*, and a dark crescent-shaped shadow in the temporal visual field, so-called *negative dysphotopsia (ND)*.

PD was first described in the early 1990s and was linked to the truncated edges of the IOLs, with internal reflections at the interface, that are triggered by light approaching the eye in a critical oblique angle. A high-refractive index was also linked with the occurrence of PD.[35]

Negative dysphotopsia, on the other hand, is often described as a crescent-shaped shadow. Different theories were described to explain its origin. First is the relationship of the anterior capsule and the IOL optic,[36] suggesting that ND could be prevented or eliminated when the IOL optic lies in front of the anterior capsule. Changing a capsule IOL with a sulcus IOL and reverse optic capture in which the IOL optic is placed anterior to the rhexis edge were discussed as possible treatment

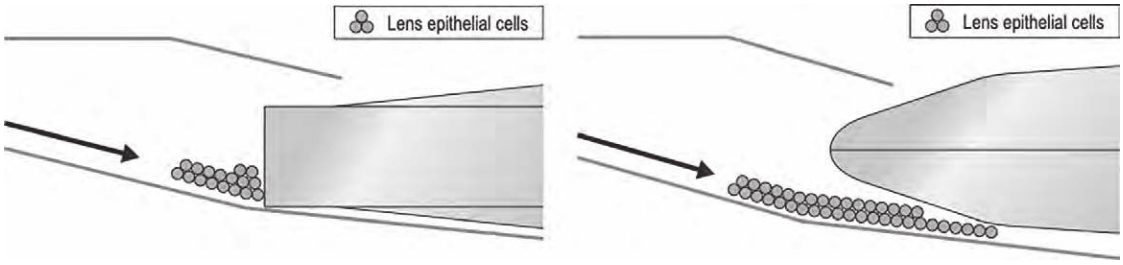

Fig. 7.5 *Left,* Schematic representation of epithelial cell migration inhibited by the IOL's sharp posterior edge in contact with the posterior capsule. *Right,* In contrast, cells can migrate along a round edge.

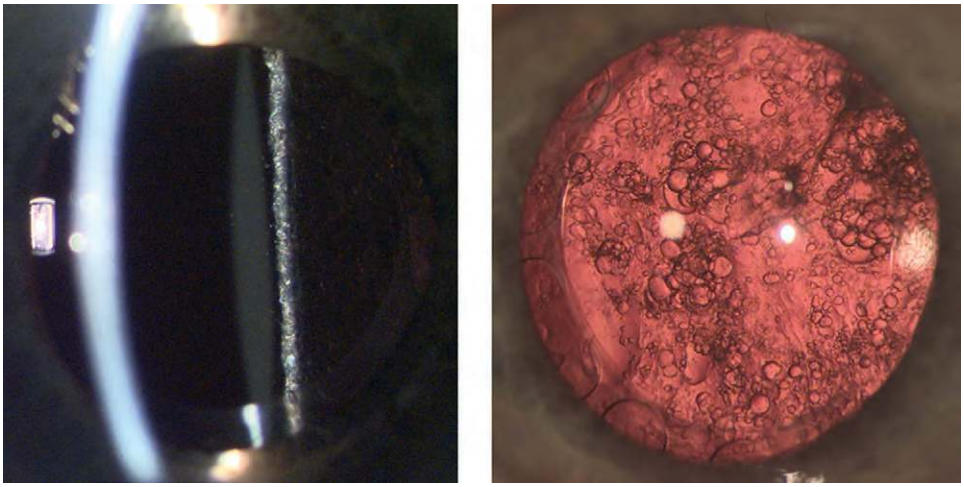

Fig. 7.6 Gap between IOL and posterior capsule, leading to significant PCO.

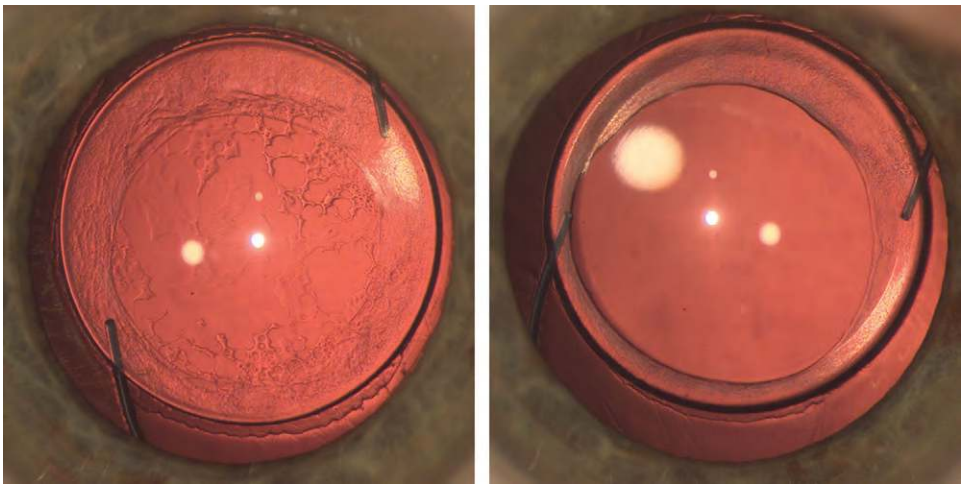

Fig. 7.7 Comparison of round edge vs. sharp edge after 3 years. *Left,* AR40. *Right,* AR40e.

options.[37] Another theory, by Holladay et al., based on ray tracing found a shadow between the light rays refracted by the IOL and the light rays passing anterior to the IOL optic and missing it.[38] However, the exact mechanism still needs to be clarified, but it is widely accepted that the cause is multifactorial. Luckily, in the majority of these patients, the symptoms of PD and ND are transient, diminishing within the first months after surgery.

Novel Intraocular Lens Designs to Reduce Dysphotopsia

Modifications were made to reduce the amount of dysphotopsia caused by the sharp edge. First, the optical edge was textured or frosted to reduce glare. Further round anterior edges reduce the rate of PD. The so-called OptiEdge design in which the anterior edge is round and the posterior edge is sharp can reduce the rate of PD and still prevent PCO.

Special anti-ND IOLs were designed after the theory that the relationship of the anterior capsule with the IOL optic is critical. The IOLs are designed to hold the capsulorrhexis within them, mimicking a reverse optic capture.[37,39]

Recently a novel approach was presented. Using an experimental ray-tracing model, it was shown that a curved posterior IOL surface redirects the light rays more anteriorly, thereby closing the gap.[40] As the shadow gap is closed, complaints of ND should decrease. No published clinical results are available to date.

Single- and Three-Piece Intraocular Lenses

Single-piece IOLs are lenses made out of a single piece (Fig. 7.9). Therefore the haptic and the optic are made of the same material. The current single-piece IOLs are available in open-loop or in modified plate-haptic design. Acrylic material is usually used to craft open-loop IOLs as good stability and high memory is necessary to stabilize the IOL in the capsular bag. Furthermore, the haptics need to be bulkier than the thin PMMA or polyvinylidene difluoride (PVDF) loops of three-piece IOLs to maintain the shape and stabilize the IOL; thus implantation into the ciliary sulcus should be avoided, as rubbing of the more bulky IOL haptic on the posterior iris can lead to dispersion of pigment, inflammation, intraocular pressure rise, and hyphema, the so-called uveitis-glaucoma-hyphema syndrome.

In three-piece IOLs during the production process, the haptics are manually connected to the optic, and different materials may be used (Fig. 7.10). Usually haptics of three-piece IOLs are made out of PMMA, polypropylene (Prolene [PP]), polyimide (Elastimide), or PVDF. These are more rigid than the materials used in single-piece designs, allowing thinner haptic manufacturing and the implantation into the ciliary sulcus. However, damaging of haptics during IOL insertion into the human eye is more common in three-piece designs. Three-piece IOLs are typically available with a haptic angulation, which is usually between 0 and 15 degrees, to increase the distance of the optic from the iris.

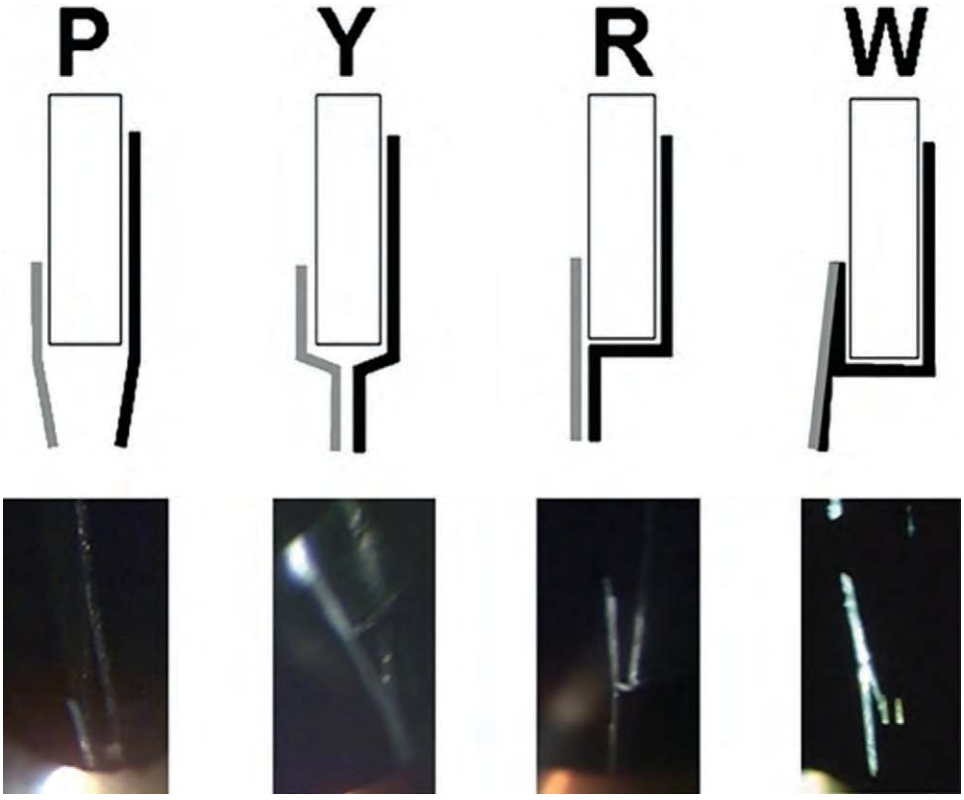

Fig. 7.8 Configuration of the anterior and the posterior capsule in relation to the IOL optic.[34]

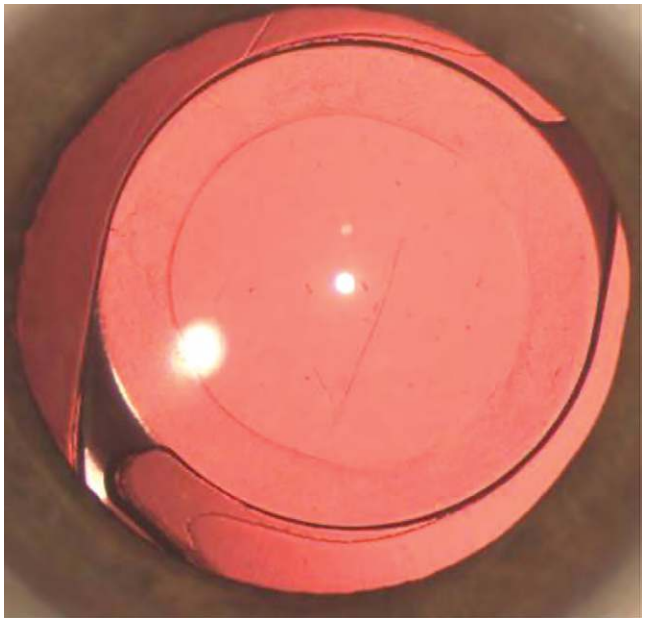

Fig. 7.9 Single-piece IOL 1 month after implantation.

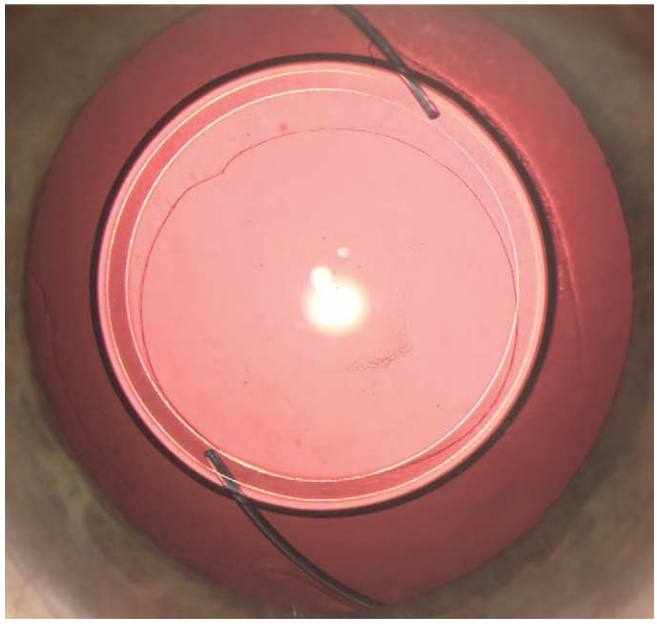

Fig. 7.10 Three-piece IOL 1 month after implantation.

Both haptic designs, single- and three-piece, were compared in several studies on axial IOL stability, position in the capsular bag, centration, and tilt. Typically, angulated three-piece IOLs tend to undergo a forward shift during the first months after surgery because of memory loss when the capsule bag undergoes fibrotic change and contracts. Studies indicate that the single-piece design results in better axial IOL stability, which allows earlier spectacle prescription and may also result in less refractive outliers after surgery.[41–43]

No significant difference was found between single-piece and three-piece IOLs with regard to PCO density or capsulotomy rate.[44–46]

Intraocular Lens Optic

The IOL optic is the refractive and optical active part of the IOL. Cataract surgery aims to remove the cloudy lens and replace it with a clear artificial lens to provide the best optical quality. Therefore proper centration and a clear optic are prerequisites.

Whereas the optic's edge design is critical for PCO formation, the optic itself can be equipped with many attributes. Next to spherical IOLs, special IOLs are used more frequently today, such as aspherical, toric, or multifocal IOLs. In the past different IOL optic diameters ranging from 5.5 to 6.5 mm were used, and IOLs with a diameter of 6.0 are most commonly used today. Reduction of IOL optic diameter had the great advantage of realizing implantation through a smaller incision as the optic is the largest part of the IOL. A three-piece IOL with a larger diameter of 7.0 mm was used to decrease higher-order aberrations for scleral fixation. However, the comparison to an IOL with a 6.0-mm diameter optic found no difference.[47] Implantation of an IOL with a larger IOL optic (7.0 mm) leads to a larger anterior capsule opening, which might be beneficial in patients with retinal disease.[48] IOLs with larger IOL optics were also used in patients with a larger pupillary diameter, iris trauma, or iris coloboma to reduce the amount of edge glare and to reduce ND.

The refractive power of the IOL can be distributed symmetrically between the anterior and posterior surface of the IOL. In a so-called biconvex, optic refractive power is equally distributed, whereas in plano-convex or convex-plano, the refractive power is set by the posterior or anterior surface, respectively.

Overall, the human eye has a slightly positive spherical aberration. The average cornea has a positive spherical aberration (between +0.27 and +0.30 µm), which is counteracted by the negative spherical aberration of the crystalline lens (−0.20 µm). In contrast to the cornea in which spherical aberration is almost constant throughout life, the crystalline lens' spherical aberration increases with age and, as cataract develops, decreases the quality of vision. With cataract surgery and IOL implantation, modification of the eye's total spherical aberration is possible.

Early conventional IOLs had a positive spherical aberration, increasing the total spherical aberration after implantation into the human eye, which led to a decrease in image quality and contrast sensitivity. For that reason, newer IOL models have zero or a negative spherical aberration to counteract and ultimately neutralize the corneal aberration, increasing image quality. The performance of these lenses depends on pupil size and on IOL centration. On the other hand, the depth of focus is decreased as spherical aberration is reduced.

The light-filtering features of the IOL optic have gained interest. Whereas filtering of UV radiation is realized in all IOLs, some IOLs offer an additional filter in the short wavelength spectrum, so-called blue light filters. Filtering of UV light is achieved by incorporating specific chromophores, such as benzotriazole and benzophenone, into the IOL optic, blocking the UV radiation in the range of 300 to 400 nm.[49]

The violet and blue light spectrum has a bandwidth of around 400 to 500 nm. This blue light may cause retinal phototoxicity caused by reactive oxygen species formation, damaging retinal tissues. It was hypothesized that this blue light caused phototoxicity (or hazard) and is linked to the progression and development of retinal diseases, such as age-related macular degeneration. The rationale for implanting blue light filtering IOLs (yellow IOLs) is preventing further damage from high-energy blue light to the retina. The first blue light filtering IOL was introduced as early as 1991. Also, so-called "orange IOLs" were introduced, which intend to allow even better protection (blocked bandwidth around 400–600 nm).

Today, several blue light filtering IOLs are available, and, currently, approximately 25% of all IOLs implanted worldwide are blue-filtering.[50] Although blue light filtering IOLs reduce parts of the visual light spectrum, no difference in visual acuity, color perception, and contrast sensitivity between blue light filtering and UV light blocking (standard) IOLs was found under photopic conditions.[51–53] Nevertheless, impaired color vision in the blue light spectrum was seen under mesopic light conditions.[52,53]

A Cochrane review summarized 51 trials investigating if there is a benefit for using blue light filtering in comparison with standard IOLs.[54] The authors concluded with moderate certainty that there is no significant difference in best corrected visual acuity between blue light filtering and nonblue light filtering (follow-up 3–18 months). However, whether there is a protective effect of blue light filtering for the macula is still uncertain because of the short follow-up period.

Haptic Material and Design

The function of the haptics is the stabilization of the IOL within the capsular bag, which is realized via an outside (centripetal) pressure. During the folding, the haptics and the optics are compressed to fit through the small incision. After insertion, the haptics need to regain their original shape and keep the IOL centered in the bag. Therefore two main features are necessary: the haptic rigidity, which is the resistance against external forces, and the haptic memory, which is the tendency to keep the original shape. Flexibility should be high enough to allow adequate folding, but the haptics must also be rigid enough to withstand the capsular pressure, which is important in the case of anterior capsular contraction and/or zonule weakness.[55]

The overall diameter of the majority of modern IOLs range between 11.5 to 12.5 mm. Sometimes IOLs with a larger overall length (13–14 mm) can be used if placement in the ciliary sulcus is necessary to increase IOL stability. However, with regard to rotational stability of a single-piece IOL placed into the capsular bag, no difference was found between the overall diameters of 12 and 13 mm.[56]

As mentioned earlier, the haptics of three-piece IOLs are made out of materials that are more rigid. Nevertheless, apart from the haptic material, other factors, such as haptic length, angulation, the haptic optic junction, and haptic design (thickness, shape), also influence memory and rigidity. Early studies show that PVDF had a better shape recovery than PP and extruded PMMA haptics.[57] PVDF has an adequate flexibility with rare haptic breaks, so this material may be preferable for scleral fixation in cases in which there is no more capsular support.[58]

Haptic material had no influence on anterior capsule contraction.[59] In an early study, open-loop single-piece PMMA IOLs had been noted to have the best haptic memory,[60] possibly because of the combination of the high rigidity of the material and the high memory of the open-loop, single-piece design. More recently, Izak and colleagues investigated the loop memory of four different three-piece IOLs sharing the same optic material (silicone) with different haptic materials—PMMA, PVDF, polyamide, and PP—in a laboratory setting. PMMA, PVDF, and polyamide had comparable results with regard to the haptic memory, whereas the silicone IOL with PP haptic had the lowest haptic memory.[55]

ALTERNATIVE FIXATION OF THE INTRAOCULAR LENS IN THE POSTERIOR CHAMBER

The capsular bag is the preferred location for IOL implantation because of the physiological position and stable fixation of the IOL. However, in case of deficient capsular support, such as after intraoperative complications or loose zonules after trauma or in pseudoexfoliation syndrome, alternative fixation of the IOL must be considered. If the anterior capsule is intact, in most cases, a three-piece IOL can be placed in the sulcus. One should strictly avoid placing a single-piece IOL into the sulcus to avoid uveitis-glaucoma-hyphema syndrome. In cases in which a lack of capsular support exists, three alternative options are available for IOL implantation: an anterior chamber IOL with angle

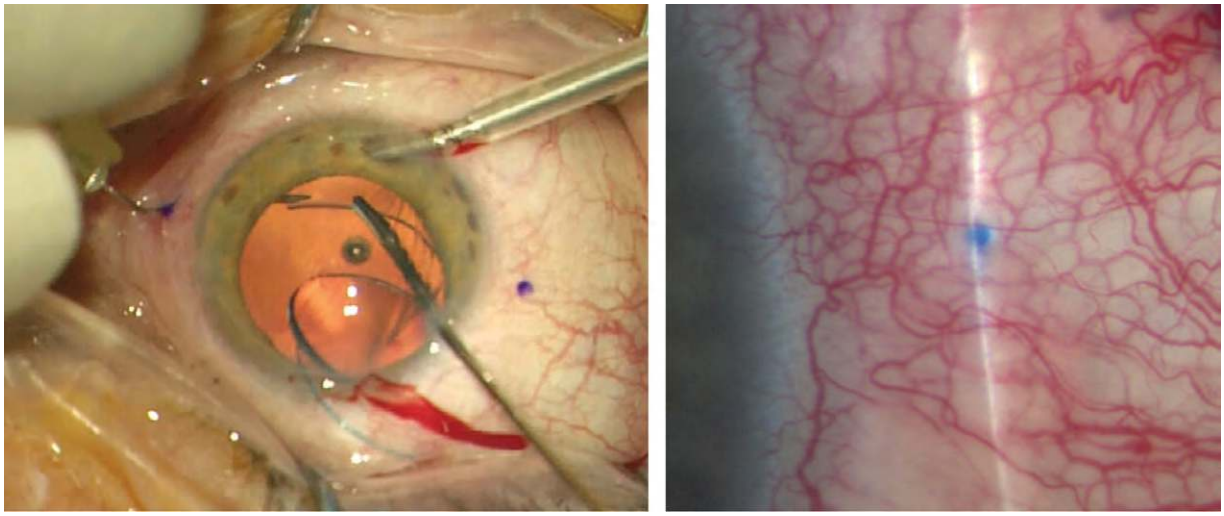

Fig. 7.11 Yamane technique. Positioning haptic into a 30-g needle with VR-forceps *(left)*; flanged haptic tip under conjunctiva *(right)*.

fixation, an iris-fixated (sutured or iris-claw) IOL, or a scleral-fixated IOL (sutured or sutureless). The choice of the approach is dependent on the surgeon's skills, the availability of IOLs, and the patient's eye (see Chapter 41).

Iris Fixation

IOL fixation to the iris is an alternative approach in case of insufficient capsular support. Suturing the IOL to the midiris can be performed primarily via securing a dislocated IOL or as a secondary IOL implantation. The haptics of the IOL are sutured to the midperiphery, and different techniques were used. The common complications of iris suturing are pupil ovalization, iris atrophy, hyphema, and late suture breaks, especially when 10–0 PP was used.

In the case of iris-claw lenses, specifically designed IOLs are implanted and the iris is enclavated into the special haptics, either on the posterior or anterior surface of the iris. These lenses are made out of PMMA because they require an adequate stability and have a unique design in which small slits in the haptics are used to capture iris stroma in the mid-periphery. This location is preferable as it is less vascularized and inflammatory reaction is reduced to a minimum. Implantation of iris-claw lenses are a safe and effective treatment modality for aphakia.[61,62] Possible complications using iris-claw lenses include pupil ovalization, IOL desenclavation with IOL subluxation or luxation, or pseudophakodonesis resulting in oscillopsia.[63,64]

Scleral Fixation

Scleral fixation can be performed with sutures or with sutureless techniques, the common feature of which is the fixation of the haptics with or within the sclera. Therefore the haptics are either sutured to the scleral wall or externalized and fixated within scleral pockets or the haptic ends are thickened to allow fixation.

Sutureless fixation of an IOL was first published in 2007. Scharioth and Pavlidis presented a technique to fixate the IOL haptics of a three-piece IOL within a scleral pocket.[65] In 2010 Scharioth and colleagues published the first series of patients in which the "scleral tuck technique" was used.[66] In contrast to the previous used methods, Scharioth fixates the haptic within a scleral tunnel without glue or sutures.

Another technique was published in 2017 by Yamane et al.[67] Briefly, the two haptics of a three-piece posterior chamber IOLs are externalized through the sclera 2 mm behind the limbus using two 30-g needles. Thereafter the haptic ends are heated, resulting in the thickening of the end (flange), which is pushed back into the sclera for fixation. In the first published series of 100 eyes, a good visual acuity was achieved, and no severe adverse event occurred.[67] Eight eyes showed an iris capture, five showed some vitreous hemorrhage, and one showed cystoid macular edema. Recently, flange formation of different IOLs and materials was evaluated.[68] Seven different three-piece IOLs (5 PMMA and 2 PVDF) and one single-piece IOL were investigated. Flange formation was different between the materials but also within the PMMA haptic group, which may be because of the additives in the PMMA material, according to the authors. Since 2017 several adaptations to the Yamane technique have been published (Fig. 7.11).

Hook-shaped haptics of a novel special IOL are placed in an intrascleral tunnel after externalization of the haptics using a specialized IOL and haptic manipulator.[69] These hook-shaped haptics ensure stable fixation of the IOL. A novel technique in which the haptic is internalized via a Y-shaped scleral tunnel has been described.[70] With this technique the externalized haptic is reinserted into the scleral wall for IOL fixation. No additional gluing, suturing, or flange formation is necessary.

SUMMARY

The field of posterior chamber IOL is a very rapidly changing field with constantly new developments on the way. These progresses include IOL design and material. Furthermore, new features are incooperated into the IOL, enhancing their functionality and tolerability. The development in cataract surgery over the last decades turned the procedure into a more safe and frequently performed one, and improvement of posterior chamber IOL played a major role in this development.

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8

Toric Intraocular Lenses

Valentijn S.C. Webers and Rudy M.M.A. Nuijts

CONTENTS

INTRODUCTION

In modern cataract surgery, spectacle freedom is becoming more and more desirable. In many patients who have cataract surgery, emmetropia can be achieved by correcting for refractive errors by implantation of a monofocal intraocular lens (IOL). However, approximately 20% to 30% of patients undergoing cataract surgery have preexisting corneal astigmatism of 1.25 diopters (D) or more, which, when uncorrected during surgery, will result in spectacle dependency postoperatively.[1,2] Toric IOLs provide an opportunity to correct corneal astigmatism at the time of cataract surgery to achieve postoperative freedom from spectacles for a certain distance. Accurate IOL calculation and alignment are necessary to optimize postoperative outcomes. Numerous studies have shown that the implantation of a toric IOL is safe and effective and, furthermore, are superior to monofocal IOLs to correct preexistent corneal astigmatism at time of surgery.[2,3] After toric IOL implantation, up to 70% of all patients are spectacle-independent for distance visual acuity.[2,3] Although many presbyopia-correcting IOLs also have toric versions, this chapter focuses on monofocal toric IOLs.

CAUSES

In corneal astigmatism, the horizontal and vertical meridians of the cornea have a different curvature and therefore different power. This unequal curvature may be present at merely the anterior cornea, posterior cornea, or both. Corneal astigmatism is often classified according to the axis of astigmatism (Fig. 8.1).

- In with-the-rule (WTR) astigmatism, the steepest corneal meridian is oriented vertically (90 ± 30 degrees).
- In against-the-rule (ATR = horizontally) astigmatism, the steepest meridian is vertically orientated (180 ± 30 degrees).
- In oblique astigmatism (OBL), the axis is in between WTR and ATR (30–60 degrees or 120–150 degrees).

WTR astigmatism is most often present (approximately 50% of eyes), whereas OBL is seen the least (approximately 20% of eyes). With increasing age, the magnitude of astigmatism increases and ATR astigmatism becomes increasingly prevalent.[1] The cause of these changes is unclear; however, it is hypothesized to be the result of changes in upper eyelid tension, intraocular pressure, and possible change to corneal structure.

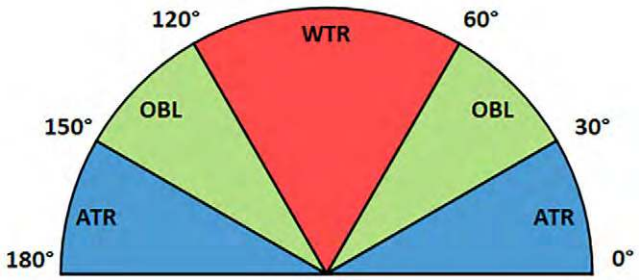

Fig. 8.1 A schematic overview of the distribution of with-the-rule *(WTR)*, against-the-rule *(ATR)*, and oblique *(OBL)* astigmatism.

Furthermore, astigmatism can be classified as regular or irregular. Preferably, corneal topography should be performed to distinguish regular astigmatism, with a typical bow-tie pattern, from irregular astigmatism. Irregular astigmatism occurs when the curvature of the cornea is pronounced in any direction, not just the center. An asymmetric pattern is seen in irregular astigmatism.

COMORBIDITIES

Toric IOLs are most effective in regular astigmatism. However, toric IOL implantation could be considered in select patients with mild to moderate stable irregular astigmatism and whose vision is satisfactorily corrected using spectacles. Pathologic, surgically induced, and posttraumatic causes of cornea astigmatism should be identified during the preoperative evaluation. In some corneal ectatic disorders, such as keratoconus and pellucid marginal degeneration, irregular astigmatism is highly prevalent. Evaluation by corneal topography of both the anterior and posterior cornea is essential because some of the ectatic disorders present with changes on the posterior corneal surface before any changes may be seen on the anterior corneal surface. A number of other conditions are known to cause irregular astigmatism, including the following:

- Anterior basement membrane dystrophy

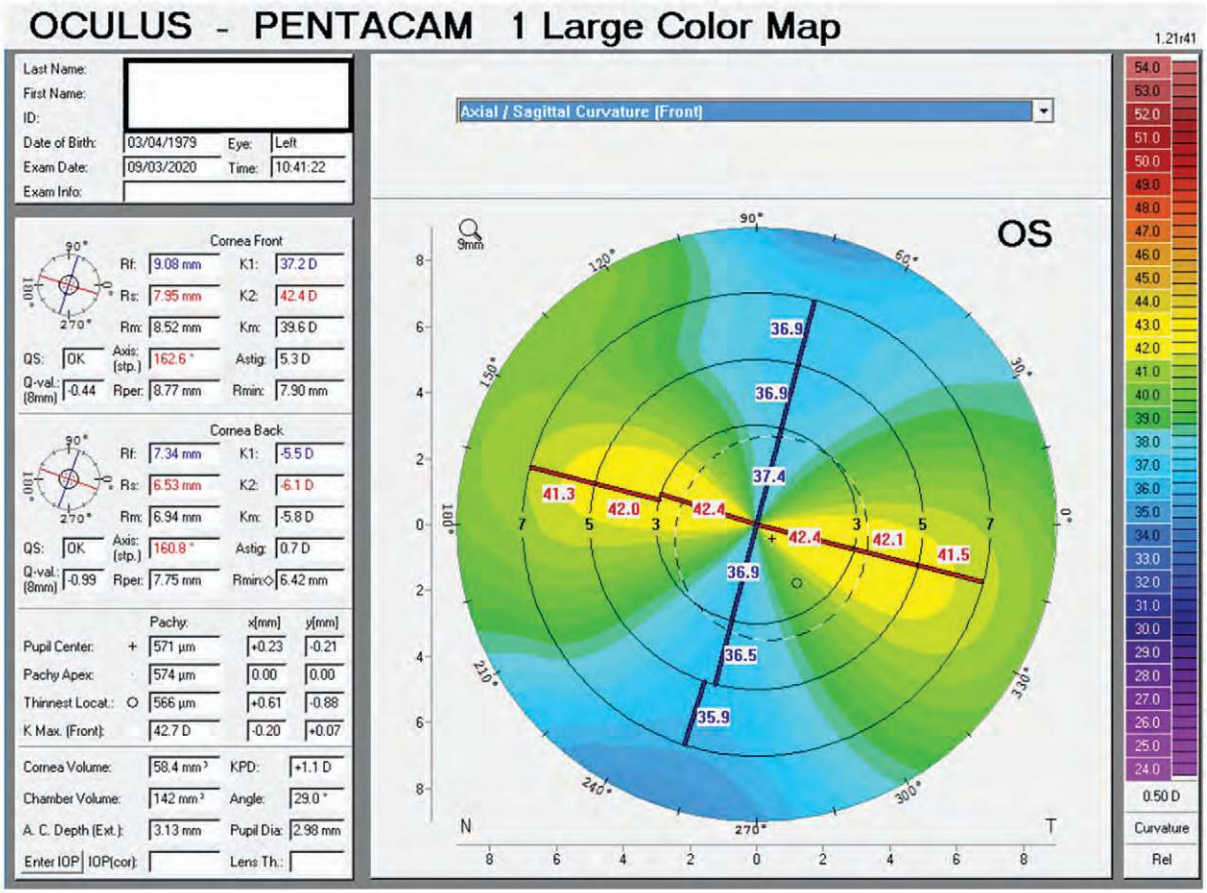

Fig. 8.2 Image obtained by Scheimpflug corneal tomography showing a bow tie indicating existing regular corneal astigmatism.

- Salzmann nodules
- Corneal scars
- Pterygia

High postkeratoplasty astigmatism, even after suture removal, is common and may limit the visual acuity despite a clear corneal graft. Toric IOLs should be considered only when irregular astigmatism is stable and a satisfactory vision is achieved by spectacles.

Another relative contraindication for toric IOL implantation is preexistent ocular pathology that might need keratoplasty in the future (e.g., Fuchs' endothelial dystrophy). Furthermore, potential bag instability may result in rotation or decentration of the toric IOL. Therefore patients with pseudoexfoliation syndrome or trauma-induced zonulolysis are generally not suitable for toric IOL implantation.

PREOPERATIVE MANAGEMENT

Accurate and repeatable measurements of corneal astigmatism, accurate toric IOL power calculation, and toric IOL alignment are essential for achieving good and repeatable postoperative refractive results and patient satisfaction.

Patient Selection

A regular bow-tie astigmatism is most suitable for toric IOL implantation (Fig. 8.2). Different methods are available for measuring corneal astigmatism, including the following:

- Automated keratometry
- Manual keratometry
- Corneal topography
- Scheimpflug imaging

Although these devices have been shown to be comparable in measuring astigmatism, the advantage of Scheimpflug over most devices is the capability of measuring both anterior and posterior cornea. In this manner, detection of early stage ectatic disorders of the cornea is possible. Recently, a partial coherence interferometry device (IOLmaster 700 [Carl Zeiss Meditec AG, Jena, Germany]) was introduced. This biometry also has the ability to measure both the anterior and posterior corneal curvature with integrated optical coherence tomography, and metrics have been developed for total keratometric measurements of both surfaces.[4]

Toric IOL implantation could be considered with astigmatism as low as 1.0 D depending on orientation of the steep axis. In WTR patients, the posterior astigmatism will decrease the total cornea power, whereas ATR astigmatism will result in a higher corneal power. Therefore the cut off for considering toric IOL is lower in ATR patients:

- In ATR astigmatism 0.75 to 1.0 D and above
- In WTR astigmatism 1.25 D and above

Toric Intraocular Lens Calculation

Multiple online toric calculators are available to calculate the correct toric IOL. A toric IOL power and implantation is suggested after completing the mandatory items (Fig. 8.3).

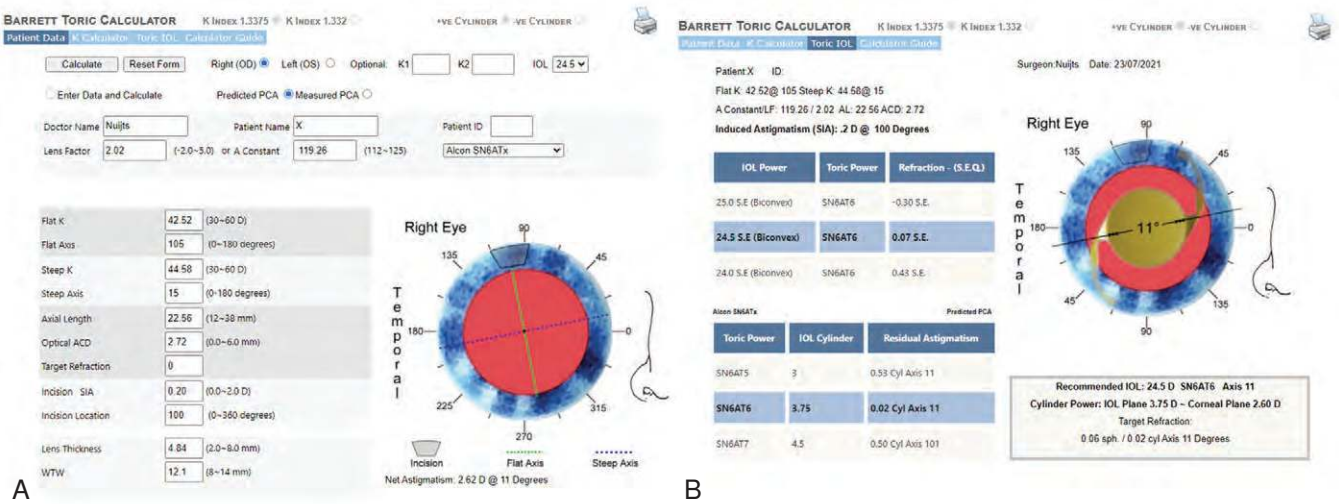

Fig. 8.3 An example of a toric IOL calculator. (A) Overview of mandatory items needed for calculation. (B) The suggested toric IOL power, implantation axis, and the predicted residual astigmatism and spherical equivalent are calculated.

TABLE 8.1 Overiew of Commonly Used Toric IOLs

IOL Model	Material	Sphere power (D)	Cylinder power (D)	Haptic design
Acrysof IQ Toric (Alcon)	Hydrophobic acrylic	+6.0 to +30.0	0.75 to 6.0	Loop
Lentis Tplus LS-313 (Oculentis)	Hydrophilic acrylic + hydrophobic surface	+10.0 to +30.0	0.75 to 5.25	Plate
AT Torbi (Carl Zeiss Meditec)	Hydrophilic acrylic + hydrophobic surface	−10.0 to +32.0	1.0 to 12.0	Plate
T-flex (Rayner)	Hydrophilic acrylic	−10.0 to +35.0	1.0 to 11.0	Closed loop
Torica-aA/aaY (Humanoptics)	Hydrophilic acrylic	−20.0 to +59.0	1.0 to 30.0	Loop
EnVista Toric (Bausch and Lomb)	Hydrophobic acrylic	+6.0 to +30.0	1.25 to 5.75	Loop
Hoya Vivinex Toric (Hoya Surgical Optics)	Hydrophobic acrylic	+10.0 to +30.0	1.0 to 6.0	Loop
Morcher 89A (Morcher GmbH)	Hydrophilic acrylic	+8.5 to +30.0	0.5 to 8.0	Bag-in-the-lens
Ankoris Toric (PhysIOL)	Hydrophilic acrylic	+6.0 to +30.0	1.5 to 6.0	Double-loop
Precizon Toric (Opthec)	Hydrophobic + hydrophilic	+1.0 to +34.0	1.0 to 10.0	Loop
Tecnis Toric (Johnson & Johnson Vision)	Hydrophobic acrylic	+5.0 to +34.0	1.5 to 6.0	Loop

TORIC IOL CHECKLIST

- Orientation and magnitude of the corneal meridians
- The axial length
- Anterior chamber depth
- The surgically induced astigmatism (SIA; induced by the corneal incisions)
- Incision location
- Target refraction

Since the introduction of toric IOLs, several adjustments have been made to the calculation of the toric IOLs. There are multiple factors affecting the postoperative outcomes, including accurate estimates of the total corneal astigmatism (TCA), SIA based on centroid value, effective lens position based on axial length and anterior chamber depth, correct alignment, and rotation stability of the toric IOL. It is known that neglecting the posterior corneal astigmatism (PCA) can result in unexpected postoperative residual astigmatism. The influence of the PCA is different for eyes with WTR astigmatism or ATR astigmatism. Because the posterior astigmatism acts as a minus power, TCA is overestimated in WTR eyes and underestimated in ATR eyes without considering the PCA.[5] There are several second-generation online toric IOL calculators using nomograms available that predict the TCA based on the magnitude and axis of the anterior corneal astigmatism or have the option to manually insert the measured posterior astigmatism.

Every surgical intervention to the cornea causes a change in both the power and the orientation of the principal meridians. Various factors including the location, size, and architecture of the corneal incision have an impact on the amount of SIA. Furthermore, every eye heals differently, and how the eye heals also plays a role. Incisions on the steep axis will cause flattening, which will reduce the amount of preexistent astigmatism. Therefore a standard temporal or superior approach will influence the SIA differently depending on the preoperative corneal curvature. All these factors make SIA variable between surgeons and it is therefore of great importance to analyze the SIA before implanting a toric IOL. There are several online SIA calculators available (e.g., sia-calculator.com and the SIA tool available at www.ascrs.org) for calculating the SIA based on a case series using pre- and postoperative corneal characteristics. For a single surgeon using a fixed incision location, using the centroid values for SIA rather than the mean (absolute) SIA results in a significantly reduced error of predicted residual astigmatism.[6]

Toric Intraocular Lens Overview

There are many toric IOL models available (Table 8.1 and Fig. 8.4) that vary by IOL design and biomaterial. Both biomaterial and IOL design have an important factor in toric IOL stability. Early

Fig. 8.4 An overview of available toric IOLs.

Fig. 8.5 Three-step procedure for manual marking. (A) In supine position marking the 0-90-180 degree axis. (B) Followed by intraoperative marking, the desired implantation axis with a Mendez ring. (C) The toric IOL marks are aligned with the ink marks.

postoperative rotation may be caused by the movement of the haptics prior to the fusion with the capsular bag. Increasing the friction may reduce the occurrence, therefore a larger IOL diameter may be helpful. Long-term stability is higher in plate haptic IOLs compared with commonly used loop haptics. However, early postoperative rotation occurs more frequently with plate haptic IOLs.[7, 8] Haptic material can also influence postoperative rotation stability with acrylic materials providing the best stability and silicone materials the least.[9] Anatomic features may affect rotation stability as well, such as longer axial length and capsular bag size.[10, 11] Currently, with most commonly used IOL designs, the average postoperative rotation ranges from 1 to 5.[12]

SURGICAL PROCEDURE

Intraoperative sources of residual refractive astigmatism after toric IOL implantation include variations in SIA and misalignment of the toric IOL. A reduction of 3.3% in astigmatism correction for every degree of misalignment of the toric IOL axis to its desired axis reflects the importance of perfect intraoperative alignment and excellent postoperative rotation stability. The magnitude of this error is more apparent the higher astigmatic power of the IOL. There are various methods to mark the eye prior to toric IOL implantation, which can be divided into two major groups: manual marking and digital marking.

- **Manual marking** is considered to be the most common marking method. The most important factor in using this method is to eliminate cyclotorsion of the eye. Cyclotorsion of the eye from upright to supine position is common, on average ranging from 2 to 5 degrees but can be more than 10 degrees.[13] Because of its unpredictability, reference marks should be applied in supine position preoperatively. Manual marking techniques consist of either a three-step or two-step procedure. The three-step procedure starts with marking the horizontal axis of the eye with the patient sitting upright. This may be done using the slit lamp, a pendulum, a bubble marker, or by using a special marking device on the Goldmann tonometer (Fig. 8.5) followed by intraoperative marking of the desired toric IOL implantation axis by an angular graduation instrument (Videos 8.1 and 8.2). In the two-step procedure, a special device, for example, the Robomarker (Surgilum, Wilmington, DE, USA), is used to apply the ink markings with the desired implantation axis in one step to the eye with the patient sitting upright. Each step of the manual marking methods may result in misalignment averaging 1.8 to 4.9 degrees in total.[14, 15]
- Various methods of **digital marking** for toric IOL implantation are available. Commonly used devices are the Verion Image-Guided System (Alcon Laboratories, Inc. Fort Worth, TX, USA) and the Callisto Eye System (Carl Zeiss Meditec AG, Jena, Germany) (Fig. 8.6). Both of these systems obtain preoperative high-resolution images of the eye. Intraoperatively, these images are matched using multiple reference points on the conjunctiva and iris to create a digital overlay of the preoperative image and the live-surgery image. Because of the eye-tracking navigation of the system, cyclotorsion and eye movements are eliminated, allowing the desired implantation axis of the toric IOL to be accurately projected in oculars of the

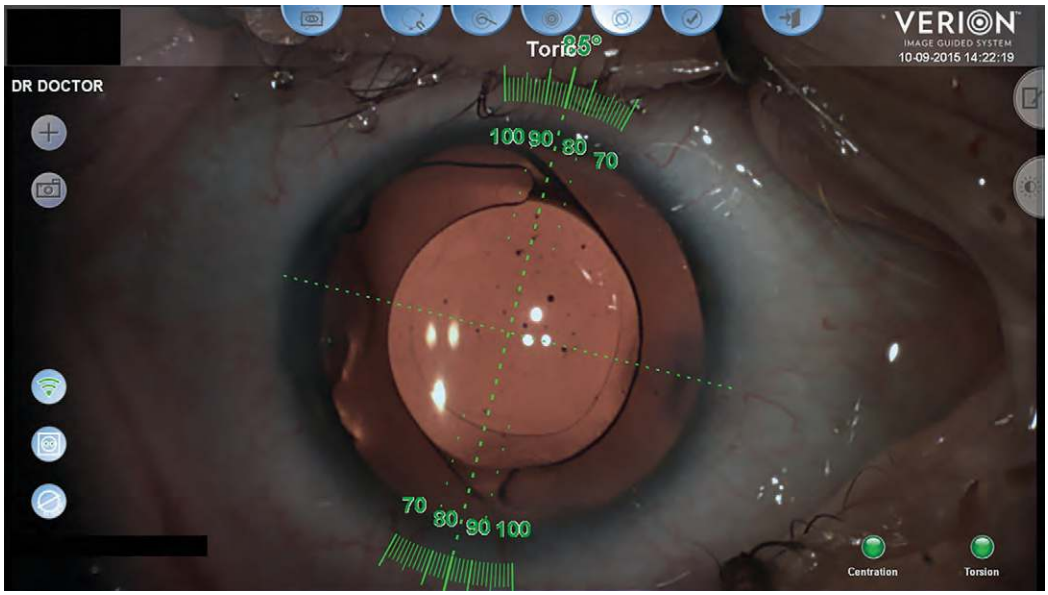

Fig. 8.6 An example of digital marking. In the oculars of the surgeon, a digital overview is created, showing the desired implantation axis.

surgeon's microscope. Several studies comparing manual and digital marking showed a reduction up to 50% in misalignment at the end of surgery.[16–18] A reduction in overall time required to perform the surgery was seen using digital marking compared with manual marking.[17] However, no clinically relevant advantages were found in terms of uncorrected distance visual acuity.

- Another **digital marking** method is provided by the intraoperative aberrometry (e.g., ORA System [Alcon Laboratories Inc, Fort Worth, TX, USA]). This noninvasive, noncontact integrated, intraoperative wavefront aberrometer system uses real-time intraoperative optical measurements and replaces ink markings by matching the IOL axis with the axis of astigmatism using refractive data gathered and processes by the system.[19] Several studies have shown the high accuracy in predicting the postoperative residual astigmatism and spherical equivalent. Especially in low astigmatism the intraoperative aberrometry could outperform the preoperative formulas (Video 8.3).[19, 20]

For the implantation of toric IOLs itself, a standard phacoemulsification technique may be performed. After completion of the phacoemulsification, the empty capsular bag is filled with the ophthalmic viscosurgical device (OVD), followed by insertion of the toric IOL. Using clockwise rotation, a gross alignment of the toric IOL is achieved while its haptics are unfolding. After removal of the OVD from the anterior chamber, accurate alignment of the toric IOL is achieved by using a bimanual irrigation and aspiration device or for example a Sinskey hook (Video 8.4).

There are several key points to improve postoperative outcomes are discussed in the box below.

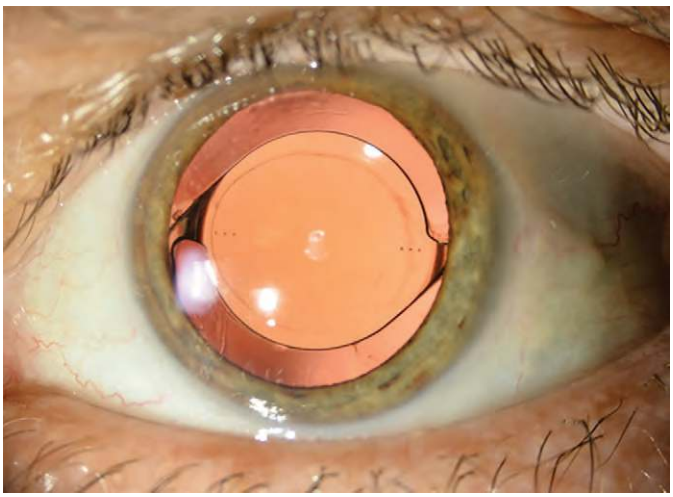

Fig. 8.7 Postoperative retroilluminated slitlamp photographs showing the alignment of the toric IOL marks. A 360-degree overlap by the capsular bag edge and the IOL optic is visible.

KEY POINTS TO IMPROVE POSTOPERATIVE OUTCOMES

- **Capsulorrhexis:** A well-centered and well-sized capsulorrhexis providing a 360-degree overlap of the optic by the capsule is needed to achieve postoperative IOL stability, to reduce tilt of the IOL, and to reduce the incidence of posterior capsule opacification.[21] The size of the capsulorrhexis should be adjusted to the IOL optic diameter but ranges approximately from 4.5 to 5.5 mm. Creating a femtosecond laser-assisted capsulotomy provides the opportunity to create precisely sized capsulotomy (e.g., 4.8 mm for a typical 6.0 mm diameter of an IOL optic).
- **Removal of OVD:** Incomplete removal of OVD can cause early IOL rotation. When comparing 1 hour, 1 day, 1 week, and 1 month after surgery, the highest IOL rotation was seen within 1 hour of surgery.[22] It is hypothesized that incomplete removal of OVD prevents contact of the IOL with the capsular bag and prevents ideal friction and subsequent stabilization of the IOL in the bag.
- **Capsular tension ring (CTR):** Recent studies showed no improvement of toric IOL stability after additional CTR implantation in normal eyes.[23, 24] However, the usage of a CTR during toric IOL implantation may be reserved for a special situation like higher myopic eyes and zonular instability at time of surgery.

POTENTIAL COMPLICATIONS

General complications are those associated with cataract surgery and IOL implantation: posterior capsule opacification, cystoid macular

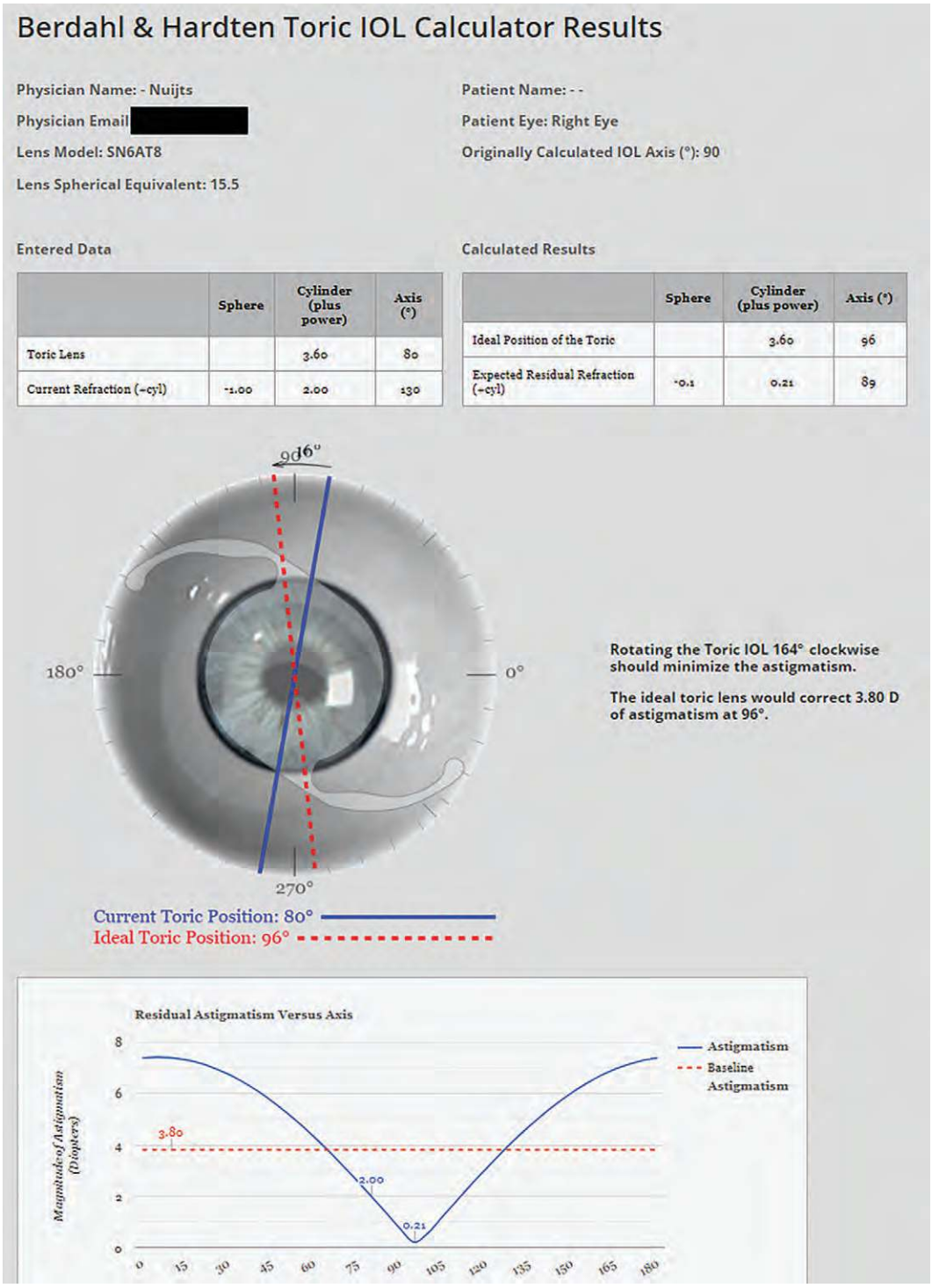

Fig. 8.8 An example showing rerotation would be beneficial (astigmatismfix.com). In this case a SN6AT8 (3.60 D cylinder at corneal plane) was implanted at 90 degrees. Postoperative alignment was 80 degrees with a current refraction of S –1.00: C 2.00 × 130 degrees. Rerotation to 96 degrees would decrease the refractive error to S –0.10: C 0.21 × 89 degrees. *IOL,* Intraocular lens.

edema, peripheral vitreous detachment, macula hole, retinal tear, and retinal detachment. Intraoperative complications, such as anterior capsule tear and zonulolysis of several clock hours, may reduce postoperative stability of the toric IOL, decreasing the visual outcome.

Misalignment can be caused by both inaccurate alignment of the IOL during surgery or postoperative rotation of the IOL. Because of its major influence on the visual outcome, misalignment should be examined and, if needed, treated postoperatively.

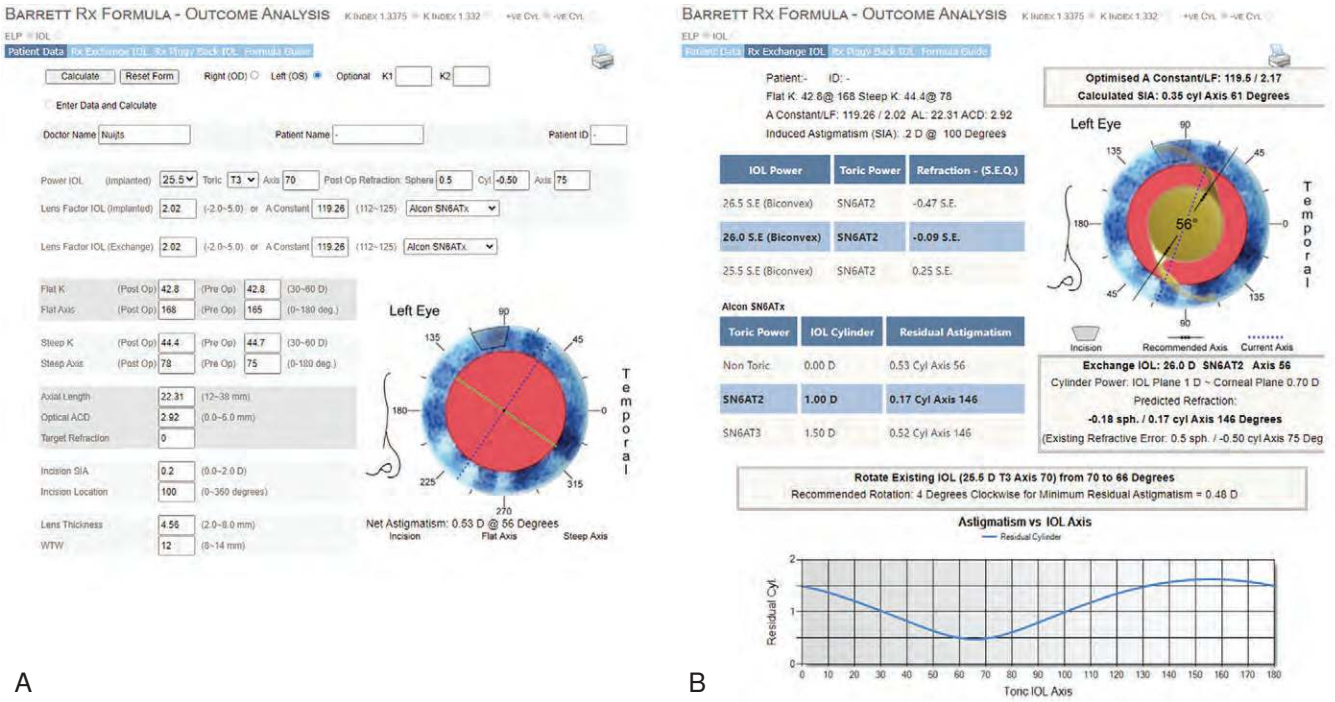

Fig. 8.9 An example showing that IOL exchange would be more beneficial than IOL rotation (Barrett Rx Formula). (A) Mandatory items such as current toric IOL, postoperative refraction, and pre- and postoperative corneal k-values. (B) Rotation of the current toric IOL (SN6AT3 25.5 D) would result in higher residual astigmatism (0.48 D) than IOL exchange (SN6AT2 26.0 D with implantation axis of 56 degrees with predicted residual astigmatism of 0.17).

POSTOPERATIVE MANAGEMENT

Postoperative care after implantation of a toric IOL is the same as that provided for patients undergoing standard cataract extraction and IOL implantation. However, to address potential misalignment, orientation of the toric IOL axis should be examined postoperatively (Fig. 8.7). It is known that most rotation of toric IOLs occurs in the early postoperative period (within 1 day to 1 week).[22] Generally, 10 degrees of misalignment is an indicator that rerotation surgery is necessary. However, because every degree of misalignment reduces the anticipated correction of corneal astigmatism by 3.3%, both the amount of misalignment and the power of the toric IOL interfere with patients' satisfaction. Lower misalignment after higher toric IOL power implantation may be more disturbing compared with higher misalignment in lower toric IOL power implantation. Both misalignment and the patients' satisfaction and subjective refraction should be considered before planning rerotation surgery. Therefore no defined cut off in degrees of misalignment is available when a misaligned toric IOL must be repositioned.

Online calculators are available to aid in the planning of the rotation of a misaligned toric IOL. An online back-calculator (www.astigmatismfix.com [Ocular Surgical Data LLC, USA]) based on the current manifest refraction, lens orientation, and lens power assists surgeons in determining whether rerotation of a misaligned toric IOL would result in lower residual astigmatism or not (Fig. 8.8). Another option is the Barrett Rx Formula (available online at https://calc.apacrs.org/). This formula determines whether exchanging or rotating the toric IOL to adjust spherical and toric powers will improve the postoperative refractive outcome (Fig. 8.9).

Furthermore, the timing of the rerotation is of great importance: performing rerotation within 1 week after initial surgery may increase the incidence of rotation after the rerotation surgery. Delaying rerotation for several weeks could be more challenging because of contraction of the capsular bag increasing the risk of damaging the Zinn's zonules.[25] Ideal timing for rerotation surgery seems to be between 1 and 3 weeks. One should assure that the patient's eye is stable with respect to the surgery and that there are repeatable and stable manifest refractions. Many studies reported the incidence of repositioning surgery ranging from as low as 0% up to over 3%, varying for different IOL designs.[25]

SUMMARY

- Preexistent corneal astigmatism can be addressed at the time of cataract surgery by implantation of a toric IOL.
- Eliminate irregular corneal astigmatism by sufficient patient selection and preoperative evaluation.
- Use a second-generation toric calculator to take the posterior astigmatism into account.
- Use either manual or digital marking for correct alignment of toric IOLs.
- A regular, well-sized capsulorrhexis/femtocapsulotomy and total removal of OVD is needed for higher IOL stability.
- Detect misalignment early postoperatively to outpace capsular contraction.

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Video 8.1: Manual marking of target axis for a toric IOL.

Video 8.2: Marking of reference (0-180 degree) axis pre-operatively.

Video 8.3: Alignment of toric IOL utilizing intraoperative guidance.

Video 8.4: Insertion alignment of a toric IOL.

9

Presbyopia-Correcting Intraocular Lenses

Myriam Böhm, Eva Hemkeppler, and Thomas Kohnen

CONTENTS

KEY POINTS

- The condition of the eye should be healthy and almost flawless before implanting a multifocal intraocular lens (MIOL) to achieve long-term patient satisfaction, and preoperative measurements need to be performed with high precision for intraocular lens (IOL) calculation and correction of astigmatism.
- Trifocal IOLs provide good visual acuity at near, intermediate, and far distances but can lead to reduced contrast sensitivity and perception of optical phenomena.
- Extended depth-of-focus (EDOF) IOLs provide comparable intermediate and far distance with a decrease of near visual acuity compared to trifocal IOLs but show fewer side effects with regard to optical phenomena.
- After implantation of a MIOL or EDOF IOL, a time period of about 12 months needs to be assumed for neuroadaptation.

INTRODUCTION

In 2015 presbyopia was estimated to affect 1.8 billion people globally with an unmet need for presbyopia correction in 45% of the people.[1] Of people aged 70 years or older, the prevalence of presbyopia exceeds 90%, whereas of people aged 35 years or older, 60% already suffer from at least a mild near vision impairment. It is caused by an age-related loss of accommodation leading to near vision impairment that hinders patients from performing near visual tasks, thereby reducing a patient's quality of life.

Presbyopia can be corrected by various optical means and procedures:

- Spectacles
- Contact lenses
- Refractive surgery using the optical principles of monovision or multifocality[2]

Multifocal intraocular lenses (MIOLs) have been developed to appease an increasing patient demand for high quality vision with complete spectacle independence. Presbyopia-correcting IOLs (PC-IOLs) have been implanted since the late 1980s and have shown a steady increase in implantation rates.[3,4]

Over the last few years, a higher number of patients not suffering from cataracts are opting to receive refractive lens exchange surgery to treat refractive errors, including presbyopia to achieve less spectacle dependence. The correction of presbyopia still remains a challenge for refractive surgeons, particularly to obtain good quality range of vision from far to near vision with the minimal perception of optical phenomena.

The four pseudophakic approaches for presbyopia correction at the lens level are:

- Monovision with monofocal IOLs
- MIOLs
- Extended depth-of-focus (EDOF) IOLs
- Accommodative IOLs

This chapter is intended to give ophthalmologists and ophthalmic surgeons an overview of the optical principles, the associated advantages and disadvantages, and the patient selection and indication of these four lens-based approaches for presbyopia correction.

CAUSES

The pathophysiology of presbyopia is associated with the deterioration in structure and function of a number of interrelated tissues. The onset of presbyopia is caused by an age-related loss of accommodation caused by geometric and mechanical property changes in the accommodative system. The loss of accommodation leads to near vision impairment, hindering the patient from performing near visual tasks.

Examples of areas affecting age-related accommodative changes include:

- Viscoelastic properties of the lens capsule and matrix
- Geometry of zonular attachments
- Ciliary body
- Zonular fibers
- Aqueous and vitreous humors[5, 6]

COMORBIDITIES

When selecting patients for the implantation of an MIOL, the ophthalmic surgeon should consider comorbidities that can cause complications or impair the effectiveness of the IOL. The advantages and disadvantages of MIOLs should be discussed very carefully with these patients, and implantation should be carried out only if the patient expressly wishes. Concerning presbyopia-correcting strategies for patients with ocular comorbidities, it is important to mention that monovision or accommodating IOLs are the preferable treatment options as a result of the light-splitting design of multifocal and EDOF IOLs, which lead to loss of contrast sensitivity and the perception of optical phenomena, even in healthy eyes.

COMORBIDITIES AND PATIENT SELECTION FOR PRESBYOPIA-CORRECTING INTRAOCULAR LENSES

- Identify the patient's motivation for the procedure and postoperative vision goals.
- The condition of the eye should be healthy or almost flawless to achieve long-term patient satisfaction.
- Ocular comorbidities such as corneal dystrophies, glaucoma, maculopathy, diabetic retinopathy, and other diseases that are associated with a reduction in contrast sensitivity and/or visual acuity should be carefully considered with much caution.
- The presence of comorbidities must be weighed against the patient's motivation and goals for vision.
- Patients should have a detailed understanding of the pros and cons of the planned presbyopia-correcting surgery.

DRY EYE DISEASE

The tear film together with the cornea comprises two-thirds of the refractive power of the eye. Dry eye is an important topic for cataract and refractive surgeons because an unstable tear film leads to high variations in the refractive power (and surgical measurements). A significant increase in the incidence of dry eye symptoms, such as eye discomfort and irritation, is often present after lens surgery.[7]

It is therefore important to discuss dry eye risk factors and symptoms during a preoperative examination to know a patient's history of dry eye symptoms. If there are preexisting ocular surface problems, it is important to start dry eye treatment preoperatively and assure improvement before considering a PC-IOL.

CORNEAL DYSTROPHIES

Fuchs endothelial corneal dystrophy (FECD) is one of the most common corneal dystrophies that impacts PC-IOL selection and success rates and is characterized by the following:

- A progressive loss of corneal endothelial cell number and structure
- A thickening of the Descemet membrane
- Deposition of an extracellular matrix in the form of guttae

Endothelial decompensation gradually leads to the development of central stromal edema. Additionally, patients typically show a slow increase in blurred vision that occurs more frequently in the morning.[8] The patient's motivation for PC-IOL implantation, age, and the severity of the FECD stage should be considered when deciding whether to implant a PC-IOL. A reduced endothelial cell count and already measurable loss of contrast sensitivity is a clear contraindication for MIOL implantation. It should be kept in mind that FECD is a progressive disease that is associated with a progressive loss of endothelial cell count and an increase in guttae so that the disease can significantly affect the patient's vision over time and the need for surgical treatment with Descemet's membrane epithelial keratoplasty to restore vision. Depending on the degree of FECD and the risk tolerance of the patient, one can consider monovision and/or accommodating IOLs in these patients.

AGE-RELATED MACULAR DEGENERATION OR RETINAL DISORDERS

Age-related macular degeneration (AMD) is characterized by a central loss of vision caused by a degenerative and/or neovascular change in the macular region of the retina.[9] By examining the macula using optical coherence tomography (OCT), early signs of the maculopathy can be detected even before vision impairment occurs. Thus during preoperative examination for PC-IOL surgery, an OCT examination is also recommended to detect minimal changes in the macula area at an early stage and to take this into account when deciding on PC-IOL implantation. A patient with good visual function could do well with a multifocal or EDOF IOL. However, as macular degeneration progresses, the benefits of these types of IOLs will be lost. In general, implantation of an MIOL is not recommended in the presence of macular degeneration, but there is no clear yes or no answer. There is some debate as to whether EDOF IOLs are suitable for those with AMD. In these cases, a monovision is most likely the better alternative if a patient wishes to achieve more spectacle independence.

GLAUCOMA

Glaucoma is characterized as irreversible progressive damage to the optic nerve head resulting in severe vision field loss and eventual blindness. This is best diagnosed by the visual field test in which external restrictions and focal deficits (scotomas) are found. As the disease progresses, the patient may unconsciously compensate for steadily deteriorating visual field, contrast sensitivity, and even color vision for a limited time.

It is therefore of great importance to examine the optic nerves before the implantation of a PC-IOL by means of a fundoscopy or an additional papillary OCT and, if any abnormalities are found, to perform a formal visual field examination. The implantation of an MIOL/EDOF IOL with preexisting visual field defects with loss of central visual acuity is certainly contraindicated. There have been anecdotal reports of successful implantation of nondiffractive EDOF IOLs in early stage glaucoma, but further studies have to be conducted for final approval.

PSEUDOEXFOLIATION SYNDROME OR POST TRAUMA

Pseudoexfoliation (PEX) syndrome is common in old age and is characterized by the production and deposition of extracellular, fibrillary material in the area of the anterior chamber.

PEX syndrome is often associated with the following:

- Increased glaucoma and cataract development
- Impaired function of corneal endothelium
- Pigment dispersion
- Disruption of the blood-aqueous barrier
- Poor pupillary dilation and formation of posterior synechiae
- Zonular weakness

Clinically, PEX syndrome often appears one-sided or highly asymmetric. Therefore an examination in mydriasis is necessary for a reliable diagnosis of PEX syndrome. It is often associated with nuclear cataract, and during cataract surgery, zonular weakness and insufficient mydriasis can lead to complications. A preoperative assessment with regard to the presence of PEX is particularly important when planning PC-IOL implantation because PEX syndrome is a frequent cause of postoperative lens (sub)luxations, and the function of most PC-IOLs is heavily dependent on good centration.[10]

INDICATION AND PREOPERATIVE MANAGEMENT

A comprehensive preoperative examination is critical to surgical success and good visual results for the patient and should include the following:

- Patient's expectations
- Personality traits of the patient
- Detailed medical history including profession and hobbies
- In-depth ophthalmic evaluation
- Review of habitual refraction
- Informed consent
- Preoperative risk assessment to determine which IOL is best for the patient

PATIENT'S MOTIVATIONS

For postoperative patient satisfaction, it is particularly important to consider the individual needs and expectations. Factors such as ocular and systemic comorbidities, the patient's state of health, desired reading distance, and age could influence preoperative expectations and predict patient satisfaction more precisely. Depending on the pseudophakic approach chosen to treat presbyopia, the ophthalmic surgeon should explain the advantages and disadvantages such as optical phenomena or loss of contrast sensitivity.[11]

If the implantation of a multifocal or EDOF IOL is planned, the patient should be advised about the process of neuroadaptation. These IOLs split light entering the eye into different focal points so that the brain perceives several images at the same time. This process of neuroadaptation can take several months, which can often be frustrating for patients. It is known that neuroadaptation is not only dependent on refractive factors. In patients who have certain personality traits, such as compulsive control addiction, efficiency, orderliness, and sense of duty, more glare and halos are typically reported postoperatively. Therefore the selection of the MIOL/EDOF and patient counseling should also take these personality traits into account.[12]

INDICATION AND PATIENT SELECTION

A detailed medical history should be taken at the first preoperative examination so that a patient's social and professional history can be taken into account to discuss specific visual requirements of the patient's private and professional life. Some professions, such as pilots or firefighters, have specific visual requirements. Patients with jobs that have specific visual demands, for example, pilots, surgeons, or truck drivers, should not receive an MIOL. Patients should have a strong desire to be spectacle independent for which a possible reduction in contrast sensitivity and greater dependence on lighting are accepted.

PREOPERATIVE EXAMINATIONS

The preoperative examination starts with the measurement of refraction with uncorrected and best corrected visual acuity near and far, as well as a slit lamp microscopy. In addition, the dominance of the eye should be determined for patients who might be interested in monovision. To ensure that the eye has perfect conditions with good light transmission and optical quality, the number and morphology of the endothelial cell counts should also be determined. For optimal results without residual refractive errors, the optical biometry and the corneal topography measurement should be carried out before the fundus and intraocular pressure measurements because the application of eye drops and the measurement of the intraocular pressure can influence the corneal curvature (Fig. 9.1).

Biometric data with an automated noninvasive optical biometer are required to determine the adequate IOL strength for postoperative spectacle independence. Corneal topography and tomography are important to assess astigmatism and to rule out corneal diseases such as anterior basement membrane disease, ectatic diseases such as keratoconus, and irregular astigmatism. Exact knowledge of the type and

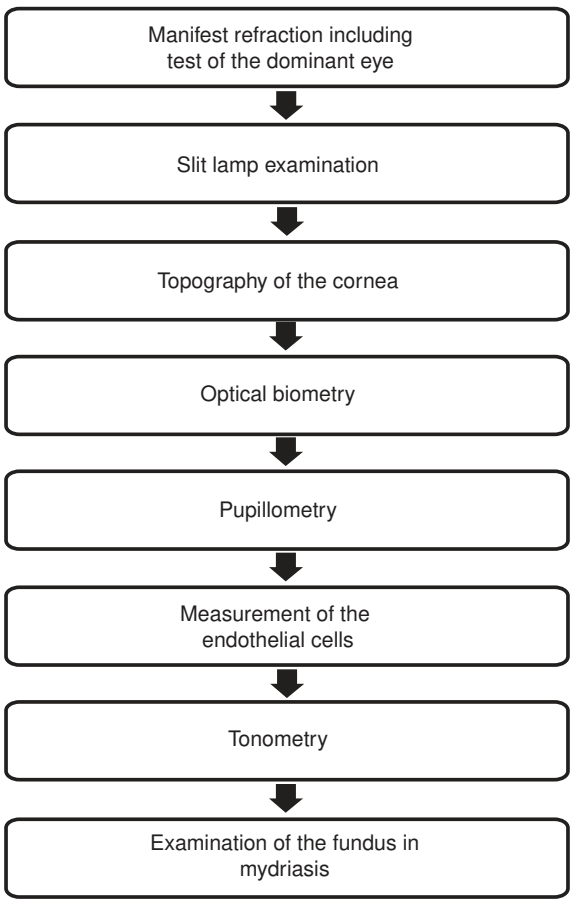

Fig. 9.1 Preoperative examination schedule.

location of the astigmatism is crucial for planning limbal relaxing incisions (LRIs), laser astigmatic incisions, and the calculation of a toric IOL.

After these measurements, a pupillometry should be performed under different light conditions. The fundus examination should be carried out with a wide pupil to exclude macula and optic changes. In addition, peripheral degenerations or holes in the retina should be ruled out in myopic patients and, if necessary, treated with laser coagulation before surgery. If there are abnormal findings, further examinations such as a visual field examination or OCT of the macula are indicated.

PRESBYOPIA-CORRECTING INTRAOCULAR LENSES

The modern cataract surgeon has many IOL choices for treating presbyopia and addressing the needs and wishes of the patient:

- Spherical, aspherical, or toric
- Monofocal
- Multifocal (bifocal and trifocal)
- EDOF
- Accommodating

MONOVISION

Monovision with contact lenses has been used since the early 1960s. In 1999 the conventional monovision technique was used for the first time to correct presbyopia after cataract surgery.

Optical Principles

- The classic monofocal IOL is a spherical monofocal lens that compensates the spherical equivalent of the eye. In addition, aspherical monofocal IOLs have an optimized prolate surface curvature that can compensate for the residual spherical aberration of the eye to enable an improvement optical quality and contrast vision.
- Monovision is achieved by correcting one eye for distance vision (dominant eye) while correcting the other eye for near vision (nondominant eye -1.5 D) (conventional monovision). In the hybrid monovision technique, a diffractive multifocal IOL is implanted in the nondominant eye while a monofocal IOL is implanted in the dominant eye.[13]

Results

Monovision works with interocular, distance-dependent suppression. A near correction by means of myopization that is stronger than -1.75 D is not recommended because this can lead to a significant loss of stereopsis and is usually not well tolerated.[14] Monovision enables excellent uncorrected visual acuity in the distance with no significant difference compared with multifocal or accommodating IOLs and good visual acuity at near distance. The advantages of monovision are the independence from glasses in combination with a lower risk of optical phenomena. Disadvantages are a possible loss of stereopsis and contrast sensitivity. Monovision is reversible if it is not well tolerated because myopia can be corrected by laser treatment of the cornea.

MULTIFOCAL INTRAOCULAR LENSES

MIOLs are designed to provide patients with good visual acuity at specific distances. They offer two or more focal points and thus enable near, intermediate, and far vision without additional optical correction depending on the make/model. Because of the optical concept of several focal points of MIOLs, disruptive optical phenomena such as glare or halos can occur more frequently than after implantation of a monofocal lens.[15]

Optical Principles

- MIOLs are characterized by the separation of light into two (bifocal) or more (trifocal or panfocal) focal points and thus cause the light that falls into the eye to be scattered. This optical principle provides patients with good visual acuity at specified distances without additional optical correction.
- A basic distinction is currently made between diffractive and refractive MIOL models. Diffractive MIOLs consist of a spherical refractive surface and a diffractive anterior or posterior surface. Depending on the lens, about 30 concentric rings with a step height of 2 µm act as a phase grating on the posterior surface to diffract the incident light rays. These separate incident light into two (bifocal) or three focal points (trifocal) (i.e., for near and far vision and the intermediate vision for trifocal lenses). Refractive MIOLs have two or more ring-shaped spherical zones of different refraction. The near part is usually located in the center of the lens optics. Because of miosis that occurs when looking at near objects, it is primarily the near part that should be effective when looking in the distance with a wider pupil, the far part.
- Depending on the lens, about 30 concentric rings with a step height of 2 µm act on the rear surface as a phase grating to diffract the incident light rays. A disadvantage is that, for physical reasons, about 20% of the light is lost as scattered light. However, the great advantage is that the same image is created at every point of the optics with constant exposure so that the effect is more independent of the pupil diameter and centering.

Results

The two optical principles of diffraction and refraction allow the subdivision of MIOLs into refractive and diffractive lenses, as well as segmental lenses (Fig. 9.2, Table 9.1).

Studies have shown a clear advantage of trifocal IOLs in terms of visual acuity at intermediate distance compared with bifocal lenses.[16] Diffractive trifocal IOLs, such as the AT LISA tri 839MP (Zeiss, Germany) and the AcrySof IQ PanOptix (Alcon, USA), provide patients with spectacle independence at near, intermediate, and far distance and show a high level of patient satisfaction despite the appearance of optical phenomena.[17–19] A comparative study of the AT LISA 839MP with the PanOptix IOL showed that the PanOptix IOL results in better visual acuity at intermediate distance at 60 cm compared with the trifocal AT LISA IOL at 80 cm. Both lenses offer a similarly high degree of spectacle independence, contrast sensitivity, and patient satisfaction.[20] The FineVision (PhysIOL, Belgium) also demonstrates good, uncorrected visual acuity at all distances.

In addition, there have been newer versions of refractive MIOLs that refract the light over an extended focus area. For example, the segmental LENTIS Mplus X LS-313MF30 (Oculentis, Netherlands) combines an aspherical, asymmetric distance part with a sector-shaped near part of +3.00 D. For an optimal performance of the Mplus IOL, the adequate positioning of its optical axis on the visual axis is necessary. A study by Böhm et al (2019) compared the defocus curves of two diffractive MIOLs (AT LISA tri, PanOptix), one segmental refractive MIOL (M Plus X), and one EDOF IOL (Symfony).[17] The defocus curves showed no significant difference at 4 m to 2 m between the four IOL groups.

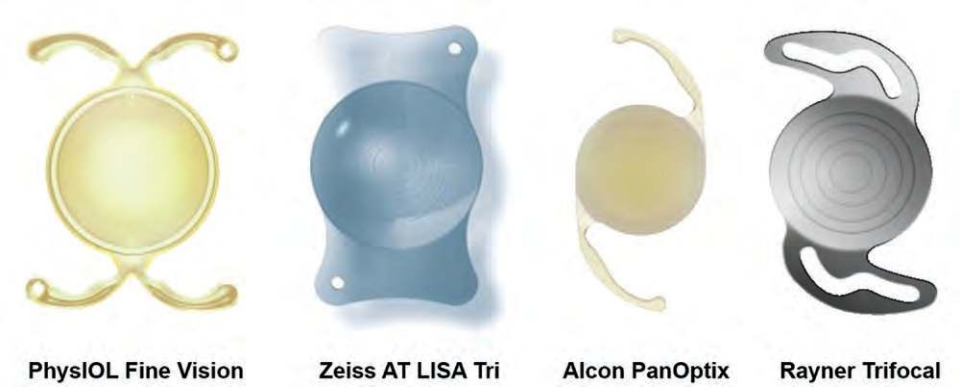

Fig. 9.2 Design of four multifocal IOLs.

TABLE 9.1 Overview of Multifocal Intraocular Lens Characteristics and Their Design

	PhysIOL Fine Vision	Zeiss AT LISA Tri	Alcon PanOptix	Rayner Trifocal
Diffractive technology	Diffractive apodized trifocal across full optic surface	Diffractive trifocal up to 4.34 mm; thereafter bifocal	Diffractive trifocal up to 4.5 mm; thereafter monofocal	Diffractive trifocal up to 4.5 mm; thereafter monofocal
Diffractive steps	26 diffractive steps	29 diffractive steps 0.0 D	15 diffractive steps	16 diffractive steps
Diffractive orders	0, 1, 2	0, 1, 2	0, 2, 3 (nonsequential)	–1, 0, 1
Light loss 3.0 mm pupil	14%	14.3% (Ave.)	12%	11%
Light energy split 3.0 mm pupil	49% D / 18% I / 34% N	50% D / 20% I / 30% N	42% D / 24% I / 22% N (includes 12% light loss)	52% D / 22% I / 26% N

EXTENDED DEPTH-OF-FOCUS INTRAOCULAR LENSES

An EDOF IOL provides a single elongated focal point that enhances the range of vision. The result is an increase in the depth of field and good uncorrected visual acuity at distance and in the intermediate range (60–100 cm). The visual acuity at near distance is also improved compared with monofocal IOLs but does not reach the level of trifocal IOLs.[17, 21] For "nonperfect" eyes with, for example, an irregular corneal surface or early stage glaucoma, there is potential that nondiffractive EDOF IOLs might become a presbyopia treatment option, but no peer-reviewed papers have been published yet.

Optical Principles

- The basic principle of diffractive EDOF IOLs is that they are MIOLs that place two foci so close together that there are no multiple peaks but rather a plateau in the defocus curve. Pinhole IOLs use the pinhole principle to increase the depth of field. The advantage is that, in spite of the increased depth of field, little or no optical phenomena occur.
- EDOF IOLs can be divided into diffractive, nondiffractive, and pinhole models[21] (Fig. 9.3, Table 9.2).

Results

EDOF IOLs focus on good, far, and intermediate vision, with functional near vision in combination with the lowest possible optical phenomena and good contrast sensitivity. In comparison to the AT LISA tri, PanOptix, and MPlus X MIOL, the Symfony IOL shows comparable far and intermediate visual acuity and worse near vision.[17] Tarib et al. (2019) investigated a mixed implantation of an EDOF IOL in the dominant eye and a trifocal IOL in the other eye compared with a binocular EDOF implantation. With good results in both groups, there was significantly better near vision in the Mix & Match group because of the trifocal lens.[22]

To use the positive effects of optical quality of EDOF IOLs and to achieve greater spectacle independence at near distance, currently IOLs are manufactured that combine trifocality with an EDOF design. At present there are still few prospective studies, but the first results are promising. Torun et al. (2016) showed that patients with the Reviol Tri-Ed show good visual performance at far, intermediate, and near distance, as well as high-contrast sensitivity and subjective satisfaction.[23] A new technology of continuous-range-of-vision IOL (TECNIS Synergy, Johnson & Johnson Vision Care, Inc.) was first presented at the ESCRS congress 2019 in Paris from Chang et al. who found excellent VA at far, intermediate, and near comparable to a multifocal IOL.

A new nondiffractive EDOF IOL (Vivity, Alcon, USA) shows good first results at far, intermediate, and near distances. Patients reported few optical phenomena and good contrast sensitivity.[24] Overall, the visual results with EDOF IOLs are very good at far and intermediate distances, with moderate visual phenomena and good contrast sensitivity. Near visual acuity is often suitable for everyday use.[17]

ACCOMMODATING INTRAOCULAR LENSES

Accommodative IOLs try to imitate the physiologic process of accommodation to create the closest possible focus.

Optical Principles

- A distinction in accommodative IOLs is made between three basic methods (Fig. 9.4, Table 9.3):
  1. The optic shift method is based on shifting the position of the optics by contracting the ciliary muscle with a subsequent change in refractive power.

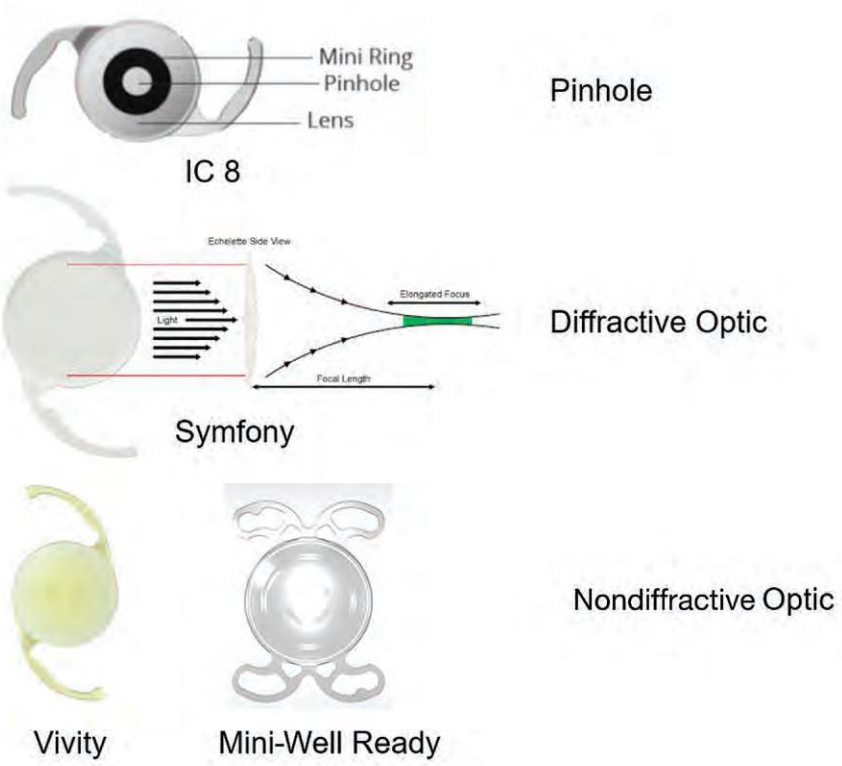

Fig. 9.3 Design of four EDOF IOLs divided in pinhole, diffractive, and nondiffractive models.

TABLE 9.2 Overview of Extended Depth-of-Focus Intraocular Lens Characteristics and Their Design

	IC-8	Tecnis Symfony	Mini-Well	Vivity
Design	Pinhole	Diffractive	Nondiffractive	Nondiffractive
Haptic design	C-Loop	TRI-FIX-Design	4-Loop	STABLEFORCE Modified-L haptics
Material	Hydrophobic acryl	Hydrophobic acryl	Hydrophil acryl	Hydrophobic acryl
Correction astigmatism	< 1.5 D	< 4.0 D	< 4.5 D	< 3.0 D

2. The dual optic principle is achieved by the ciliary muscle contraction changing the position of the anterior in relation to the posterior optic.
3. The liquid-filled IOL method is theoretically able to change its refractive power by creating a fluid shift in the IOL during ciliary body contraction.

- The primary advantage of these IOL types is that by dispensing with multiple optical zones, spectacle independence can theoretically be achieved without causing optical phenomena.

Results

The Crystalens (Bausch & Lomb, Germany) was tested for near, intermediate, and distance vision and was compared with the AcrySof ReSTOR + 3.0 D (Alcon, USA), the Tecnis + 4.0 D (Johnson & Johnson, USA), and the Kamra inlay. The distance visual acuity showed no significant difference in all three groups, whereas the intermediate visual acuity with the Kamra inlay and the Crystalens was better than with the ReSTOR + 3.0 D and the Tecnis + 4.0 D, which had a better near vision. A secondary finding was a better contrast sensitivity in the patients with the Crystalens, which is probably because of less loss through scattered light than with multifocal optics.[25] In comparison to an aspherical monofocal IOL, the accommodative IOL shows a significantly better near visual acuity. Because there was no shift of the IOL, the assumption remains that the improvement in intermediate and near vision might be caused by induction of spherical aberrations and not by a change in the refractive power of the IOL. The accommodating IOL (lumina) provided over 2.5 dpt more depth of field in the range of 0.2 to 0.5 logMAR visual acuity than the monofocal SA60AT. The visual acuity was also significantly better in the range from -0.5 to -5.0 dpt (defocus curve). A pilot study in six subjects of the shape-changing LensGen Juvene IOL with preoperative BCDVA of 20/40 or worse showed all achieved best corrected visual acuity of 20/25 or better and a mean objective accommodation of 1.2 D (range, 0.7–1.38 D). However, there is no peer-reviewed literature available on this yet. The FluidVision accommodating IOL (PowerVision, Inc, Belmont, CA, USA) has recently entered clinical trials. The results show monocular subjective amplitude of accommodation was over 3 D across studies and 4 D binocularly by defocus.[26]

Fig. 9.4 Design of three accommodative intraocular lenses.

TABLE 9.3 Overview of Accommodative Intraocular Lens Characteristics and Their Optic Principle

	Crystalens	Lumina Dual Optics	LensGen Juvene
Optic principle	Forward movement	Moving two optical elements	Modular fluid optic intraocular lens
Shape	Biconvex	Aspheric	Curvature-changing
Material	Biosil (silicone elastomer)	Acrylic hydrophilic polymer material	Biomimetic liquid silicone

POTENTIAL COMPLICATIONS

! POTENTIAL COMPLICATIONS

- Light-splitting, presbyopia-correcting lenses lead to optical phenomena but provide spectacle independence.
- Dry eye disease should be treated preoperatively.
- Anamnesis and a good quality of preoperative examinations are critical to prevent potential complications (avoid poor patient selection).

OPTICAL PHENOMENA

As a result of the optical principles of the above lenses, photopic phenomena are unavoidable. A multiple foci lens produces multiple images on the retina. Clinically, this leads to a manifestation of halos, glare, starburst, ghost images, or double vision for the majority of patients. Another change in optical quality concerns the reduction in contrast sensitivity, which leads to a deterioration in optical quality under mesopic and scotopic light conditions. Because of neuroadaptation, patients often report optical phenomena but are not disturbed by them.

DRY EYE DISEASE

Lens surgery can directly cause and exacerbate preexisting dry eye disease (DED). This is important not only with regards to the symptomatology of DED but also for an increased risk of infections and accuracy of preoperative examinations. In addition, DED may cause patients dissatisfaction after cataract surgery.[27]

RESIDUAL REFRACTIVE ERROR

To avoid undesired refractive errors, it is important to choose the correct IOL power and implant it in the right position. Therefore a good preoperative examination, including an exact biometry and topography, is necessary. Additionally, preoperative characteristics of the eye might be a risk factor for a poor refractive outcome. To get qualitative good preoperative examination results, a sufficiently good CDVA is important so that the patient can fix properly during measurements. A healthy eye despite cataract minimizes the risk of refractive errors.[28] Finally, use of modern biometric formulas decreases the risk of an untoward refractive error.

SECONDARY CATARACT

Posterior capsule opacification (PCO) is one of the most common complications after surgery and is reduced by most IOL designs because of the sharp optic edge. PCO is usually treated with neodymium-yttrium aluminum garnet (Nd:YAG) laser capsulotomy. The incidence of Nd:YAG capsulotomy within the first 4 years after surgery is between 10% and 30%. PCO prevention becomes increasingly important because of high risks of complications in other structures of the eye. During the past decades, various forms of prevention have been developed, including general measures during surgery.

SURGICAL PROCEDURE

Femtosecond Laser Assisted Cataract Surgery

Next to traditional manual phacoemulsification, femtosecond laser-assisted cataract surgery (FLACS) now enables capsulotomy, corneal incisions, and lens fragmentation. FLACS allows the surgeon great precision when making corneal incisions and planning the size and centering of the capsulotomy. Moreover, the femtosecond laser can be used to make corneal incisions during lens surgery, such as LRIs, astigmatic keratotomies, or a main incision on the steep meridian to achieve the most precise astigmatism reduction. However, it needs to be pointed out that a good surgical outcome depends as much on an experienced surgeon as on the cutting-edge technology (Videos 9.1 and 9.2).[29]

ASTIGMATISM

Astigmatism correction is critical for achieving spectacle independence. Toric IOLs show a lower postoperative residual astigmatism and no regression effect, and allow a larger refractive range and offer better predictability than nontoric IOLs in combination with LRIs. Therefore for the correction of regular astigmatism of > 0.75 D, primarily toric MIOLs are recommended. The authors recommend treatment with LRIs or laser astigmatic incisions only in the presence of astigmatism > 0.75-2.0 D, if the implantation of a toric IOL is not possible or rather difficult.

Irregular astigmatism is generally considered a contraindication for implanting PC-IOLs because it is not possible to control the refractive outcome.

PREVIOUS REFRACTIVE SURGERY

Today, millions of patients who are interested in the implantation of MIOLs previously had some kind of prior refractive surgery, such as laser in situ keratomileusis (LASIK), small incision lenticule extraction, photorefractive keratectomy, or radial keratectomy to eliminate their refractive error.

Patients who have previously undergone refractive surgery present several challenges for the surgeon because patients who have already undergone corneal refractive surgery show corneal aberrations. In general, patients after hyperopic LASIK of ≤+1.5 D or after myopic LASIK of ≤-3.0 D may be considered for MIOL implantation, but mainly the high-order aberration of the cornea limits MIOL calculation and affects refractive surgery, so these should be taken into account when deciding which IOL fits best. Additionally, it is very important to choose the most suitable calculation formula for the individual conditions.[30] If the aberrations are too high, MIOLs lead to dissatisfaction. An EDOF IOL is more tolerable regarding the visual outcome and should be the best choice for eyes with higher order aberrations.[31] Current research covers the correlation between aberrations and patient satisfaction after MIOL and EDOF in eyes with previous corneal refractive surgery. Nevertheless, the patients need to be well informed that a high-quality visual outcome is more difficult to accomplished because of their decreased contrast sensitivity.

If patients had myopic LASIK, they will most likely suffer from spherical aberration depending on the pupil size. The benefit of having a small pupil is influenced by the MIOL design because there are currently also pupil independent MIOLs on the market. The key message is that not every patient will suffer from problems after a LASIK procedure and an MIOL implantation, but that aberrations are very likely and influence the patient's satisfaction. This implies that it is critical to discuss expected outcomes with patients so that they understand the difficulties of predictability after prior refractive surgery. If patients still choose the implantation of a MIOL, they need to be informed that it is very likely that they will need to use a miotic agent postoperatively to achieve satisfactory visual quality, particularly at night. Moreover, patients should be counseled that they might need a piggyback lens if there is a postoperative refractive error that is disturbing, thereby lowering their expectation level.

POSTOPERATIVE MANAGEMENT

After lens surgery:

- Continuously check for complications.
- Measure refraction and IOL pressure.
- Control the axis position for toric IOLs.
- Use postoperative drug therapy to reduce edema.

After lens surgery, patients should be routinely checked (Table 9.4) to determine the development of postoperative complications. A check on the first postoperative day with measurement of the intraocular pressure is mandatory. After 1 week an examination with an initial subjective refraction and, in the case of toric IOLs, a determination of the IOL axis in mydriasis is recommended. A well-founded determination of the refraction and a possible residual error can be made after 4 to 6 weeks.

The determination of the axis position for toric IOLs and the resulting indication for operative rotation of the IOL should be based on the calculation of the correct axis position of the IOL if there is a residual error. Using IOL parameters, postoperative refraction, and a regression analysis, appropriate calculators can calculate the optimal IOL axis and the corresponding residual astigmatism after the rotation. A rotation is recommended if the patient is disturbed by the residual error and a significant reduction in residual astigmatism is likely to be achieved through rotation.

Postoperative drug therapy should be based on established perioperative therapy for lens surgery. Studies have shown that perioperative therapy with nonsteroidal antiinflammatory drug (NSAID) eye drops can significantly reduce the incidence of cystoid macular edema. In addition, postoperative application of steroid-containing eye drops in combination with NSAID eye drops can further reduce the incidence and reduce anterior chamber irritation, local inflammation, and the formation of synechiae. Deka et al. show positive clinical outcomes after a combination of topical NSAIDs and topical steroids.[32] Therefore the authors recommend the application of eye drops containing NSAIDs the evening before the surgery and for 4 to 6 weeks postoperatively in

TABLE 9.4 Postoperative Management: Examinations and Therapy

Time Since Surgery	Examinations	Therapy
1 day	• Uncorrected visual acuity • Slit lamp examination • Intraocular pressure measurement	**Topic:** **Standard:** • Steroid eye drops (Dexa EDO 1,3 mg/mL eye drops 4x/day for 2 weeks) • Nonsteroidal antiinflammatory eye drops (e.g., Nevanac 3 mg/mL eye drops 1x/day for 6 weeks) • Artificial tears, if needed
1 week	• Uncorrected and corrected visual acuity at far, intermediate, and near distances • Slit lamp examination • Intraocular pressure measurement • Toric IOLs: determination IOL axis position in mydriasis	
2–3 months	• Uncorrected and corrected visual acuity at far, intermediate, and near distances • Slit lamp examination • Intraocular pressure measurement	

IOL, Intraocular lens.

combination with eye drops containing steroids for 2 weeks postoperatively.[33] In addition, it is important to educate the patient about the postoperative increased occurrence of dry eye and guide them that a sufficient basic sicca therapy is immanent. For this reason, the authors recommend the application of tear substitutes without preservatives 3 to 4 times a day postoperatively, and more often if necessary and in combination with a gel applied at night.

SURGICAL PEARLS PRESBYOPIA-CORRECTING INTRAOCULAR LENSES

Intraoperative Pearls:

- Avoid overstretching the pupil because patients benefit from having a small pupil so it is preferable to avoid using retractors or rings if not necessary. If necessary, use iris retractors to a maximum of about 4.5 mm.
- Perform a femtosecond laser-assisted capsulotomy or use a corneal or digital marker (6.0 mm) as a guide to maintain the size of the capsulorrhexis.
- The surgeon should anticipate that he might have to exchange or remove the IOL at some point. Therefore he should do two things to facilitate removal if necessary: (1) Plan that the edges of the capsulotomy or capsulorrhexis cover the IOL optic by at least 0.5 mm 360 degrees; and (2) this eases the viscodissection maneuver to free the IOL from the capsule so that the IOL can be removed without damaging the capsule.
- The IOL should be centered perfectly.

Postoperative Pearls:

- Be aware that in general you might have to YAG earlier in MIOL patients than in monofocal patients because, on average, MIOL patients are younger and thus their capsule opacifies sooner.
- Regularly review your pooled postoperative outcomes and give special analysis to outliers and try to learn from those.

SUMMARY

- Trifocal IOLs provide good visual acuity at near, intermediate, and far distances but can lead to a slightly reduced contrast sensitivity and perception of optical phenomena.
- EDOF IOLs provide comparable intermediate and far distance, however in exchange for near visual acuity, but present fewer negative side effects with regard to optical phenomena.
- After implantation of MIOLs or EDOF IOLs, a time of about 12 months could be assumed for neuroadaptation.
- Preoperative measurements need to be performed with high precision for MIOL calculation and correction of astigmatism.
- Patient's motivations and expectations need to be discussed, and the patient should be informed about possible side effects of the multifocal optics.
- For MIOL implantation, the capsulotomy or capsulorrhexis needs to be precise to achieve good IOL centration. This can be achieved by femtosecond laser-assisted lens surgery or using a corneal or digital marker.
- Dry eye symptoms need to be treated prior to surgery to achieve the best possible refractive result and visual quality.
- Secondary cataract needs to be removed early because already slight opacities will lead to a loss of near visual acuity.

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Video 9.1: Femtosecond laser assisted implantation of extended depth of focus IOL: Vivity (Alcon).

Video 9.2: Femtosecond laser assisted implantation of toric trifocal IOL: PanOptix (Alcon).

10

Adjustment Of Intraocular Lens Power

Andrew D. Barfell, Raphael Penatti, and George O. Waring IV

CONTENTS

KEY POINTS

- Meeting or exceeding the expectations of refractive cataract patients depends on achieving spectacle independence while maximizing optical quality.
- New technologies provide novel ways of managing residual refractive error while minimizing risks to the patient.

INTRODUCTION

Cataract surgery is the most commonly performed surgical procedure in the world. In the past decade, advances in surgical technique, intraocular lens (IOL) technology, and biometric screening have enabled safer surgeries with more predictable outcomes. As technology has advanced, so too have patient expectations. The goal of cataract extraction and lens placement is no longer to simply improve best corrected visual acuity but rather to restore the full range of vision—distance, intermediate, and near—and to achieve spectacle independence post operatively with maximum optical quality.[1–3]

Despite significant advances in the field of ophthalmology, accurate and predictable IOL power calculation remains one of the most significant challenges during lens removal. In fact, the most frequent complication after cataract surgery is uncorrected refractive error. Residual myopia, hyperopia, astigmatism, and spherical aberration leave a patient suboptimally corrected and increase the likelihood of spectacle dependence and decreased contrast sensitivity, factors which may be unacceptable to the refractive cataract patient. Residual refractive error after cataract surgery can be attributed to a number of etiologies including errors in obtaining preoperative biometry, unexpected wound healing, surgeon-induced astigmatism, or other unanticipated factors. Medical errors may result in implantation of the wrong lens at the time of surgery.[4]

The likelihood of residual refractive error increases in patients with prior keratorefractive procedures including radial keratotomy (RK), photorefractive keratectomy (PRK), and laser in situ keratomileusis (LASIK).[5] Although such refractive errors are often correctable with spectacles or contact lenses, these options may not be satisfactory to patients who have previously undergone elective procedures to reduce spectacle dependence. Historically, correction of residual refractive errors has relied on IOL exchange or implantation of a second "piggy-back" IOL.[2] Though perhaps effective, such means of correction places the patient at additional risk of endothelial cell damage, retinal detachment, or endophthalmitis, among other surgical complications.[6] Although keratorefractive procedures such as LASIK and PRK offer less invasive means of correction, not all patients are candidates and even these procedures are not without their own risks and side effect profiles.

Recent advances in intraocular technologies offer the potential to correct residual refractive error after cataract surgery. Broadly speaking, we differentiate these technologies into two distinct categories: directly modifiable systems and indirectly modifiable systems (Table 10.1).

DIRECTLY MODIFIABLE IOLS

A directly modifiable IOL is able to undergo changes in its intrinsic properties that ultimately result in changes to the optical power, toricity, or multifocality of that intraocular lens. Two examples of this technology include light-adjustable lenses and refractive index shaping.

Light-adjustable Lens

Since receiving approval by the United States Food and Drug Administration (FDA) in November 2017, the Light Adjustable Lens (RxLAL) by RxSight has begun gaining traction in certain refractive practices. This lens is a foldable, three-piece IOL composed of a photosensitive silicone material that allows for the adjustment of IOL power using irradiation with ultraviolet (UV) light. The IOL itself is composed of photosensitive macromers with a UV-filtering material on the posterior optic designed to protect the retina during the adjustment procedure.[7] Because focal areas of the lens are irradiated with UV light, the silicone macromers photopolymerize and thereby create a concentration gradient between areas of the lens which are irradiated and those areas which are not. The result is a change in IOL shape and power (spherical and cylindrical).[3,8–20]

Adjustment treatments are typically carried out within 2 to 4 weeks after implantation of the IOL as a patient's vision and refraction stabilize. Once the desired adjustment is to the patient's satisfaction, the IOL is again irradiated with UV light to polymerize the remaining unreacted macromers to stabilize the overall treatment. After this final "lock-in" treatment occurs, no further adjustments can be made to lens power as there are no longer unreacted macromers within the lens itself (Fig. 10.1).[1,3,16]

As an example, to treat a hyperopic error after cataract surgery, the central portion of the lens would be irradiated resulting in photopolymerization of those central macromers. More peripheral macromers would be forced to move centrally along a concentration gradient

resulting in a steepening of the central aspect of the lens. Optically, this would cause a myopic shift of the focusing light rays. The magnitude of hyperopia corrected can be adjusted by tempering the duration and magnitude of UV light exposure. Conversely, a myopic refractive error can be treated by irradiating the peripheral aspect of the lens to force macromers to shift from central to peripheral. This would trigger a relative flattening of the lens centrally and thus an overall reduction in dioptric power of the IOL. (Video 10.1)[1,3,16]

Because the light-adjustable lens relies on a UV-emitting light delivery device to alter lens power, several considerations must be given to evaluating potential candidates. First, because incidental UV light from sunlight exposure may induce a change in the macromeric configuration of the lens, patients must adhere to strict use of UV-protecting eyewear after implantation and leading up to a final lock-in procedure. Failure to do so may result in undesired dioptric changes to the IOL and/or premature locking in of the lens. Thus potential candidates must be able and willing to comply with postoperative regimen and adjustment after surgery. Furthermore, use of the LAL is contraindicated in patients taking systemic medications that may increase sensitivity to UV light as such medications (tetracyclines, psoralen, and amiodarone among others) may lead to irreversible phytotoxic damage to the eye during treatment with the light delivery device. And finally, patients with prior ocular herpes simplex infections may be at increased risk of reactivation after exposure to UV light.[17]

In general, the safety and efficacy of using a UV light-adjustable silicone IOLs have been demonstrated in correcting the refractive spherical and cylindrical error in eyes with normal corneas. In fact, studies have shown that light-adjustable lenses provide stable refractions with good visual acuity and no IOL associated pathologies as far as 7 years after surgery and lock-in.[21] Eyes of patients that have undergone previous refractive surgery represent a challenge for biometric calculations. This increases the chance of IOL power calculation uncertainty and errors. For this specific group, the light-adjustable lens may be an option to maximize refractive precision and visual outcomes after cataract surgery.[9–12,14,15]

If successful, this technology may fundamentally alter the way in which cataract surgery is approached. No longer would patients be required to synthesize vast amounts of complex information in a short appointment with the ophthalmologist before surgery to make decisions on refractive goals. No longer would surgeons be required to assess multiple different formulae to determine the ideal lens for a patient. The uncertainty of final effective lens positioning, healing, and surgeon induced astigmatism would be obviated as corrections to residual refractive error, and multifocality could be enhanced, added, or subtracted post operatively.

TABLE 10.1 Directly Modifiable IOL Systems vs. Indirectly Modifiable IOL Systems

Directly Modifiable IOLs	Indirectly Modifiable IOLs
After implantation, the refractive properties of the IOL are modified without removal of the lens from the eye.	After implantation, additional optical portions may be implanted or exchanged in a modular fashion.
Generally requires irradiation with femtosecond lasers or ultraviolet light.	Generally requires additional intraocular surgery.
Advantages include the ability to make adjustments to IOL power, cylinder, higher order aberrations, and potentially multifocality or extended depth of focus without additional intraocular surgery.	Advantages include improved ability to place or exchange a second IOL compared with traditional means, and additional space for future technologies such as drug delivery devices.
Examples include the light-adjustable lenses and refractive index shaping.	Examples include the modular IOLs and refractive capsules.

Patient Considerations for Light-adjustable Lens

Article I. Dilation: Patients should achieve good pupillary dilation (>7 mm) preoperatively to ensure effective visualization of the optic after surgery and during treatment with the light delivery device.

Article II. Patients with prior ocular herpes may be at an increased risk for viral reactivation after exposure to UV light and thus may not be ideal candidates.

Article III. Certain medications may photosensitize various structures of the eye and are, at the time of this writing, considered a contraindication to implantation.

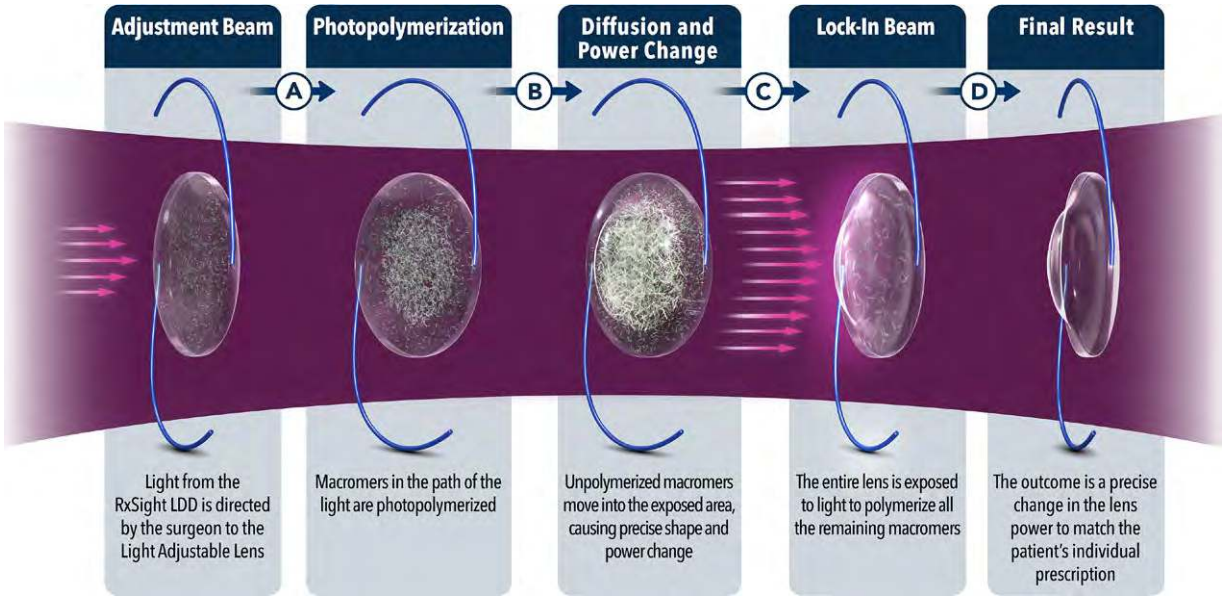

Fig. 10.1 Illustrates how the light-adjustable lens allows for adjustment of refractive power after surgical implantation (Source: Courtesy RxSight).

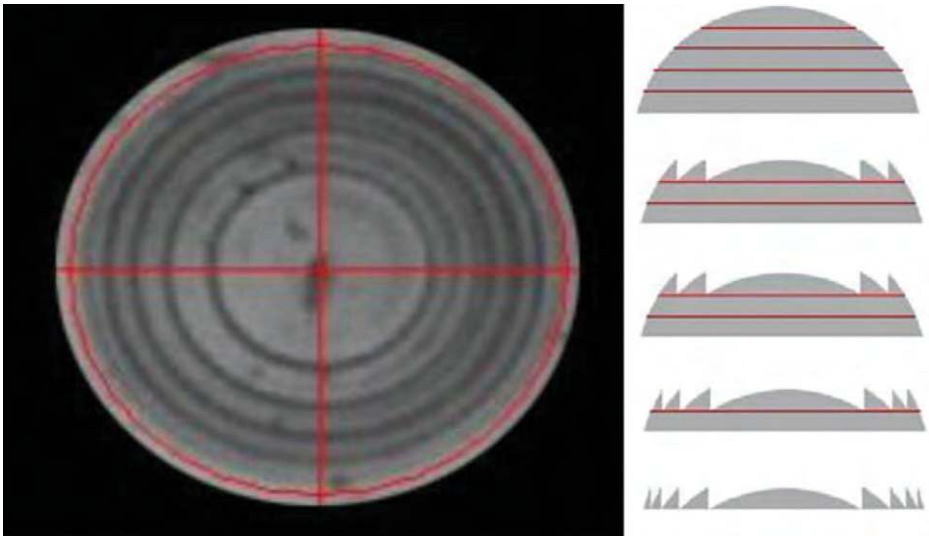

Fig. 10.2 Phase-wrapped aspheric refractive optic, creating refractive index shape changes in an intraocular lens.

Article IV. Failure to adhere to use of UV-protecting eye-wear after implantation of the LAL may result in premature polymerization of the unredacted monomers.

Article V. As silicone-based IOLs can impede visualization during vitreoretinal surgery, the potential need for future retinal surgery should be considered before implantation of any silicone IOL (high axial myopes, should be weighed carefully before implanting any silicone IOL).

Refractive Index Shaping

Refractive Index Shaping (RIS) is a new technology that is currently under development. This technique uses a femtosecond laser to alter the power of hydrophilic or hydrophobic intraocular lenses in vivo and holds the potential to change how residual refractive error is managed after cataract surgery.

With RIS, no particular IOL is required. A standard hydrophilic or hydrophobic IOL is implanted during otherwise conventional cataract surgery. Post operatively, the patient's residual refractive error can be measured while spherical error and cylindrical error may be adjusted to meet the desired refractive goals of the patient.[1,21,22] Similarly, multifocality can be added or removed. And because the procedure is minimally invasive, adjustments are made in a laser suite as opposed to the operating room, which may reduce risk.

Refractive Index Shaping uses a femtosecond laser to selectively alter the refractive index of a material, effectively creating a refractive shape within an optical system.[23,24] The laser is employed to alter the focal hydrophilicity of a specific area within a material at a depth 50 um below the surface of the lens.[22] A resultant absorption of water molecules yields a change in the shape of the material and in the refractive index. And because the treatment is beneath the surface of the IOL, multiple adjustments can be made to the same IOL including placement, removal, and customization of multifocality.[1,24]

An optical principle known as phase wrapping is used to produce a significant refractive change within an IOL. This allows for spatial efficiency of refractive modification as the standard IOL does not have a large enough space in its center to create the RIS lens. Because the phase-wrapped structure contains the complete curvature of a traditional lens collapsed into a sole layer, conventional lens height is not used to direct the light (Fig. 10.2).[1,24]

In Vitro testing has demonstrated both precision and accuracy to a variation of 0.10D of the intended target without clinically significant reduction in the modular transfer function (MTF) of the lens. The lens essentially remains clear.[1,24] For patients with residual refractive error or intolerance to multifocality of an IOL, RIS has the potential to provide an alternative, noninvasive option for correction of an IOL after cataract surgery.

INDIRECTLY MODIFIABLE IOLS

An indirectly modifiable IOL is a modular system in which the optical portion of a device implanted during cataract surgery can be more readily exchanged or removed than a standalone standard intraocular lens in the bag. Although this typically requires additional intraocular surgery, addition and or exchange of the IOL should be much easier than exchanging a traditional IOL.

The Harmoni Modular IOL System (Alcon) is a two-component system made of an acrylic base that secures an acrylic optical component. The base is implanted into the native capsular bag and enables the optical component to be exchanged at any time. This system allows for easier IOL exchange than traditional acrylic IOLs. As such, it may have special application in pediatric cataract surgery to enable IOL exchange throughout a patient's lifetime, cases of failed neuroadaptation with multifocal IOLs, or for patients who desire to "upgrade" their IOL as new technologies emerge.[3]

Similarly, the Gemini Refractive Capsule (Omega Ophthalmics) is a device that is designed to neutralize variables related to effective lens position (ELP). Rather than using two-dimensional arms to center the lens, this capsule controls lens positioning within the z axis of the eye. It additionally maintains an open space in the capsular bag to allow for theoretical incorporation of drug delivery, biometric sensors, or additional refractive lens platforms.[25]

The Juvene modular IOL (LensGen, Irvine, CA, USA) also offers similar potential advantages. It is composed of a silicone base lens that is implanted into the capsular bag and a shape-changing fluid lens. Early studies have shown ease of IOL exchange with the possibility for upgradeability with time if needed. Additionally, as the Juvene fills the capsular bag, studies have shown very stable ELP with minimal fibrosis of the capsular bag.[26]

Although these devices are currently under investigation, their successful development could significantly advance the field of refractive cataract surgery.

SUMMARY

1. The ability to adjust IOL power and multifocality post operatively offers the refractive cataract surgeon more opportunities to meet or exceed patient expectations.
2. Light-adjustable lenses are already FDA approved and may provide an effective means of adjusting spherocylindrical error after cataract surgery.
3. Refractive index shaping is an emerging technology that allows for IOL customization after implantation.
4. Indirectly modifiable technologies like the Gemini Refractive Capsule, Harmoni Modular IOL System, and the Juvene IOL enable safer exchange of IOLs.
5. These technologies and others have the potential to improve and refine patient outcomes after cataract surgery.

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Video 10.1: Video illustrates how the RxLAL allows for adjustment of refractive power after surgical implantation. Irradiation of the RxLAL with UV Light induces a shape change of the lens which results in a change to the refractive index of that lens. Source: Video courtesy of RxSight.

11

Modular Intraocular Lenses

Aman Mittal, Douglas D. Koch, and Sumit (Sam) Garg

CONTENTS

KEY POINTS

- Modular intraocular lenses (IOLs)s consist of multiple components.
- Several have been developed but none are commercially available in the United States.
- Modular IOLs are designed to treat astigmatism and presbyopia.
- Modular IOLS may facilitate treatment of postoperative refractive error.

INTRODUCTION

Advances in intraocular lens (IOL) technology led to the development of hydrophobic acrylic and silicone lens technologies to address astigmatism with toric optics and to address presbyopia with pseudoaccommodative multifocal, trifocal, and extended-depth-of-field optics. No available lens, however, has all characteristics of the ideal IOL, providing excellent, predictable, and reproducible uncorrected near, intermediate, and distance vision with minimal modifications to current standard cataract surgery and without significant complications. The ideal goal of cataract surgeons is to provide patients with spectacle-free vision free of distortions and dysphotopsias. A new generation of IOLs, called *modular IOLs*, consists of multiple separate components. Modular IOLs have a different set of tradeoffs than traditional single- and three-piece IOLs and can allow for presbyopia correction, easier IOL exchange, decreased rate of posterior capsular opacification, and even implantation of other complementary technologies such as sensors or drug-eluting inserts. Facilitating IOL exchange is another important possibility and can have significant effects on treatment of postcataract surgery refractive error correction. Here, we will briefly review the current and upcoming modular IOLs. Of note, this review is not all-inclusive, and much of the data regarding these IOL designs is proprietary and confidential. The data reviewed is publicly available.

Table 11.1 summarizes the modular IOLs reviewed in this chapter.

PRECISIGHT

- Foldable acrylic dual IOL system
- Base lens in capsular bag with spherical correction only
- Front lens anterior to bag with toric/presbyopia-correcting lens
- Available in Europe

The Precisight IOL (Infinite Vision Optics) is a foldable acrylic dual IOL system that can fit through a 2.2-mm clear corneal incision. The first lens is a hydrophobic base lens providing only spherical correction with a plate haptic that is designed to sit within the capsular bag similar to a standard posterior-chamber IOL. The base lens has small bridges on each haptic where the front lens can "dock." The second component is a front lens that consists of two thin lens components, held together by hydrostatic forces, that provide spherical, cylindrical, and multifocal correction. The front lens has two small haptics that are designed to sit within the bridges in the base IOL to secure it. The front IOL is placed anterior to the capsular bag, sandwiching the anterior capsule between the two components to avoid the interlenticular opacification that can sometimes occur when multiple lenses are placed within the capsular bag. The front IOL can be easily exchanged to adjust sphere, cylinder, or multifocality and can be adjusted based on postoperative outcomes or evolving patient needs over time.

Clinical Data

Six patients (two with prior LASIK) with Precisight:[1]

- 2-year UDVA was 20/25–20/40 and CDVA was 20/20–20/32.
- Methicillin-resistant *Staphylococcus epidermidis* (MRSE) was −0.75 to +1.50 D.

Twenty-five patients with Precisight underwent front lens exchange for residual refractive error:[2]

- Preoperative MRSE was −1.6 to +3.0 D, and postoperative MRSE was −0.6 to +1.0 D.
- 64% had UDVA 20/20 or better; 100% had UDVA 20/32 or better.
- No reported postoperative complications.

The Precisight is currently available in Europe with a monofocal aspheric optic but is unavailable in the United States (Fig. 11.1).

HARMONI

- Foldable acrylic dual IOL
- Base in capsular bag with no optic
- Optic into base (in capsular bag)
- Not currently available

TABLE 11.1 Overview of Modular Intraocular Lenses in Development (Past and Present)

Intraocular Lens	Material	Posterior Component		Anterior Component		
Precisight	Hydrophobic acrylic	Two C-loop haptics	Spherical only	Optic with two plate haptics	Attached to base, sandwiching anterior capsule	Spherical, cylindrical, multifocal correction
Harmoni	Hydrophobic acrylic	Two J-loop haptics	Open (no posterior optic)	Optic with two spring haptics	Bag, within base lens	Spherical, cylindrical, multifocal correction
Synchrony	Hydrophobic acrylic	Two C-loop haptics	Negative power	Optic with four spring haptics	Bag, within base lens	Fixed large plus power
Opira	Unknown	Two C-loop haptics in sulcus	Monofocal or toric	Optic with two plate haptics	Sulcus, within base lens	Spherical, moving
FluidVision	Hydrophobic acrylic	N/A	N/A	Two large hollow haptics containing silicone oil	Bag	Thin hollow optic connected to hollow haptics; power changes with ciliary body contraction
Gemini Refractive Capsule	Unknown	Single-piece circular haptic in bag	Open (no posterior optic)	N/A	N/A	N/A
Atia Vision	Unknown	Single-piece circular haptic, in bag	Power changes with ciliary body contraction	Single piece	Bag, within base lens	Fixed power
Juvene	Silicone	Two-piece circular haptic in bag	Fixed power	Hollow optic containing fluid (silicone oil)	Bag, within base lens	Spherical and cylindrical correction; power changes with ciliary body contraction

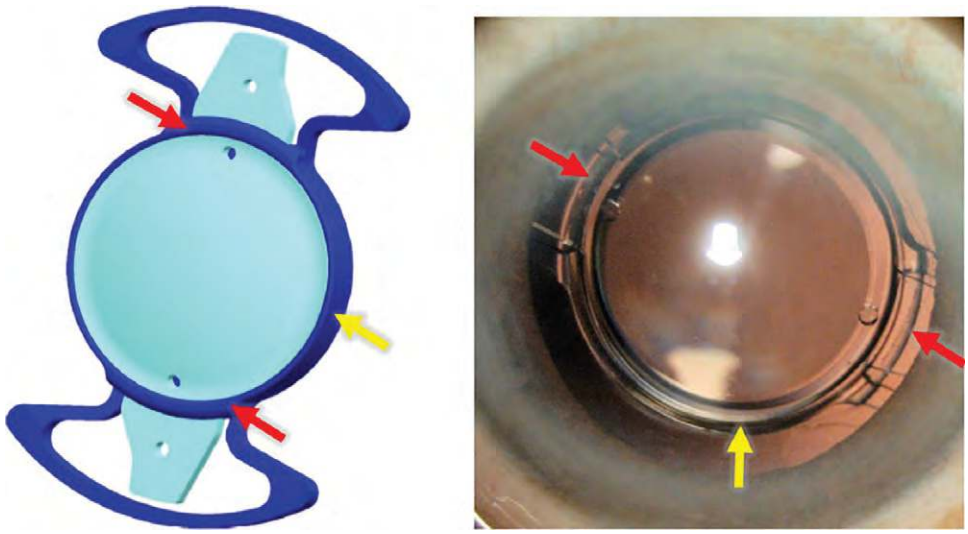

Fig. 11.1 The Precisight lens consists of two refractive lenses. The two lenses are assembeled outside the eye and injected together into the capsular bag. *Red arrows* show Precisight MCIOL base-lens bridges; *yellow arrows* show the base-lens collar. (From Uy, HS., Tesone-Coelho C, C., Ginis, H. (2019). Enhancement-procedure outcomes in patients implanted with the Precisight multicomponent intraocular lens. *Clin Ophthalmol*. 13: 107–114. 10.2147/OPTH.S188383.)

ClarVista Medical has developed another modular IOL called the *Harmoni*. This lens is a foldable acrylic dual IOL with hydrophobic base and optic components. The base body is 8.5 mm, and the total base size is 13.0 mm including the haptics. The body is open in the center, and the 5.8-mm diameter optic is placed within the body to form the final lens. Both parts of this IOL are designed to be placed within the capsular bag. The base has a square edge on the anterior and posterior sides, designed to reduce the rate of posterior capsular opacification (PCO). The rate of PCO is further reduced by the large size of the base, preventing central migration of proliferating lens epithelial cells.

Preclinical Data

Six rabbits with Harmoni in one eye and Acrysof (control) in the contralateral eye, enucleated after 6 weeks:[3]

- Well-centered lenses and significantly less PCO and Soemmering's ring formation in study eyes

  Five rabbits with Harmoni and Acrysof (control), with IOL exchange after 2 weeks:[4]
- No issues with explantation of study lens
- 1 out of 5 study eyes had incompletely seated optic in base for one clock-hour[5]
- Rate of PCO formation similar

- Control eyes with more posterior synechiae and four cases of partial pupillary capture, no cases of posterior synechiae in study eyes
- Postmortem implantation of Harmoni in one eye and Acrysof in fellow eye:[6]
- Eyes connected to perfusion system and UBM used to measure ACD over a range of intraocular pressures (IOPs)
- ACD change in study group 0.03 to 0.07 mm over all eyes and IOPs
- ACD change in control group 0.26 to 0.87 mm over all eyes and IOPs
- Harmoni may allow for more predictable ELP (Fig. 11.2)

SYNCHRONY

- Foldable silicone dual IOL with accommodation via movement of lenses
- Base lens in capsular bag with negative power
- Front lens in capsular bag with positive power
- Not available; the Food and Drug Administration (FDA) trial suspended

Fig. 11.2 The Harmoni Modular IOL System, Liliana Werner, MD, PhD. Cover Focus, May 2018. Bryn Mawr Communications, LLC. Available at: https://crstodayeurope.com/articles/2018-may/the-harmoni-modular-iol-system/. Accessed August 24, 2020.)

The Synchrony was another dual optic foldable IOL that provided accommodation via movement of the anterior lens. The lens is no longer in development after safety issues encountered during its FDA trial. This design used a plus power anterior lens of 32 D and a minus power posterior lens, with the power selected to achieve emmetropia. Ray tracing analysis showed that this configuration produced a greater change in total lens power for a given amount of accommodation than a single optic lens. The anterior lens was 5.5 mm in diameter, the posterior lens was 6.0 mm in diameter, and the lenses were connected to each other via four spring haptics. Total lens thickness ranged from 4.0 mm outside the eye to 2.2 mm within the capsular bag.[7]

Preclinical Data

Ten rabbits with Synchrony in one eye and silicone plate haptic IOL in fellow eye, enucleated after 6 weeks:[8]

- 3 of 10 study eyes had dislocation of IOL into AC with diffuse corneal edema on POD1
- 3 of 10 study eyes developed posterior synechiae and iris bombe, requiring peripheral iridectomy
- Complications thought to be caused by large capsulorrhexis, increased posterior pressure, and smaller AC in rabbits
- Lenses remained rotationally stable with minimal PCO formation after 6 weeks

Clinical Data

Synchrony implanted in 24 eyes of 21 patients:[9]

- 19 of 24 eyes had UDVA of 20/40 or better and all had CDVA of 20/40 or better after 6 months.
- All eyes had distance corrected near visual acuity (VA) of J3 or better.
- 17 eyes required +1.00 D or less of add to achieve J1+.
- Defocus curves showed mean range of accommodation of 3.22 D for Synchrony and 1.65 for monofocal IOLs.

Bilateral Synchrony implantation in 36 eyes of 18 patients:[10]

- Mean CDVA 20/23 and best UDVA 20/44 after 6 months
- Mean UNVA 20/36, requiring mean add of +1.50
- Accommodative amplitude 2.25 D at POM1 and POM6 (Fig. 11.3)

OPIRA

- Foldable dual IOL with accommodation via movement of lenses
- Anterior lens in sulcus
- Posterior lens in sulcus and in capsular bag
- In development

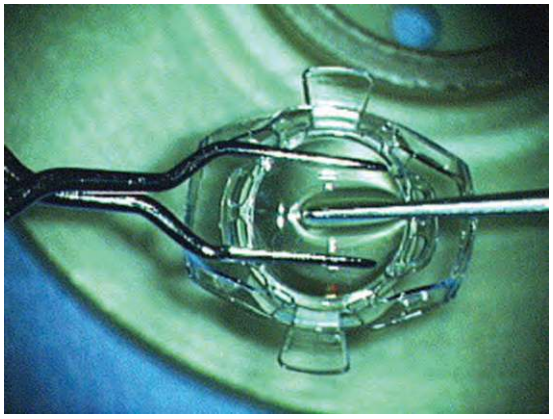

Fig. 11.3 Synchrony IOL. (From I. Ossma, A. Galvis, L. Vargas et al. (2006). Synchrony dual-optic accommodating intraocular lens: Part 2: Pilot clinical evaluation. *Journal of Cataract & Refractive Surgery*. 33(*1*) PP 47–52.)

ForSight Labs is developing the Opira accommodating IOL. This lens is a dynamic lens with a moving anterior lens and a fixed posterior lens, designed to sit in the sulcus with additional haptics fixating the posterior lens within the capsule. The posterior lens is available in a monofocal or toric version. Sulcus placement of this lens enables direct ciliary body engagement without the variability of zonular support, capsular bag size, and amount of elasticity and fibrosis of the capsular bag.

Clinical Data

Sixteen patients with Opira in one eye and monofocal IOL in contralateral eye:[11]

- CDVA of 20/20 in both groups
- Study group had distance corrected intermediate VA of 20/20 and distance corrected near VA of 20/25.
- Control group had distance corrected intermediate VA of 20/30 and distance corrected near VA of 20/60.
- Study group patients reported no halos, glare, haze, or distortions and reported starbursts at an equal rate to the control group (Fig. 11.4).

FLUIDVISION

- Single IOL with fluid-filled haptics
- Accommodation via shape change of optic
- In development

The FluidVision IOL (Alcon) was developed in the mid-2000's and is an accommodating IOL that relies on movement of fluid with accommodative effort to reshape the central optic to provide additional power. The lens is a hydrophobic acrylic lens that consists of large fluid-filled hollow haptics and a thinner central hollow optic with channels connecting the haptics and optic. The lens is filled with an index-matched silicone oil, which moves from the haptics to the optic as the ciliary body contracts and vice versa. The total diameter of the lens is 10 mm, and the optic diameter is 6 mm. The lens is designed to fill the capsular bag.[12]

Preclinical Data

Six rabbits with FluidVision in one eye and a monofocal IOL in contralateral eye, enucleated after 6 weeks:[13]

Fig. 11.4 The Opira IOL. (Available at: https://crstoday.com/articles/feb-2022/accommodating-iols-where-are-we-now-and-whats-on-the-horizon/.)

- Minimal anterior and posterior capsular opacification in study eyes, demonstrating benefits of leaving capsular bag open[14]
- Minimal Soemmering's ring formation and capsular opacification in study eyes

Clinical Data

FluidVision implanted in 28 eyes of 20 patients:[15]

- Mean CDVA better than 20/20 and mean accommodation over 2.50 D
- Mean binocular distance-corrected near VA was 20/25 in 8 patients who had bilateral implants

FluidVision 20/20 implanted in 27 eyes of 27 patients:[16]

- Mean CDVA better than 20/20, distance-corrected intermediate VA of 20/22, and distance corrected near VA of 20/28 after 6 months
- Mean accommodative amplitude was 2.0 D (maximum of 4.1 D)
- No dysphotopsias noted (Fig. 11.5)

GEMINI REFRACTIVE CAPSULE

- Single-piece scaffold in capsular bag
- Compatible with most currently available lenses
- In development

The Gemini Refractive Capsule (Omega Ophthalmics) is a single-piece implant similar to the base of the Harmoni, but with the unique capability of accepting most modern lens designs, making it part of a modular system. The implant is placed within the capsular bag, stenting it open, and is open centrally. By opening the capsular bag, the rate of PCO formation is reduced, and IOL exchange is facilitated as the Gemini maintains space and prevents adhesion of the lens to the capsular bag. Omega Ophthalmics is developing a hydrophobic acrylic optic that can be used with the Gemini alone or with a traditional IOL to refine refractive outcomes.[17]

Clinical Data

Gemini implanted in 8 patients:[18]

- CDVA was 20/25 at POM1, POM3, and POM6
- 4 of 8 patients had piggyback IOLs because of residual refractive error, successfully placed in Gemini, with mean UDVA of 20/27 (Fig. 11.6)

Fig. 11.5 The FluidVision Lens. (Available at: https://www.beye.com/product/fluidvision-accommodating-intraocular-lens. Accessed August 24, 2020.)

Fig. 11.6 The Omega Refractive Capsule. "Why Omega?" (Available at: https://www.omegaophthalmics.com/why-omega/. Accessed August 24, 2020.)

Fig. 11.7 The Juvene modular IOL. Note the central shape changing fluid lens (with yellow rim) and the peripheral (blue) base lens/haptic. Courtesy of LensGen, Inc.

ATIA VISION

- Dual IOL with accommodation via shape change of posterior lens
- In development

Atia Vision is developing a modular IOL that acts to correct presbyopia. It consists of a back and front lens similar to other designs. The back lens sits within the capsular bag, filling it and maintaining contact with the posterior surface of the bag. It changes shape with the contraction and relaxation of the ciliary body, thereby increasing and decreasing its power. The front lens is a fixed power optic that is selected to minimize residual refractive error. This design theoretically allows for natural accommodation of the IOL and selection of the appropriate power for each patient. The Atia Vision lens is currently undergoing in-human trials in Europe.[19]

JUVENE

- Dual IOL with accommodation via shape change of the fluid-filled anterior lens
- Designed to fill entire capsule
- In development

Another new modular IOL that provides presbyopia correction by allowing accommodation is the Juvene (LensGen, Irvine, CA, USA). The Juvene IOL consists of a base component with a fixed-power optic that fills the capsular bag, and a fluid-filled anterior lens that changes power with contraction and relaxation of the ciliary body. A unique advantage of the Juvene is that the lens fills the entire capsular bag, anterior to posterior. This allows more accurate prediction of effective lens position, increases rotational stability, prevents capsular opacification, and potentially reduces anterior vitreous movement, reducing the rate of posterior vitreous detachment and possibly retinal tears or detachments. The anterior fluid-filled lens sits within the base component and is held in place by three tabs. The power of the anterior lens can be selected based on preoperative biometry, and can be spherical or toric. The platform also allows for future developments such as implants that can be used to deliver intraocular medications and implantable sensors.

Clinical Data

Juvene implanted in 44 eyes ("GRAIL" exploratory study):[20,21]

- Mean rotation of 1.7 ± 0 .9 degrees at POM3 in 10 eyes
- 100% of patients achieve 20/25 at distance and intermediate
- 86% of patients achieve J2 at near distances
- Binocular defocus curves show mean uncorrected VA of 20/40 or better from −3.0 to +1.5 D
- All eyes correctable to 20/20 with appropriate refraction
- 14 patients implanted with Juvene experienced minimal dysphotopsia and have similar mesopic contrast sensitivity to a the Tecnis monofocal IOL measured with the M&S system with and without glare (Fig. 11.7)

SUMMARY

- Current IOLs have inherent compromises for treatment of presbyopia and for patients with unusual biometry or changing needs.
- Modular IOLs offer the possibility of improving upon many of the limitations of current IOLs with few potential drawbacks.
- Exciting options to be explored with modular IOLs are additional components for applications such as drug delivery and monitoring of IOP.

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PART III

Anesthesia and Initial Steps

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12

Anesthesia for Cataract Surgery

Alexander Knezevic and Sumit (Sam) Garg

CONTENTS

KEY POINTS

- A number of systemic, regional, and local options of anesthesia are available to the cataract surgeon.
- Review of Anatomy and Applied Anatomy

INTRODUCTION

Modern intraocular cataract surgery involves many technologies. The current standard of care procedure in developed countries includes, among many others:

- Phacoemulsification
- Foldable intraocular lenses
- Clear corneal incisions

These techniques have forced a reevaluation of the anesthetic needs for anterior segment surgery because there is less universal demand for akinetic anesthesia. Although retrobulbar and peribulbar blocks may be appropriate in some settings such as mature cataracts, solely topical corneo-conjunctival anesthesia is favored by most surgeons for routine cataract surgery.[1] When needed, systemic anesthesia is commonly used via oral or intravenous sedation with special circumstances necessitating general anesthesia. Each patient presents a new set of unique circumstances and factors for the surgeon to consider in preparation for cataract surgery (Table 12.1).

SYSTEMIC ANESTHESIA

Cataract surgery is performed mainly in elderly patients where coexisting diseases can present hazards for general anesthesia. Thus the procedure now is commonly performed under monitored anesthesia care (MAC). Mild sedation, defined as the level of sedation in which the patient is easily roused and able to respond to verbal stimulus, can be used. Medications preferred include propofol, midazolam, fentanyl, or some combination of the three.[1] Noninvasive blood pressure, electrocardiographic, and oxygen saturation monitoring should be routinely used before and during the induction of anesthesia and intraoperatively. Observation of and subsequent initial supervision by personnel with wide clinical experience and knowledge is recommended.

General Anesthesia

In settings where a patient is not cooperative for cataract surgery, general anesthesia (GA) may be appropriate. There are a host of predisposing factors like pediatric age, dementia, nystagmus, or underlying psychiatric conditions where general anesthesia may be appropriate. The surgeon, anesthetist, and patient must carefully weigh the risk and benefit profile before undergoing general anesthesia. There are initiatives to help the clinician make these complex decisions. For example, the American Board of Internal Medicine (ABIM) foundation launched the "Choosing Wisely" campaign in 2012 to help evaluate and avoid unnecessary medical procedures. Many anesthesia departments have implemented this initiative based on Global Deterioration Scale (GDS) in patients with dementia undergoing cataract surgery considering GA.[2]

Oral Sedation

Oral sedation in cataract surgery has been gaining popularity as a cost- and resource-saving measure. A transition to oral sedation opens the potential to move from the operating room to procedure room or office-based settings. There has been suggestion of similar rates of patient satisfaction, surgeon satisfaction, and surgical complications for oral compared with intravenous sedation (oral triazolam vs intravenous midazolam).[3] There are a number of available formulations including oral diazepam, oral lorazepam, and the MKO Melt (ImprimisRX Pharmaceuticals, Inc). The MKO melt is a combination of sedative (Midazolam 3 mg) and anesthetic (Ketamine HCL 25 mg, Ondansetron 2 mg).

REGIONAL ANESTHESIA (RETROBULBAR, PERIBULBAR, SUB-TENON'S)

Knowledge of the basic science disciplines (pharmacology of ocular and local anesthetic drugs, physiology of the eye, anatomy of the orbit and

TABLE 12.1 Techniques of Anesthesia for Cataract Surgery

General anesthesia
Retrobulbar
Peribulbar
Sub-Tenon's
Topical

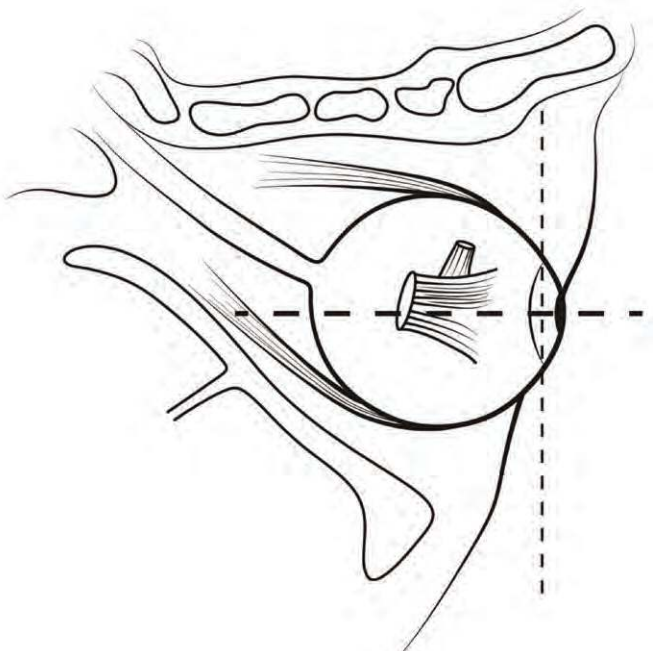

Fig. 12.1 Plane of the iris and midsagittal plane of the globe in primary gaze; view from above. The fine dashed line indicates the plane of the iris, and the coarse dashed line indicates the midsagittal plane of the eye. The visual axis through the center of the pupil. The optic nerve lies on the nasal side of the midsagittal plane of the eye. The temporal orbital rim is posterior to the rest of the orbital rim which makes for easy needle access to the retrobulbar compartment. (Courtesy: Dr. Alexander Knezevic and Sumit (Sam) Garg.)

its contents) is essential to safe practice of orbital regional anesthesia, including retrobulbar block. Retrobulbar refers to the conical compartment within the confines of the four rectus muscles and their intermuscular septa (Fig. 12.1). Compared with the peripheral orbit where fat is more dense, the retrobulbar cone contains fat that is arranged in large globules and a matrix of connective tissues, which supports and allows dynamic function of the orbit contents, controlling the spread of local anesthetic solutions.[4] Currently, the authors use retrobulbar anesthesia for complex anterior segment surgeries such as scleral fixated IOLs, iris surgery, and any anterior surgery requiring scleral manipulation including those that require a pars plana vitrectomy.

For conduction block of nerves and the resulting akinesia of their supplied muscles to occur, local anesthetics in blocking concentration have to reach and diffuse to the core of an exposed 5- to 10-mm segment of each of these motor nerves in the posterior retrobulbar space. Retained activity of the superior oblique muscle is often seen after retrobulbar local anesthetic injection because its motor nerve, the trochlear, runs outside the muscle cone. Total blockade of the smaller-diameter sensory and autonomic nerves, including the ciliary ganglion, on the other hand, is more easily achieved. Corneal and perilimbal conjunctival sensory innervation, along with the superior-nasal quadrant of the peripheral conjunctival sensation, are mediated through the nasociliary nerve, which lies within the retrobulbar space. The remainder of the peripheral conjunctival sensation, however, is supplied through the lacrimal, frontal, and infraorbital nerves coursing outside the muscle cone.[4]

The adjective peribulbar refers to the location external to the confines of the four rectus muscles and their intermuscular septa. In the technique known as peribulbar block, local anesthetic agents or mixtures are deposited within the orbit but do not enter within the geometric confines of the cone of rectus muscles. The intermuscular septum between the rectus muscles is incomplete and permits anesthetic deposited outside the cone of rectus muscles to spread centrally (Fig. 12.2).

An alternative anesthesia is injection beneath Tenon's capsule of small volumes of local anesthetic referred to as Sub-Tenon's block. Tenon's capsule is an anterior extension of dura. It fuses with conjunctiva near the surgical limbus. Therefore it can provide access to the retrobulbar space. In this procedure, a dissection is made through conjunctiva and Tenon's capsule down to bare sclera; the Greenbaum cannula (or other blunt cannula) is used; and, by making the incision small enough, the fluid can be forced to dissect posteriorly, and, usually, only a few milliliters of anesthesia are required. The anesthesia is of rapid onset, but the globe akinesia takes a few minutes to occur. The degree of abolition of extraocular muscle movement is proportional to the volume of injectate. After placement of local anesthetic by cannula beneath Tenon's capsule, spread occurs into the anterior retrobulbar space.[5]

RETROBULBAR BLOCK TECHNIQUE

The selection of anesthetic agent with additives depends mainly on the desired duration of effect. Concentrations up to but not exceeding 4% lidocaine (or agent of equivalent potency) are appropriate. Retrobulbar needles can vary in gauge, length, and sharp or blunt tip. The Atkinson-style needle has a short-bevel and blunt tip. The authors prefer an Atkinson tip, 25GA, 38-mm retrobulbar needle.

The inferior-temporal orbital quadrant is the preferred location for retrobulbar needle placement because it provides easy access to the retrobulbar cone compartment (Fig. 12.3). The axial length of the globe to be blocked is noted, as is the position of the globe in the orbit (enophthalmos versus exophthalmos), by observing the plane of the iris and the location of the globe equator relative to the temporal orbital rim. To avoid complications, needles must never be inserted deeply to the orbital apex.

The inferior-temporal rim of the orbit is palpated and the desired entry point chosen just inside the orbital rim at the 7:30 position for the right eye (see Fig. 12.3a) or the 4:30 position for the left eye. With the patient's eyes in primary gaze, the needle is advanced in a sagittal plane with a 10° upward inflection from the transverse plane, at first invaginating the skin while being directed safely between the globe and temporal orbit wall. It very soon penetrates the skin and can then be advanced to the depth of the globe equator before being redirected upward and inward toward an imaginary point behind the pupil, approaching but not passing the midsagittal plane (see Fig. 12.3a and b). The globe is continuously observed during needle placement to detect globe rotation that would indicate engagement of the sclera by the needle tip. In regional block techniques (both retrobulbar and peribulbar), all needles should be orientated tangentially to the globe with the bevel opening faced toward the globe. Having reached the desired final needle-tip location, and after checking by aspiration for

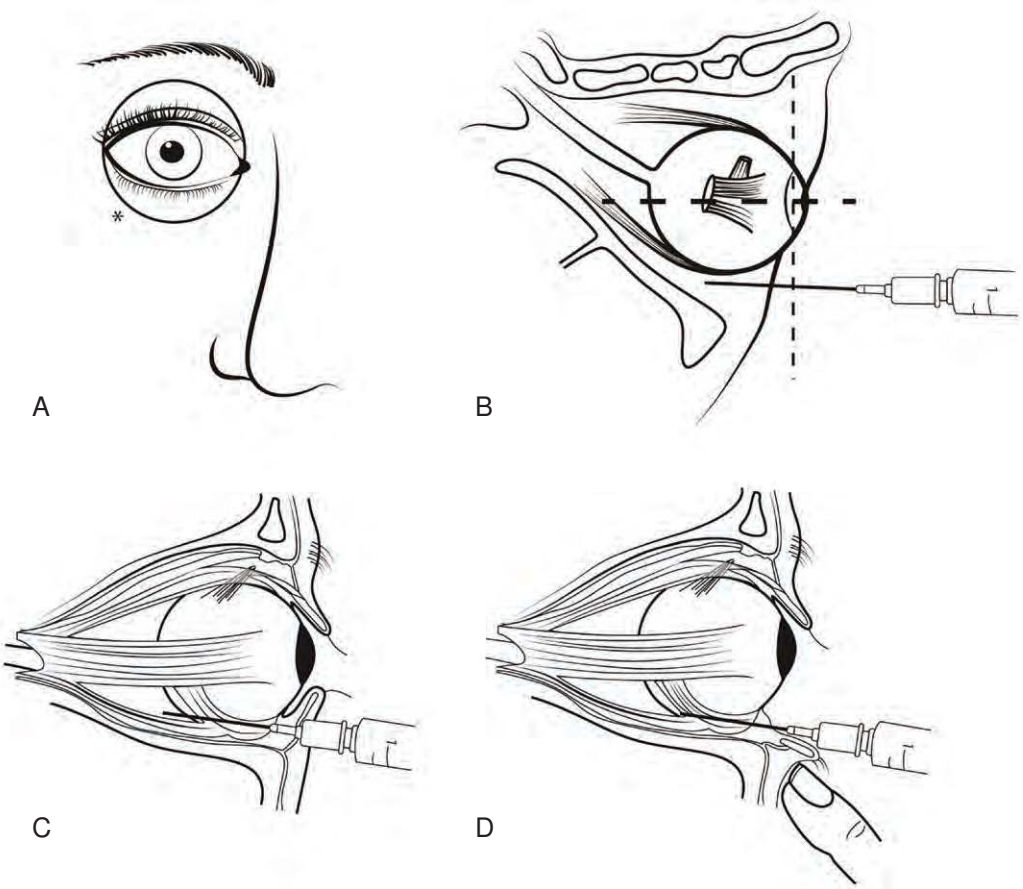

Fig. 12.2 Peribulbar block, inferior-temporal injection. A, Frontal view; B, view from above; C and D, lateral views. The inferior-temporal rim of the orbit is palpated and the desired entry point (*) is inside the orbital rim at approximately the 7:30 position for the right eye (A) or the corresponding (4:30) position for the left eye. With the patient's eyes in primary gaze, the 27-gauge 25 mm sharp disposable needle is advanced in a sagittal plane (B) with a slight upward inflection from the transverse plane (C and D), and passes the globe equator to a depth controlled by observing the needle-hub junction reach near the plane of the iris (B). Percutaneous needle entry is the preferred technique (C); however, the transconjunctival route can also be performed (D). (Courtesy: Dr. Alexander Knezevic and Sumit (Sam) Garg.)

inadvertent intravascular placement, a slow injection of the desired volume of anesthetic solution is made. Final depth of needle penetration of the orbit is gauged by observing the hub-shaft junction of the 38-mm needle in relation to the plane of the iris. In dealing with a globe of average axial length (23.5 mm), when the midpoint of the 38-mm needle is at the plane of the iris, the point of the needle will already have passed the globe equator. In like manner, ovoid globes in myopic patients (greater axial length measurement) will require a longer section of the advancing needle to guarantee passage beyond the globe equator before redirection into the retrobulbar compartment. The final desired needle-tip position lies between the lateral rectus muscle and the optic nerve, as depicted in the cadaver dissection.

COMPLICATIONS OF OPHTHALMIC REGIONAL BLOCK ANESTHESIA

There are a number of risks associated with pursuing regional block. An essential prerequisite in all locations where regional ocular anesthesia is performed is the provision of oxygen saturation monitoring in the room where the block is done and in the operating room, along with equipment to provide respiratory support and cardiopulmonary resuscitation.

In the execution of orbital blocks, it is possible for the needle tip to enter the optic nerve sheath and produce not only brainstem anesthesia, but also tamponade of the retinal vessels within the nerve and/or the small vessels supplying the nerve itself either by the volume of drug injected or by provoking intrasheath hemorrhage. It is also possible for the needle tip to enter the globe causing globe penetration (solely entrance wound), perforation (entrance and exit wounds), or ocular explosion. Because extraocular muscle malfunction can result from local anesthesia agent myotoxicity or needle trauma, it is important to choose a block technique in which the needle placement avoids needle contact with muscle. Another risk is retrobulbar hemorrhage which can vary in severity. Some are of venous origin and spread slowly. Signs of severe arterial hemorrhage are rapid and taut orbital swelling, marked proptosis with immobility of the globe, and massive blood staining of the lids and conjunctiva. Serious impairment of the vascular supply to the globe may result. By constant vigilance and keen observation of the signs immediately after needle withdrawal, bleeding may be minimized and confined by rapid application of digital pressure over a gauze pad placed on the closed lids. Signs for retrobulbar hemorrhage should monitored. These can include a rapid tightening of the periorbital tissues, elevation of intraocular pressure (IOP), and resistance to retropulsion. If retrobulbar hemorrhage is suspected, immediate action may be required. If severe and rapid, a lateral canthotomy and cantholysis may be required to release the globe from a compartment

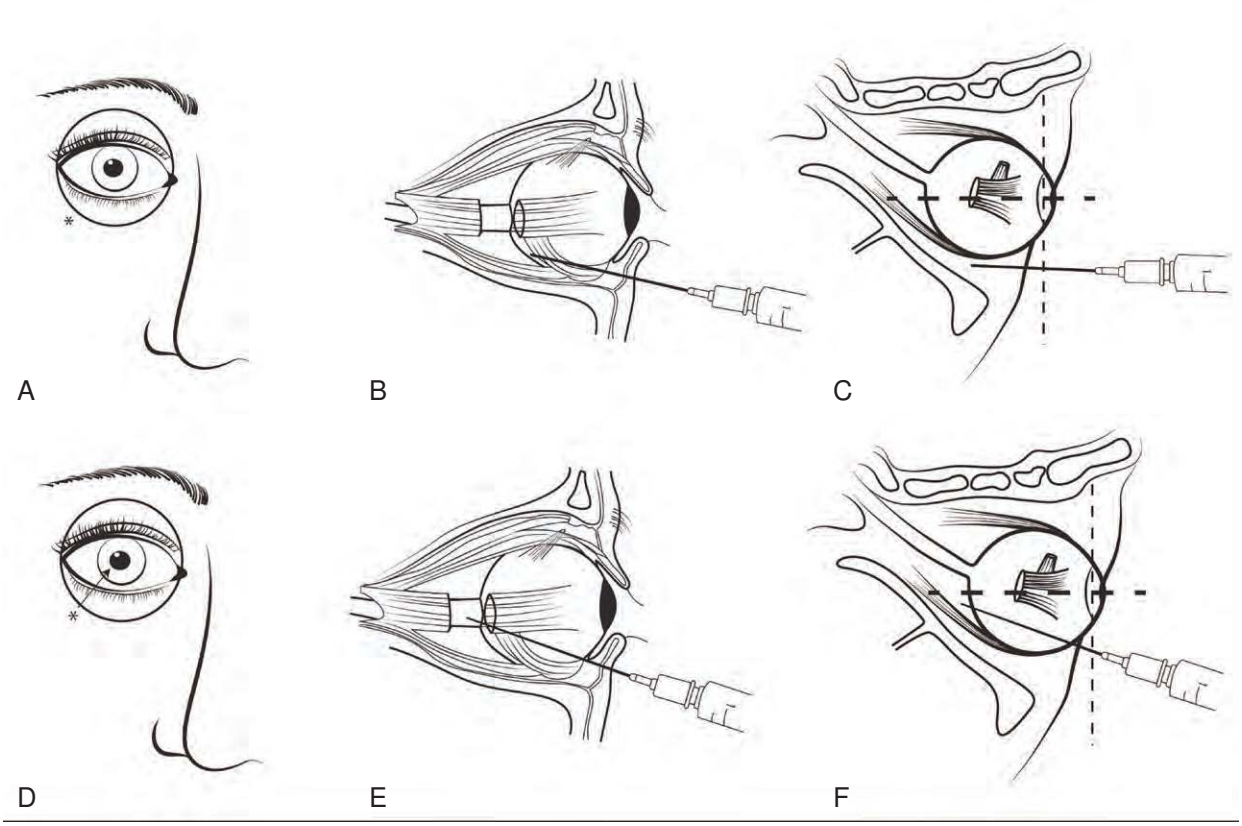

Fig. 12.3 Retrobulbar block, inferior-temporal approach. A and D, Frontal views; B and E, lateral views; C and F, views from above. The inferior-temporal rim of the orbit is palpated and the desired entry point (*) chosen just inside the orbital rim at approximately the 7:30 position for the right eye (A) or the corresponding (4:30) position for the left eye. With the patient's eyes in primary gaze, the 27-gauge 31 mm (11/4-inch) sharp disposable needle is advanced with bevel towards the globe in a sagittal plane (C) with slight upward inflection from the transverse plane (B), at first invaginating the skin while being directed safely between the globe and temporal orbit wall (C). It very soon penetrates the skin and can then be advanced to the depth of the globe equator (B and C). (If the needle were further advanced in the sagittal plane, contact with the lateral wall of the orbit would occur.) The needle is then redirected with medial and upward components (D and E) toward an imaginary point behind the pupil, approaching but not passing the midsagittal plane (F). The needle enters the retrobulbar space by passing through the intermuscular septum between the lateral and inferior rectus muscles (E). The globe is continuously observed during needle placement to detect globe rotation that would indicate engagement of the sclera by the needle tip. During needle placement, continuing observation of the relationship between the needle-hub junction and the plane of the iris establishes an appropriate depth of orbit insertion (E and F). In a globe with normal axial length as illustrated here, when the needle-hub junction has reached the plane of the iris, the tip of the needle lies 5–7 mm behind the posterior surface of the globe (E and F). Following test aspiration, up to 4 mL of anesthetic solution is slowly injected. Mild elevation of the globe is expected. (Courtesy: Dr. Alexander Knezevic and Sumit (Sam) Garg.)

syndrome as high IOP and asphyxiation of the optic nerve may lead to blindness. Other treatments including aqueous suppressants or hyperosmotic agent may be used as needed for milder cases. If serious hemorrhage, the surgical procedure should be cancelled.[4]

There is debate whether peribulbar approach provides a safer anesthesia for cataract surgery than retrobulbar block. A large review published in 2015 comparing clinical trials to date did not find convincing evidence of development of severe complications for either type of block.[4] Sub-Tenon's block was proposed as a safe alternative to ophthalmic blocks as it is performed with blunt cannula as opposed to sharp needle. Although minor adverse events have been noted, including subconjunctival hemorrhage and chemosis, severe sight-threatening events are rare with this type of regional block as well.[5]

The occurrence or avoidance of the complications mentioned previously is directly influenced by block technique. Elimination of known hazards (e.g., inappropriate globe position during block, inappropriate choice of needle path, inappropriate depth of needle placement) is the key to successfully avoiding complications.

TOPICAL ANESTHESIA

Topical anesthesia during cataract surgery may be administered in the form of an eye drop, gel, or intracameral injection. In routine small-incision cataract surgery, ocular anesthesia with topical anesthetics will usually suffice. However, depending on the surgeon's experience, there may be contraindications (relative and absolute) to the use of topical anesthesia (Table 12.2). There has been suggestion that 2% lidocaine gel may be more effective at relieving pain compared with 0.5% tetracaine during phacoemulsification cataract surgery.[6] Commonly, a combination of topical anesthetics can be used. Intracameral unpreserved 1% lidocaine is a safe and effective adjunct to topical anesthesia to lower intraoperative pain perception.[7]

Topical anesthesia has gained preference over previously preferred regional blocks because of low cost, low rates of complications, and ease of administration.[6] It can also be used safely in high-risk patients taking both anticoagulants and antiplatelet drugs.[8] When compared directly to regional anesthesia, topical anesthesia as expected tends to

TABLE 12.2 Relative Contraindications to Topical Anesthesia

Relative
Language barrier
Deafness
Uncooperative patients
High risk for complication
Extended time for surgery
Nystagmus
Allergy to the anesthetic
Planned large incision surgery, such as extracapsular cataract extraction

have higher rates of intraoperative and postoperative pain and more frequent ocular movement. Still, it remains significantly preferred by patients and achieves similar surgical outcomes.[9]

Currently, the authors use topical anesthesia preferentially for cataract surgery and secondary lens implants.

ADDITIONAL USES FOR INTRACAMERAL ANESTHESIA

Use of Intracameral Lidocaine for Pupil Dilation During Cataract Surgery

Cataract surgery pupillary dilation is important; a standard regimen generally includes tropicamide 1%, cyclopentolate 1%, and phenylephrine 2.5%. Usually three sets of drops are applied over a 15- to 20-min time frame (sets every 5 min). Dilation with this combination is good but may last many hours (patients are frequently still dilated on the day one visit). The multiple applications may also compromise the epithelial surface, allowing abrasions to recur, or reduce the clarity of the cornea, making surgery more difficult. Unpreserved lidocaine intracamerally can paralyze the sphincter muscle which leads to adequate pupil dilation. To improve the speed of dilation, 1:1000 unpreserved epinephrine is also an option (Table 12.3).

Other regimens for intracameral dilation have proven helpful in patients with intraoperative floppy iris syndrome. Dr. Joel Shugar has found his intracameral solution[10] to rapidly dilate and help prevent iris problems in patient with IFIS (especially patients on Flomax [tamsulosin]). This combination is known as *epi-Shugarcaine*. Combination phenylephrine 1% and ketorolac 0.3% intraocular solution (Omidria, Omeros Corporation) can be added to ophthalmic irrigating solution to prevent intraoperative miosis and decrease postoperative ocular pain.[11]

TECHNIQUES FOR TOPICAL ANESTHESIA

1. In outpatients, drops with 0.5% proparacaine or 0.5% tetracaine are initiated. Dilating drops and antibiotic are administered three times. Beginning with the third set and approximately 15 min before surgery, one more set of topical anesthetic drops are instilled.
2. Once in the operating theater, another drop of anesthetic can be administered and the surgical field is prepared with 5% povidone iodine solution and the eye is irrigated with the same solution (Fig. 12.4).
3. During draping, the patient's upper lid is held with a sterile 4 × 4 gauze bandage or cotton tip applicator, and the patient is asked to look down. This usually allows application of the drape without difficulty (Fig. 12.5). The patient can be told that there is an odd feeling during the process, especially when placing the lid speculum (Fig. 12.6). Most patients are quite comfortable once the speculum is in place. It is important that the lashes are covered with the drape to reduce the stimulus. The light source is very low and slowly raised as the patient becomes comfortable.

TABLE 12.3 Formula for Lidocaine/Epinephrine

Lidocaine 1% preservative free 30 mL
Epinephrine 1:1000 mL amps (1 cc)
Withdraw 0.3 mL Lidocaine 1% from vial, discard
Add back 0.3 mL Epinephrine to vial
Label: 24 h expires

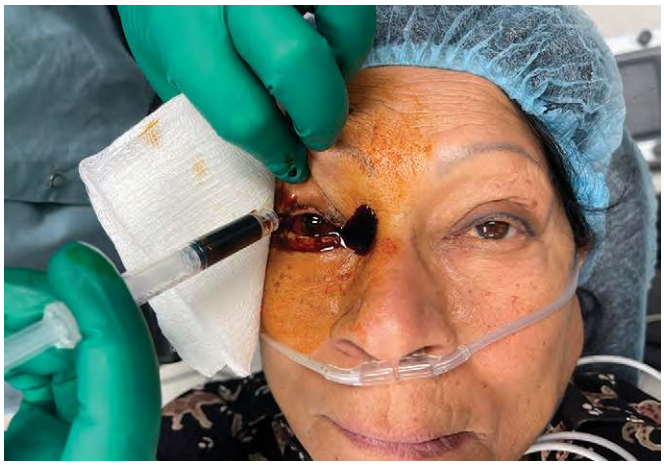

Fig. 12.4 Povidone iodine is placed in the cul-de-sac.

Fig. 12.5 Drape applied after sterile prep to isolate lids and lashes.

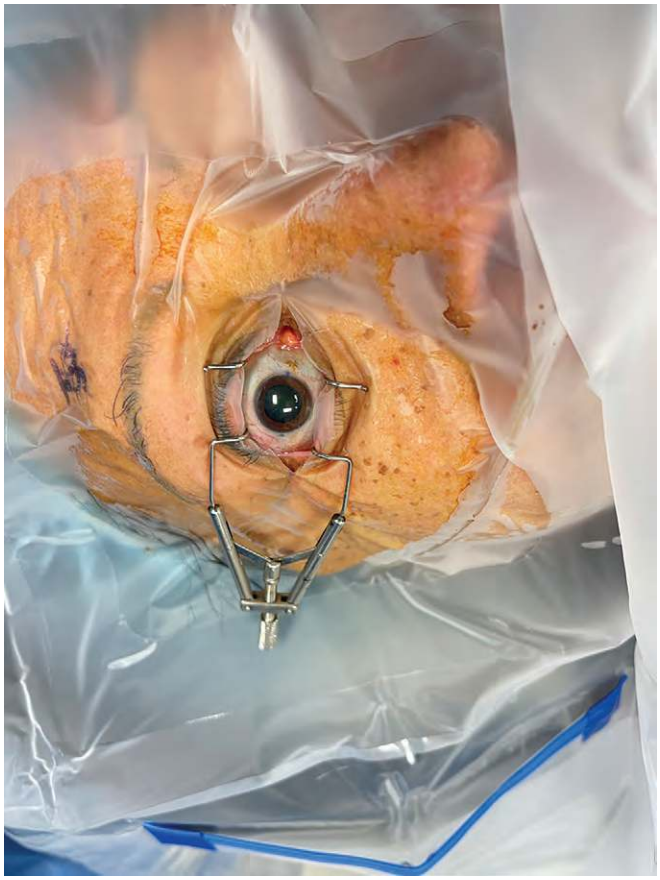

Fig. 12.6 Lid speculum placed after incision of drape, ensuring adequate coverage of lid margin and lashes.

4. A stab incision is made, and 0.3 mL of 1% unpreserved lidocaine is slowly injected. Patients can be warned that they may feel a slight sting, although most do not.
5. Sedative and anesthetic usually will be administered.

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13

Ophthalmic Viscosurgical Devices

Priyanka Chhadva and Marjan Farid

CONTENTS

KEY POINTS

- Ophthalmic viscosurgical devices (OVDs) have revolutionized ophthalmic surgery and are considered essential surgical tools.
- An OVD maintains space, protects surrounding tissue, and facilitates key steps of anterior segment surgery.
- A thorough understanding of specific properties of various types of OVDs will aid in task-specific use and facilitate surgery.

INTRODUCTION

Use of ophthalmic viscosurgical devices (OVD) has significantly impacted ophthalmic surgery (Table 13.1). Because of a unique set of properties based on structure, OVDs have become commonplace in anterior segment surgery. They aid in maintaining stability and intraocular space, provide clarity to aid surgery, and decrease the risk of damage to surrounding intraocular tissue.[1] OVDs act as both solids and liquids, and the clinical characteristics of OVDs vary based on their physical, chemical, and rheological properties.[2] A thorough understanding of these characteristics allows ophthalmic surgeons to choose an OVD that is beneficial to the task at hand.[1–4]

RHEOLOGICAL CHARACTERISTICS OF OVD

Viscoelasticity, viscosity, pseudoplasticity, and surface tension are the key rheological characteristics of OVD in ophthalmic surgery.

- **Viscoelasticity** refers to the ability of the OVD to return to its original shape after being stressed. The amount of elasticity increases with increasing molecular weight and chain length of molecules. When external forces that depress the cornea are released, or instruments are removed from the eye, elasticity allows the anterior chamber to reform. Higher elasticity OVDs work well at maintaining space.
- **Viscosity** reflects the ability of the OVD to resist flow. It is determined by concentration and molecular weight. The amount of viscosity increases with increasing molecular weight and concentration, although it varies inversely with temperature. A high-viscosity OVD is difficult to displace from the anterior chamber and effective at holding space in order to safely manipulating surrounding tissue.
- **Pseudoplasticity** refers to the ability of an OVD to transform from a gel-like material to a liquid when under pressure (shear rate). This is a function of molecular weight, concentration, and size of the flexible molecular coils of the material. At rest, a high-molecular-weight, high-viscosity OVD will maintain space, coat tissue, and provide lubrication. Under pressure, it will become more elastic and absorb stress.[5]
- **Surface tension** is the coating ability of OVD along with that of the contact material. It depends on contact angle as well. A lower contact angle (the angle formed by a drop of OVD on a flat surface) and lower surface tension have a better ability to coat;[6] however, this type of OVD is more difficult to remove from the eye. This is an important property for corneal endothelial protection.

CATEGORIES OF OVDs

To better understand the rheological properties and their clinical usefulness, OVDs are subcategorized into viscocohesive, viscodispersive, and viscoadaptive materials (Table 13.2).[7]

- **Viscocohesive** OVD high viscosity, has a high degree of pseudoplasticity, and high surface tension. This long-chain molecule material will adhere to itself and resist breaking apart. It creates space and stabilizes tissues while being easy to remove from the eye under turbulent (high shear) conditions.
- **Viscodispersive** OVD has lower viscosity, lower pseudoplasticity, and lower surface tension. This short-chain molecule material will adhere well to surfaces and break apart easily. It provides protection to surrounding tissues (i.e. corneal endothelium) but is more difficult to remove from the eye.
- **Viscoadaptive** OVD has high molecular weight and a high concentration of fragile long-chain molecules. It performs for the surgical task at hand, changing its behavior based on the environment. It is highly retentive and maintains the anterior chamber better than cohesives while coating the endothelium and being difficult to fully aspirate like dispersives. It has high viscosity at a low flow rate and a tendency to break down at higher flow rates,[8] acting as both a cohesive and a dispersive OVD, depending on the amount of turbulence present.

TABLE 13.1 Clinical Uses of OVDs

Cataract surgery
Corneal surgery/penetrating keratoplasty
Glaucoma surgery
Anterior segment reconstruction as a result of trauma
Anterior segment secondary surgery (e.g., secondary IOL placement, pupilloplasty, etc).
Posterior segment surgery

TABLE 13.2 OVD Characteristics

Viscocohesive	Viscodispersive	Viscoadaptive
High viscosity	Low viscosity	High viscosity
High pseudoplasticity	Low pseudoplasticity	High pseudoplasticity at high flow rate
High surface tension	Low surface tension	High surface tension at high flow rate
Creates space, stabilizes tissue	Protective of surrounding tissue	Maintains space, protects surrounding tissue
Easy to remove	Difficult to remove	Easy to remove at high flow rate

TABLE 13.3 Desired Properties of an Ideal OVD

Ease of infusion
Retention under positive pressure in the eye
Retention during phacoemulsification
Easy removal/no removal required
Does not interfere with instruments or IOL placement
Protects the endothelium
Nontoxic
Does not obstruct aqueous outflow
Clear

An ideal OVD has properties that make it safe and effective to use during ophthalmic surgery (Table 13.3). These characteristics include clear media, nontoxic material, ease of infusion and removal, protection of surrounding ophthalmic tissue, retention under pressure, and no obstruction of aqueous outflow.

VISCOELASTIC COMPOUNDS

Viscoelastic is made up of key compounds that contribute to its function as cohesive versus dispersive. These include sodium hyaluronate, chondroitin sulfate, and hydroxypropyl methylcellulose.

- **Sodium hyaluronate** is a biopolymer found in the aqueous and vitreous humors and in connective tissue throughout the body. It is made up of disaccharide units that form a long unbranched mucopolysaccharide chain. Increasing the concentration causes an increase in viscosity and thus an increase in elastic properties. The elastic properties are dependent on mechanical energy applied. The solution used in ophthalmic surgery (NIF-NaHa) has a low protein content (<0.5%) and a high molecular weight (2–5 million daltons). It is nontoxic, noninflammatory, nonantigenic, and sterile.[9,10] In animal models, the half-life is 2 to 7 days depending on the viscosity of the solution in aqueous humor.[11,12]

TABLE 13.4 Types of OVDs

Viscodispersive	Viscocohesive	Viscoadaptive
OcuCoat, Viscoat, Healon Endocoat, ClearVisc	Healon Pro, Healon GV, Amvisc Plus, Provisc, NuVisc	Healon 5, Healon GV Pro, DisCoVisc, Amvisc Plus

- **Chondroitin sulfate** is made of repeating disaccharide units and is one of the major mucopolysaccharides found in the cornea. It has a medium molecular weight of approximately 50,000 daltons. It is not metabolized in the anterior chamber but is eliminated in approximately 24 to 30 hours.
- **Hydroxypropyl methylcellulose** is a cellulose polymer composed of D-glucose molecules and does not naturally occur in animals. It is hydrophilic and can be irrigated from the eye. It is not metabolized intraocularly but is eliminated from the anterior chamber in 3 days as seen in animal models.[13,14]

CURRENT COMMERCIAL OVDs

Table 13.4 lists commercially available OVDs.

1. Johnson and Johnson OVDs
   - Healon® was the first commercially available sodium hyaluronate and was first used as a vitreous substitute. Initial composition (bovine hyaluronic acid preparation of low viscosity and concentration) was tolerated as a vitreous replacement but did induce a mild inflammatory response. Subsequently sodium hyaluronate derived primarily from rooster combs (high viscosity, high-molecular-weight) was formulated to be less inflammatory.[9–11] This formulation has been changed as below and is no longer available for use.
   - Healon Endocoat® is a dispersive OVD made of 3% sodium hyaluronate. It has a low molecular weight and is designed to stay in the anterior chamber to protect the corneal endothelium throughout phacoemulsification.
   - Healon® Pro is a cohesive OVD made of 1% sodium hyaluronate. It has high viscosity and can be used to maintain space and protect corneal endothelium. This OVD is used to maintain anterior chamber depth and aids in implantation of IOLs.
   - Healon GV® PRO is a high viscosity cohesive that has dispersive behavior during removal from the eye. This viscoelastic is able to help with capsulorrhexis creation, maintenance of anterior chamber space, stabilizing anterior and posterior pressure, and managing small pupils. It is very cohesive, which allows for easy removal from the eye while leaving the corneal endothelium susceptible to damage.[15] This OVD works well in other complex anterior segment surgeries such as secondary IOL placements and repositioning as it has both cohesive and dispersive properties.
   - Healon5® is a viscoadaptive OVD that is composed of 2.3% sodium hyaluronate. It behaves as a viscous cohesive during low flow rates and as a dispersive during high flow rates. This allows it to maintain anterior chamber space (highly retentive) while also protecting the endothelium.[16] It can be used in complex cases such as intumescent cataracts (Video 13.1).
2. Bausch and Lomb OVDs
   - Amvisc® is made from 1.2% sodium hyaluronate taken from rooster combs. Amvisc® Plus has cohesive and dispersive properties and is made of 1.6% sodium hyaluronate. It is slightly more viscous than Amvisc, which allows for greater maintenance of anterior chamber space and less traumatic tissue manipulation.[17]

- Ocucoat® is made of 2% hydroxypropyl methylcellulose and has significant coating ability and lacks elastic properties, making it visco-adherent. Because it is less elastic, it requires a larger bore cannula and increased infusion pressure for injection. It also does not require refrigeration.
- ClearVisc® is a new dispersive OVD (commercialized in 2021) made of 2.5% sodium hyaluronate and sorbitol. This functions to protect from free radicals that form during phacoemulsion, instrument manipulation, and implant insertion.

3. Alcon OVDs
   - Provisc® is made from 1% sodium hyaluronate dissolved in sodium chloride phosphate buffer and has a high molecular weight. It protects the corneal endothelium similar to Healon, and it also requires refrigeration. It has high molecular weight and maintains space well. It is produced by bacterial fermentation through genetic engineering techniques.
   - Viscoat® is made of 4% chondroitin sulfate and sodium hyaluronate in a 1:3 mixture. The sodium hyaluronate is made from bacterial fermentation while the chondroitin sulfate comes from shark fin cartilage. It has a high viscosity while maintaining coating abilities. It protects the corneal endothelium better (caused by added negative charges) than Healon at the iris plane but is similar at the posterior chamber plane.[18]
4. DisCoVisc® is made of chondroitin sulfate and sodium hyaluronate and has intermediate viscosity. It is a viscous dispersive, in that it has the higher viscosity of cohesives and lower viscosity of dispersives in one vehicle. Its retention and adherence to corneal endothelium is similar to dispersive;[19] however, it is easy to remove from the eye like a cohesive.[20]
5. NuVisc® is a highly cohesive OVD made from 1.2% sodium hyaluronate. It maintains anterior chamber depth while protecting ocular tissues. It has good chamber retention and is easily removed from the eye.

CLINICAL USES OF OPHTHALMIC VISCOSURGICAL DEVICES

Protection of Ocular Structures

Damage to the cornea during anterior segment surgery has been well documented through pachymetry and specular microscopy studies. OVDs help prevent mechanical and thermal injury to the corneal endothelium and also reduce oxidative stress in the anterior chamber from free radicals produced during phacoemulsion.[21]

In addition to protecting intraocular structures, OVDs can be used externally to protect the corneal and conjunctival epithelium without compromising visibility. They can also be used as a mechanical barrier to control hemorrhage and air from escaping from wounds. OVDs can mechanically expand the pupil (viscomydriasis) and be used to stabilize the iris to prevent prolapse out of corneal wounds.

Maintenance of Space

OVDs can be placed into the anterior chamber to maintain anterior chamber space during intraocular surgery. Maintaining physiologic pressure helps with wound creation, decreases the pressure differential between the anterior and posterior segment, and lessens postoperative cystoid macular edema by appropriate maintenance of intraocular pressure.

They can also be used to tamponade structures in the eye, such as the iris during intraocular floppy iris cases, or the vitreous during posterior capsular rupture. A heavy OVD with cohesive properties works well for holding the iris in place or maintaining anterior capsular integrity during rhexis creation (Video 13.2), while a dispersive OVD works well to hold back vitreous during a posterior capsular tear (Video 13.3).

Special Considerations

OVDs can also be used to better visualize structures in the eye and to open potential space. When performing minimally invasive glaucoma procedures such as iStent, cohesive OVD can help open the anterior chamber angle for better visualization of structures prior to stent implantation. Similarly, in canaloplasty, OVD is injected through a catheter threaded into Schlemm's canal to dilate this structure and promote outflow.

SURGICAL PEARLS

Viscodispersive OVD: coats intraocular structures well and compartmentalizes structures within the eye. Use this when the endothelium needs protection, such as with endothelial dystrophy, shallow anterior chamber, and dense cataracts. Dispersive OVD can also be used to create a barrier between the anterior and posterior segments in cases of vitreous prolapse.

Viscocohesive OVD: creates space and stabilizes tissues. Use this to deepen the anterior chamber, dilate the pupil and break synechiae, prevent the capsulorrhexis from radializing, and tamponade iris tissue from prolapsing from wounds.

COMPLICATIONS OF OPHTHALMIC VISCOSURGICAL DEVICES

OVDs have revolutionized anterior segment surgery; however, careful consideration must be given to possible complications associated with use.

Intraocular Pressure Elevation

If the OVD is not thoroughly removed at the end of surgery, severe intraocular pressure elevation can occur. This is caused by decreased outflow facility as the large molecules of OVD create mechanical resistance in the trabecular meshwork. The elevation in intraocular pressure is dose related and transient in nature. It typically occurs 6 to 14 hours after surgery and resolves within 72 hours postoperatively.[22] This pressure elevation is dependent on the viscosity and molecular weight of the OVD, so lower viscosity and lower molecular weight should clear the eye faster and have less impact on intraocular pressure.

In addition to thorough removal of the OVD at the conclusion of surgery (Video 13.4), use of medications to blunt intraocular pressure elevations has been proposed to reduce the incidence of IOP rise. Medications such as acetazolamide, intracameral miotics, and topical antihypertensives such as timolol, levobunolol, and pilocarpine have been shown to be effective in reducing postoperative intraocular pressure.[23,24]

Other

Other than affecting intraocular pressure, OVD's viscous and electrostatic charge can cause red blood cells to remain suspended in the anterior chamber after surgery. This can give the appearance of inflammatory cells and an anterior uveitis picture.[25]

If too much OVD is placed in the anterior chamber, it has the potential to clog the phaco probe which may precipitate wound burn (Video 13.5).

The composition of OVD can lead to certain complications. OVDs with chondroitin sulfate can cause calcific band keratopathy. OVDs produced by bacterial fermentation or made from rooster combs are susceptible to contamination from bacterial endotoxin which can be in the raw material or introduced in the manufacturing process.[26]

OVD has also been linked to toxic anterior segment syndrome.[27] Denatured OVD retained on surgical instrumentation can be denatured during the sterilization process and linked to TASS; however, single-use cannulas avoid this situation.[28]

Incomplete viscoelastic removal posterior to the intraocular lens can cause capsular bag distention syndrome.[28] This can lead to early postoperative anterior displacement of the lens, causing a myopic shift, shallowing of the anterior chamber, and elevated intraocular pressure. Capsular distention syndrome is easily treated by performing a Nd:YAG capsulotomy.

! POTENTIAL PITFALLS

Thorough removal of the OVD before the conclusion of surgery can avoid complications in the postoperative period such as elevated intraocular pressure, the appearance of anterior uveitis, and capsular bag distention syndrome.

SUMMARY

OVDs are used in anterior segment surgery for creating space, balancing anterior and posterior chamber pressure, facilitating manipulation of intraocular structures, and protecting surrounding tissues. They protect the corneal epithelium and endothelium, decreasing the amount of corneal damage that may occur during intraocular surgery. There are two categories of OVDs that aid in different steps of surgery; however, there is no single OVD that is ideal for all circumstances. Depending on the surgical task at hand, the surgeon needs to carefully consider which device is best: viscodispersive, viscocohesive, or viscoadaptive. These materials have become indispensable tools in ophthalmic surgery and a thorough understanding aids in correct and efficient use.

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Video 13.1: Intumescent cataract

Video 13.2: OVD use during cataract surgery on an IFIS patient

Video 13.3: OVD use in the setting of a PC tear

Video 13.4: Residual OVD removal from angle

Video 13.5: Corneal wound burn

14

Antibiotic Prophylaxis and Endophthalmitis

Elizabeth T. Viriya and Francis S. Mah

CONTENTS

KEY POINTS

- Risk for postoperative endophthalmitis [POE] depends on preoperative, intraoperative, and postoperative factors.
- Prospective, randomized controlled trials have demonstrated efficacy of intracameral antibiotic use for POE prophylaxis.
- Timely diagnosis and management of POE is vital to improve prognosis and visual outcomes.

INTRODUCTION

Cataract surgery is performed worldwide over 10 million times annually. However, the benefits can be negated by postoperative endophthalmitis (POE), among other less severe complications. POE is an ophthalmic emergency that can result in a final acuity of 20/200 or worse in approximately one-third of affected eyes.

The incidence of POE varies worldwide from 0.02% to 1.16%[1] with the American Academy of Ophthalmology's Intelligent Research in Sight Registry (IRIS) reporting 0.04% in the United States from 2013 to 2017. Identifying risk factors for and methods of reducing the rate of POE are critical to implementing prophylactic measures and increasing success of cataract surgery.

Risk Factors

POE involves preoperative, intraoperative, and postoperative risk factors, with the causative pathogen in about 82% of cases from the ocular surface flora.[2]

PREDISPOSING CONDITIONS FOR POSTOPERATIVE ENDOPHTHALMITIS

1. Posterior capsule rupture, anterior vitrectomy, or vitreous loss or incarceration within the incision: 3.65–5.1 times greater risk[3–6]
2. Combined surgeries such as incisional glaucoma procedures with cataract extraction or the presence of a filtering bleb[3]
3. Blepharitis, conjunctivitis, nasolacrimal duct obstruction, contact lens wear, or lid abnormalities[7–9]
4. Age <44 yrs or advanced age >85yrs[10, 11]
5. Intraocular lens contact with the ocular surface[12, 13]
6. Defects in corneal incisions, use of a previous corneal wound as a primary incision[14]
7. Diabetes mellitus, immunocompromised status, HIV[11, 15]

Ocular innate immunity, the inflammatory response, and aqueous turnover all serve as protective mechanisms. Interestingly, the incidence of endophthalmitis is about a thousand-fold lower than the reported rate of intraoperative microbial inoculation, at about 43%.[16–18] When progression to POE occurs, the factors include virulence of the organism, microbial burden, and incubation period.

Signs and Symptoms

POE is categorized and clinically distinct according to time of onset. Acute POE occurs within postoperative week 6, whereas chronic POE occurs afterward.

ACUTE POE

- More virulent organisms and their toxins cause acute POE.
- About 85% occur by postoperative week 2, with a peak incidence between postoperative days 3 to 7.
- Severe inflammatory reaction presents with periocular tenderness, photophobia, reduced vision, conjunctival hyperemia, lid swelling, hypopyon, and vitritis (Fig. 14.1). Retinal vasculitis may also be present with retinal periphlebitis and diffuse or midperipheral retinal hemorrhages.
- More severe infection and worse prognosis is associated with: afferent pupillary defect (APD), corneal infiltrate(s) or cataract wound incompetence, poor pupillary dilation, and/or absence of a red reflex.
- If corneal edema precludes intraocular examination, evaluation with ultrasonography can help detect vitritis.
- The endophthalmitis vitrectomy study concluded that visual acuity at presentation was the most important prognostic factor in predicting final visual outcome.[19]

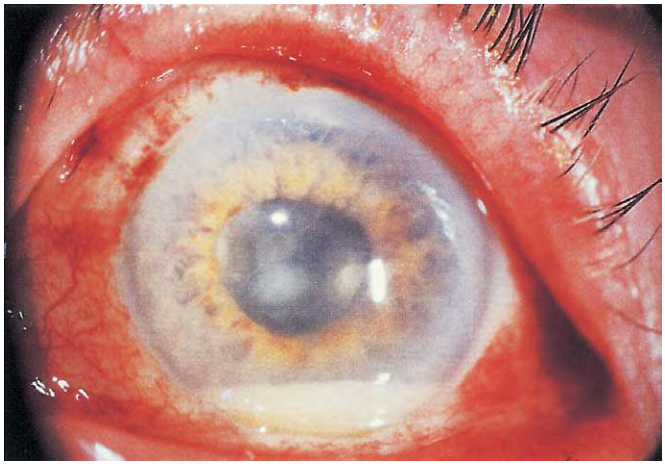

Fig. 14.1 Hypopyon in patient with postoperative endophthalmitis.

Fig. 14.2 Plaques within the capsular bag sequester pathogens in chronic postoperative endophthalmitis.

CHRONIC POE

- Less common.
- More indolent organisms, of which Propionibacterium acnes is the most likely.
- Clinical presentation seen in Fig. 14.2 includes a low-grade granulomatous anterior chamber reaction with white intracapsular plaques surrounded by cells and/or fibrin in both the anterior and posterior chamber.[20]
- Vision loss is also not as severe as in the acute form.
- Other pathogens that can cause the indolent chronic POE include *Corynebacterium*, *Mycobacterium*, *Candida*, and, less commonly, coagulase-negative *Staphylococcus* and gram-negative organisms.[21]

Differential Diagnosis

Marked inflammation after cataract surgery may be caused by other causes such as toxic anterior segment syndrome (TASS), retained lens material, rebound of preexisting or recurrent uveitis, and noncompliance with postoperative medications.

Microbiology

The most common pathogens in acute POE are gram-positive organisms, particularly coagulase-negative *Staphylococcus* such as *S. epidermidis*.[22–24] The most virulent and associated with the poorest visual outcome include *Streptococcus spp*. and gram-negative organisms. Gram-negative, particularly *Pseudomonas*, POE tends to occur more commonly in certain climates such as India and China.

Microbiological confirmation is generally advised. Gram staining and cultures can be performed on a 0.1 mL sample of aqueous and/or 0.2 to 0.3 mL of vitreous aspirate. If pars plana vitrectomy is clinically indicated, the vitreous biopsy can be submitted to microbiology for analysis.

Culture includes inoculating blood, chocolate, and Sabouraud agar. Chronic POE additionally requires an anaerobic culture, such as Thioglycolate broth. The sensitivity of cultures is low, at about 50% to 80%; therefore a negative result does not rule out infectious endophthalmitis.[25] Antibiotic sensitivities from cultures rarely change management because the empiric broad-spectrum antibiotic intravitreal injections have low reported microbial resistance from causative microbes.

In the ESCRS study, they found that polymerase chain reaction (PCR) can increase the yield of microbial confirmation by 20%.[26]

Outcomes

- Visual outcomes after POE vary widely from 20/20 to NLP.
- About half of patients, 44% to 53%, will retain visual acuity of 20/40 or better.
- Median final visual outcome was 20/100 in the IRIS report.
- 24% to 34% will suffer with a final acuity of 20/200 or worse.[27]
- A worse prognosis is associated with patients presenting with light perception vision, diabetes, more virulent organisms such as gram-negative and/or *Streptococcus*, and delayed treatment.[28–30]

ENDOPHTHALMITIS PREVENTION

Preoperative Considerations

Preexisting ocular surface conditions that are associated with a higher microbial burden or that impair reepithelialization of surgical incisions should be managed preoperatively. Examples include blepharitis, dry eye, exposure conjunctivitis, hordeola, and canaliculitis.

Surgical Preparation

- Surgical preparation of the ocular surface reduces the risk of POE.
- Microbial clearance of the periocular surgical area is achieved with the application of 5% povidone-iodine solution to the conjunctiva and the cul-de-sac for 2 to 5 minutes, and 5% to 10% povidone-iodine detergent to the periocular skin. This method has been shown to be effective in reducing the incidence of acute POE.[31, 32]
- Another effective method to prevent normal flora from entering the eye and therefore causing POE is isolation of the lids and lashes by meticulous draping.
- Perioperative topical antibiotic use, pre- or post-operatively, has yet to be proven statistically significantly effective at reducing the risk of POE in prospective clinical trials.

Intraoperative Measures

Regarding antibiotic prophylaxis for POE, there is currently no consensus on the preferred drug, dosing, timing, and modality of application. Topical eyedrop, subconjunctival injections, and use in the irrigating fluid intraoperatively have all been reported and each has gained some proponents; however, none of these modalities has ever demonstrated efficacy in a randomized, placebo-controlled, prospective clinical trial like intracameral antibiotic use by the European Society of Cataract and Refractive Surgery (ESCRS).

The ESCRS Endophthalmitis Study group compared intracameral antibiotic use to perioperative topical antibiotic use. The control group that encompassed those patients who received topical antibiotics, or no antibiotics preoperatively, had a POE rate consistent with the higher end of the worldwide incidence at 0.345%. In comparison, the incidence of POE with the use of 1 mg/0.1 mL of intracameral cefuroxime was 0.062% overall, which is associated with a statistically and clinically significant 4.92-fold reduction in the POE incidence.[33] In this landmark study, the addition of perioperative topical drops suggests a possible adjunctive benefit, but the difference was not statistically significant. Since then, numerous retrospectives studies have shown a reduction in POE rates with the adoption of intracameral cefuroxime.[34–42]

The risks for intracameral cefuroxime also warrant some attention. Dilutional errors have been associated with toxic anterior segment syndrome and, if severe, vision loss from corneal decompensation, glaucoma, and/or severe macular edema can occur.[43, 44] A catastrophic systemic complication which has been reported is anaphylaxis to the cephalosporin drug.[45, 46] Therefore a careful allergy history is advised prior to considering the use of this prophylactic agent.

Some reports have cautioned about the limited spectrum of coverage for cefuroxime, which might make it a less favorable antibiotic choice. Even though intracameral doses can exceed the minimal inhibitory concentrations (MICs) of many of the common intraocular inoculum, findings from the LV Prasad Institute and Swedish National Cataract Surgery Database demonstrated less efficacy against gram-negative isolates and methicillin resistant *S. aureus*.[47, 48] This lack in coverage is particularly important because visual loss from gram-negative endophthalmitis is devastating, and MRSA POE reports have been increasing.

Vancomycin is another agent that has been reported for intracameral use to prevent POE. However, it lost favor because of its association with hemorrhagic occlusive retinal vasculitis [HORV], a type III hypersensitivity reaction that more destructive than POE. About two-thirds of affected patients will suffer with a final visual acuity of 20/200 or worse, and about one-fifth of the patients will have no light perception.[49] Furthermore, more than half of the patients who are affected by HORV will rapidly progress to neovascular glaucoma. Therefore vancomycin should *not* be used as an intraocular prophylactic agent.

Compared with cefuroxime and vancomycin, moxifloxacin, a fourth-generation fluoroquinolone, has multiple proposed advantages. It has a broader spectrum of activity than both of the agents previously mentioned which includes *Pseudomonas* and community-acquired MRSA. Moxifloxacin is a concentration-dependent, rapidly bactericidal agent that is easily formulated as an injectable intracameral agent and is associated with low toxicity to intraocular structures compared with cefuroxime and vancomycin. An *in vitro* study by Libre et al. demonstrated that the most common gram-positive and gram-negative strains that cause POE were eradicated by high dose moxifloxacin compared with vancomycin or cefuroxime.[50]

Efficacy of intracameral moxifloxacin prophylaxis for POE was demonstrated in a prospective, placebo-controlled, randomized controlled trial that concluded a 7-fold reduction compared with no intracameral moxifloxacin from 0.38% to 0.05%.[51] Follow-up retrospective studies have demonstrated a 3- to 6-fold reduction in POE rates after switching from topical to intracameral moxifloxacin.[52–57] The concentration of safely instilled intracameral moxifloxacin reported in the peer-reviewed literature ranges from 50 to 500 ug/uL without any incidence of TASS.

The highest dose of intracameral moxifloxacin safely tolerated might want to be considered because the bactericidal effect is dose or concentration dependent.

- Delivering a dose that exceeds the minimal inhibitory concentration for resistant organisms improves microbial coverage.[58]
- Studies by Aravind used 500 µg/0.1 mL of moxifloxacin in 2 million cases.
  - The advantage of their method is ease of use because it is taken directly from a commercially available preparation (Auromax). However, loss from reflux or leakage from corneal incisions upon application can reduce the final amount of drug and, theoretically, bactericidal effect.
  - To improve reproducibility of the intraocular drug concentration, a dilution of 150 µg/0.1 mL moxifloxacin, where 0.4 to 0.6 mL is used to entirely replace the fluid within the anterior chamber and hydrate the paracentesis was proposed.[59, 60]
  - These drug concentrations have been studied *in vitro* and theoretically optimized after an evaluation of POE cases despite intracameral moxifloxacin use. However, there has been no proven reduction in POE between these two different methods of intracameral moxifloxacin delivery.

Biocompatibility, intraocular safety, and lack of toxicity has been demonstrated with the wide range of moxifloxacin drug concentrations. The prospective, placebo-controlled study by Melega et al. demonstrated no difference in acuity, endothelial cell count, central corneal thickness, and intraocular pressure with the use of intracameral moxifloxacin. When observations were extended to 3 years postexposure to intracameral moxifloxacin, Matsuura et al. confirmed the lack of adverse events reported by Melega and also added that no difference in foveal thickness occurred.[61]

Safe formulations of moxifloxacin for intracameral use include Vigamox and its Sandoz generic form (both from Novartis). On the other hand, Moxeza (Alcon), with additives such as xanthan gum, sorbitol, or tyloxapol has been reported to incite TASS. That branded topical formulation has been discontinued, but it highlighted the need to cautiously select appropriate brands.

Intracameral antibiotics have not been used without povidone-iodine in any of the landmark studies on POE prophylaxis. Even when using intracameral antibiotics in the United States, many are still reporting use with perioperative topical antibiotics. In fact, the 2014 American Society of Cataract and Refractive Surgery (ASCRS) survey reported 97% of participants still use postoperative antibiotic eyedrops.[62] Topical antibiotics are usually dosed 4 times a day for 5 to 7 days post operatively.

TREATING ENDOPHTHALMITIS

Practice patterns for the management of endophthalmitis are based on the evidence from the landmark Endophthalmitis Vitrectomy Study (EVS).

1. There is no additional benefit of systemic antibiotic use.
2. Immediate vitrectomy for presenting acuity of light perception had a 3-fold increase in achieving 20/40 final acuity, which is about 33% for that subgroup.
3. Immediate vitrectomy was just as effective as tap and inject in patients with vision of hand motion or better. Because of that landmark study, significant advances in vitrectomy and antibiotics have

developed. Thus far, the benefit of early vitrectomy is still equivocal, and it might warrant special consideration in high risk cases such as immunocompromised or monocular patients.

4. In the diabetic subgroup, there was inadequate power to determine a statistically significant benefit for immediate vitrectomy. However, it is still noteworthy to mention that visual outcomes were better for the immediate vitrectomy group versus the vitreous tap and injection of antibiotics group; 57% vs 40% achieved acuity of 20/40, respectively.
5. No recommendations for NLP vision as these patients were excluded from the EVS.

Generally, a retina specialist is involved in the management of POE and its complications. Management of POE requires microbial clearance as soon as possible, and a delay for culture results is not recommended. Gram-positive organisms are generally sensitive to vancomycin, which is administered as a single 1 mg/0.1 mL intravitreal dose. Gram-negative organisms, on the other hand, are sensitive to ceftazidime, which does not induce retinal toxicity, unlike amikacin and the other antibiotics used in the EVS for gram-negative bacteria. The dose for intravitreal ceftazidime is 2.25 mg/0.1 mL. Antibiotics are delivered in separate syringes to avoid precipitating the agents. Different antimicrobial agents are indicated based on the pathogen. Mycobacterium is treated with amikacin, for example, whereas, mycotic endophthalmitis is treated with amphotericin B.

Improvement tends to occur within 24 to 72 hours. If no improvement occurs, then a repeat injection can be considered. However, if vision worsens rapidly, particularly in diabetic or immunocompromised patients, consideration for vitrectomy is indicated.

Topical adjunctive medications are typically used to supplement antibiotic delivery to the anterior segment. Topical fortified vancomycin at 50 mg/mL and ceftazidime 50 mg/mL are typically each used hourly around the clock. Topical cycloplegic use aims to prevent synechiae formation and relieve some pain associated with ciliary spasm.

Corticosteroids to reduce inflammation and secondary toxic effects associated with POE are advocated by the EVS. Topical prednisolone 1% and systemic prednisone at 1 mg/kg are started 24 hours after initial antibiotic injection; these steroids are tapered over 6 weeks.[63] Although topical and systemic steroids are standard of care in the management of POE, intravitreal dexamethasone use is controversial. Furthermore, use of steroids are contraindicated for fungal endophthalmitis.

Complications of POE

Within 36 to 60 hours, POE may be further complicated by retinal detachment, macular infarctions, and expulsive hemorrhage. Retinal detachments were found in association with severe POE and more virulent organisms such as gram-negatives. This complication is independent of POE management with tap and injection or pars plana vitrectomy.

SUMMARY

POE is by all measures one of the most devastating complications of any ocular procedure.

- Throughout the history and evolution of anterior segment surgery, many measures have been attempted to reduce the risk of this devastating sight-threatening infection.
- Many of the strategies to reduce the multifactorial POE focus on antibiotics.
- In the last 2 decades, the optimal drug, timing, placement and concentration have started to become elucidated. Eye surgeons are on the cusp of further reducing POE rates optimizing antibiotics.
- Current recommendations to reduce POE include the use of the antiseptic povidone-iodine 5% in the conjunctiva; meticulous draping of the lids, lashes, and lacrimal system; and incisions that are water tight.
- The use of intracameral antibiotics are becoming more commonplace and should be considered at the conclusion of surgery.

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15

Inflammation in Cataract Surgery

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CONTENTS

KEY POINTS

- Management of ocular inflammation in the setting of cataract surgery is important for successful results.
- Preoperative risk factors should be addressed including ocular comorbidities such as uveitis and viral keratitis and systemic conditions such as diabetes.
- Although postoperative management of inflammation with topical antiinflammatory drops is common, there are preoperative and intraoperative treatment options as well that can be considered.

INTRODUCTION

The management of ocular inflammation before, during, and after cataract surgery is important for a successful result. All ocular surgery is expected to cause some degree of inflammation, but thoughtful planning can mitigate the adverse effects. Advancements in cataract surgery techniques have greatly decreased the risk for serious complications from inflammation.

In most routine cases, postoperative inflammation is mild and easily managed with topical medications. However, in special scenarios, prolonged or excessive inflammation can lead to a poor outcome despite a successful surgery. In moderate cases, excessive ocular inflammation after cataract surgery can lead to delayed recovery, patient discomfort, and prolonged need for medications. In severe cases, permanent vision loss can result from complications such as increased intraocular pressure (IOP), cystoid macular edema (CME), and corneal decompensation, for example.

Identifying patient risk factors is an important part of the preoperative evaluation. A study by Neatrour et al. found that 1.20% of patients without a history of ocular inflammation who underwent uncomplicated cataract surgery had postoperative iritis longer than 1 month after surgery. Risk factors included diabetes and African American race.[1] In this study, cataract density, gender, history of trauma and glaucoma were not found to be risk factors. If risk factors have been identified, additional therapeutic options for antiinflammatory management can be made either in at the pre-, peri-, and/or postoperative stage(s).

PATHOGENESIS

The pathogenesis of inflammation in the anterior chamber is believed to be caused by the breakdown of the blood-aqueous barrier (BAB). Key points to this process include the following:

- The BAB is primarily made up of tight-junction complexes between the epithelial cells of the nonpigmented epithelium in the ciliary body and the vascular endothelial cells of the blood vessels of the iris and Schlemm's canal.[2]
- They regulate the passage of ions, proteins, and circulating immune cells into the aqueous humor.
- The BAB creates an immune-privileged site in the anterior chamber by blocking the passage of cytotoxic T-leukocytes and natural killer cells.
- In vitro studies have gone so far as to suggest that the BAB can suppress T-cell proliferation and promote apoptosis of inflammatory cells through the expression of various immunoregulatory factors.[3]

Breakdown of the BAB can be triggered by infection, trauma, or surgery of the anterior chamber. Cell damage causes a release of prostaglandins and cytokines into the aqueous humor, which alters the permeability of the tight junctions.[4,5] Dysregulation of the immunomodulatory environment leads to a cascade of unchecked inflammation that causes damage

Fig. 15.1 Clinical image of a plaque posterior to the IOL in a patient who had chronic inflammation. Surgery was performed, and this patient was culture-positive for *P. acnes*. (Image courtesy Sumit Garg, MD.)

TABLE 15.1A The SUN Working Group Grading Scheme for Anterior Chamber Cells

Grade	Cells in a 1 mm × 1 mm Slit Beam Field
0	<1
0.5+	1–5
1+	6–15
2+	16–25
3+	26–50
4+	>50

Adapted from the SUN Working Group (Jabs)

TABLE 15.1B The SUN Working Group Grading Scheme for Anterior Chamber Flare

Grade	Description
0	None
1+	Faint
2+	Moderate (iris and lens details clear)
3+	Marked (iris and lens details hazy)
4+	Intense (fibrin or plastic aqueous)

of the ocular tissue. BAB disruption also leads to an increase of proteins and immune cells in the aqueous humor, which can be seen using a slit-lamp as cell or flare. The degree of cell and flare can be quantified using the Standardization of Uveitis Nomenclature (SUN) Working Group schemes[6] (Table 15.1). It can also be measured by fluorophotometry or laser flare-cell photometry,[7] although these techniques are less common in standard practice and are typically reserved for research purposes.

PREOPERATIVE CONSIDERATIONS

The treatment of inflammation during cataract surgery can be organized into three categories: preoperative, intraoperative, and postoperative management. Routine preoperative treatment with topical drops including nonsteroidal antiinflammatory drugs (NSAIDs) and steroids is often used, although this varies with frequency and length of treatment among ophthalmologist. However, there are certain populations that are more at risk for inflammation after surgery (Box 15.1), when preoperative antiinflammatory drugs should be strongly recommended (Table 15.2).

BOX 15.1 Risk Factors for Postcataract Surgery Inflammation

Systemic Disease.
Diabetes with retinopathy
Autoimmune diseases associated with uveitis
- Rheumatoid arthritis.
- HLA-B27 spondyloarthropathies.
- Behcet's disease.
- Sarcoidosis.
- Juvenile idiopathic arthritis.

Ocular Disease
Anterior uveitis.
Herpes uveitis.
Fuchs' heterochromic iridocyclitis.
Surgical Factors
Extracapsular cataract extraction/large incision.
Iris prolapse/iris trauma.
Vitreous prolapse/vitreous incarceration.
Posterior capsule rupture.
Retained lens fragment.
Dislocated IOL.
Iris sutured/anterior chamber IOL.

TABLE 15.2 Relative Potency of Ophthalmic Steroids

Medication	Common Brand Name	In Vivo Relative Antiinflammatory Activity	In Vitro Relative Potency
Difluprednate	Durezol	60	1800
Fluorometholone acetate	Flarex	40	350
Fluorometholone alcohol	FML Forte	40	350
Dexamethasone sodium phosphate	Maxidex, Decadron	25	400
Loteprednol etabonate	Lotemax, Alrex	25	550
Prednisolone acetate	Pred Forte	4	600

Sendrowski DP, Jaanus SD, Semes LP, et al, Anti-inflammatory drugs. In: Bartlett JD, Jaanus SD, eds. *Clinical Ocular Pharmacology*. 5th ed, Boston, MA: Butterworth-Heinemann, 2008:221–261.

PRE-EXISTING UVEITIS

Patients with uveitis have higher risk for surgical complications because of posterior synechiae, poor pupillary dilation, and zonular weakness. They also have higher risk for persistent postoperative inflammation, glaucoma,

CME, and posterior capsule opacification (PCO).[8,9] In patients with a history of uveitis, the following strategies should be used:

- A full inflammatory work-up should be done to look for underlying systemic disease, which may need to be treated before surgery.
- Control of inflammation through either topical or oral medication should be achieved before surgery. A period of quiescence should be realized before surgery; this may vary based on the pathology of the uveitis.
- In some cases, comanagement with a rheumatologist may be needed if the patient's uveitis is secondary to a systemic disease such as rheumatoid arthritis.
- Different etiologies may require specific medications. For example, HLA-B27 associated uveitis responds well to topical or oral steroids. However, Behcet's disease typically requires immunomodulatory tumor necrosis factor (TNF)-alpha inhibitors to achieve quiescence.
- Ideally, the patient should have at least 3 months of quiescence or less than 5 cells per high-power field. Active inflammation within 3 months of surgery is associated with a higher rate of macular edema in the postoperative period.[10]

Pretreatment with oral steroids has been used in patients with uveitis undergoing cataract surgery, although this has not been rigorously proven or standardized.

- Treatment ranges from 1 to 40 mg/kg/day (up to 60 mg/day) of oral prednisone for 7 to 14 days before surgery then tapered over 4 to 6 weeks after surgery, adjusted to the degree of inflammation.
- Contraindications to oral steroids need to be evaluated when considering the use of oral steroid prophylaxis.
- The risks need to be carefully weighed in patients with diabetes or uncontrolled cardiovascular disease.

HERPETIC DISEASE

Herpes viral uveitis is another important risk factor for cataract surgery. Recurrence of herpes simplex virus (HSV) or herpes-zoster virus (HZV) ocular infection has been reported to be as high as 25% to 40% after cataract surgery in patients with a history of disease.[11] The etiology of reactivation is not known. One study hypothesized reactivation of the dormant virus is triggered by trauma to the subepithelial nerve plexus during the corneal incision. Viral reactivation after cataract surgery can cause glaucoma, CME, corneal neovascularization, corneal scarring, and early PCO. In severe cases, herpes zoster ophthalmicus can cause neurotrophic keratitis after cataract surgery, which leads to persistent epithelial defect, corneal melting, and even perforation.[12]

The Herpetic Eye Disease (HED) study group made recommendations for antiviral prophylaxis to prevent recurrence of HSV.[13] Their recommendations for ocular HSV prophylaxis are as follows:

- acyclovir 400 mg twice a day
- valacyclovir 500 mg twice a day
- famciclovir 250 mg twice a day

Key common practices include the following in patients who have a history of HSV or varicella-zoster virus undergoing cataract surgery:

- Similar to other causes of uveitis, 3 months of disease quiescence is recommended after surgery.
- A survey of ophthalmologists revealed a common practice of starting antiviral prophylaxis 1 week before surgery and continuing for the duration of postoperative steroid use.[14]
- For HZV, the dosage of prophylactic treatment is less standardized. Some providers use the same dosage as recommended for HSV, while some will double the dosage.
- The ongoing Zoster Eye Disease study is comparing the use of 1000 mg valacyclovir once daily with placebo for 12 months for HZV prophylaxis. The results of this study will set important future guidelines for the management of HZV.

DIABETES

The cataract preoperative assessment should always include a thorough history of systemic and ocular risk factors. Diabetes is the most common risk factor for increased inflammation after cataract surgery.

- Elevated blood glucose levels cause damage to the capillaries in the iris, ciliary body, and retina.
- The microvascular changes make the small vessels more susceptible to injury from surgery.
- Additionally, patients with diabetes may have slower healing of the vessels after injury.

Many studies have shown that patients with diabetic retinopathy show increased flare after cataract surgery compared with patients without diabetes.[15]

- The degree of inflammation is correlated to the degree of retinopathy.
- Patients with proliferative diabetic retinopathy have more inflammation than those with nonproliferative diabetic retinopathy, and the inflammation lasted much longer.[16]
- The effect of diabetes without retinopathy on cataract surgery is unclear.
- Some studies have shown that diabetes without retinopathy had similar levels of postoperative flare compared with patients without diabetes.[17]

INTRAOPERATIVE STRATEGIES FOR CONTROL OF INFLAMMATION

Although postoperative drops are the standard treatment of inflammation after cataract surgery, several options are available for treatment of inflammation during surgery. These include various modes of drug delivery of inflammatory pharmacologic agents at the time of surgery (Table 15.3).

INTRAOCULAR INJECTION OF STEROID

An injection of steroid at the time of surgery can provide an immediate antiinflammatory effect. Modes of delivery include subconjunctival, sub-Tenon's, intracameral, and intravitreal injections.

- Subconjunctival injection of a short-acting steroid such as dexamethasone allows an immediate antiinflammatory effect that is transient lasting and with little side effects such as a steroid response. However, because its short duration and lack of taper effect, it is generally not adequate for postoperative inflammation on its own.
- Subconjunctival or sub-Tenon's injection of a longer acting steroid such as triamcinolone provides better drug penetration to the anterior and posterior chambers but has the risk for steroid response.[18] In addition, a sub-Tenon's injection can risk globe perforation.

TABLE 15.3 Intraoperative Options

Route	Drug	Approval
Intracameral		
	Omidria: NSAID	Pain and pupillary miosis
	Dexycu: Dexamethasone	Inflammation in ocular surgery
	Dexamethasone	Inflammation
	Triesence	Inflammation
Intracanilicular		
	Dextenza	Inflammation in ocular surgery

- Intracameral injection of steroids can also provide an immediate strong antiinflammatory effect. Common drugs include Decadron, triamcinolone, or Triesence (Alcon Laboratories, Inc., Fort Worth, TX, USA), a diluted form of Kenalog. The latter is especially useful for visualization of vitreous in the anterior chamber in the case of a posterior capsule rupture (PCR) and will help suppress inflammation. Intravitreal injection can also be performed at the end of cataract surgery, if indicated. Keep in mind that in an eye that is unicameral, an injection of steroid via the anterior chamber will often travel to the posterior chamber.
- Compounded injections of steroid are available either transzonular or intravitreal. These compounded medications are not Food and Drug Administration (FDA) approved. Although retrospective reviews have shown this agent to be a promising method to control intraocular inflammation after cataract surgery in a dropless or near-dropless form, there is concern for an increased risk for retinal tears, detachments, or zonular trauma with the transzonular method of delivery.[19]

INTRACAMERAL NSAID DELIVERY

Omidria (phenylephrine 1.0%–ketorolac 0.3%, Omeros, Seattle, WA, USA) is an example of intracameral drug delivery of ketorolac, an NSAID. The FDA approved the drug for pain and pupillary miosis during cataract surgery, and Omidria offers a combination of phenylephrine and ketorolac, which can be mixed with the irrigation fluid in the bottle or bag during phacoemulsification or used independent as an intracameral injection.[20]

- Its use as an effective pupillary dilation agent and in pain reduction has been published in detail.[21,22]
- More recent data has suggested that intracameral NSAID delivery decreases the rate of CME and postoperative inflammation after surgery.
- Visco et al. published a retrospective cohort showcasing intracameral phenylephrine/ketorolac reduced clinical CME and breakthrough iritis compared with pre- and posttreatment topical loteprednol. Both groups had pre- and posttreatmen with a topical NSAID.[23]
- Walter et al. published a retrospective series showing a reduced rate of CME in over 500 eyes compared with published data in patients who only received Omidria and postoperative NSAIDs without topical steroids.[24]

INTRACAMERAL INSERT

An alternate intracameral antiinflammatory is Dexycu, an anterior chamber intracameral dexamethasone drug delivery suspension (DEXYCU; Icon Bioscience Inc., Newark, CA, USA). It provides 21 days of sustained-release medication with a single application at the end of cataract surgery.

- Donnenfeld et al. showed clearing of the anterior chamber cell by post operative day 8 in 63.1% and 66% in the 342- and 517-µg treatment groups, respectively, of patients compared with placebo without NSAID drops given and no serious adverse events.[25]
- A second study compared Dexycu to topical prednisolone acetate 1% showing similar reduction in the anterior chamber cell by day 8 between the two groups. In addition, patients "strongly agreed" that they liked not having to use eye drops.[26]
- The intracameral drug delivery of Dexycu involves placing the suspension under the iris within the ciliary sulcus space, although in some cases the suspension can migrate to the anterior chamber and sit within the angle. Although this depot can migrate from behind the iris and into the anterior chamber, sometimes causing visually significant floaters or corneal edema, these are typically self-limited and resolve as the drop dissolves.

INTRACANALICULAR INSERT

Dextenza (Ocular Therapeutics) is another option for drug delivery is intracanalicular dexamethasone 0.4 mg (Dextenza, Ocular Therapeutics, Bedford, MA, USA) ophthalmic plug.

- Inserted in the operating room at the time of cataract surgery, the 0.4-mm dissolvable intracanalicular insert delivers a taper of dexamethasone over the course of a month.
- The plug is tagged with fluorescein for easy identification and monitoring at the slit lamp during postoperative visits.
- At day 14, more patients had absence of anterior chamber cell in the Dextenza arm compared with placebo (52.3% vs. 31.1%) with the rate of adverse events being similar. In this same study twice as many placebo patients required rescue therapy compared with treatment patients by day 14.[27]
- In the rare case of steroid-induced ocular hypertension, the punctal insert can be easily removed in clinic by massaging the plug out of the punctum.
- Side effects may include temporary epiphora, although this was not reported in the initial clinical trials.

FUTURE OF DRUG DELIVERY

Advances in drug delivery will likely see new methods in the future, with the goal to provide safe and efficacious control of inflammation at the time of cataract surgery. Surgeons will need to weigh the risks and benefits of these new strategies for each patient compared with preoperative and postoperative topical treatment alone. In addition, new drug delivery systems may have side effects and efficacy challenges requiring patients to supplement with rescue treatments. Despite these challenges, exciting options continue to be developed for inflammation control at the time of cataract surgery.

POSTOPERATIVE INFLAMMATION

Postoperative inflammation after uncomplicated cataract surgery usually causes only mild symptoms and typically resolves over 4 to 6 weeks with adequate treatment. Advancements in surgical techniques have dramatically decreased the degree of inflammation as a result of cataract surgery.

- A study comparing extracapsular cataract extraction (ECCE) to phacoemulsification showed that ECCE causes significantly more anterior chamber flare 60 days after surgery, particularly in the first week after surgery. The level of flare returned to normal after 60 days in the phacoemulsification eyes and after 90 days in the ECCE eyes.[28]
- Phacoemulsification through a smaller, clear corneal incision have also been shown to cause less postoperative inflammation than a sclerocorneal wound.[29]
- The natural history of inflammation after routine cataract surgery is typically up to 2+ cells on postoperative day 1 and decreases to 1+ cell by postoperative day 15.[30]
- Darker iris pigmentation and African American ethnicity may be associated with risk for prolonged inflammation after surgery.[31]

TREATMENT

The treatment for postoperative inflammation after routine cataract surgery is most commonly topical corticosteroids, NSAIDs, or a combination of both.

Corticosteroids inhibit the activity of phospholipase-A2 to decrease the release of arachidonic acid.

- For topical corticosteroids, difluprednate, prednisolone acetate 1%, betamethasone 0.1%, fluorometholone 0.1%, loteprednol 0.5%, and dexamethasone 0.1% are the most popular (Table 15.1).
- Most studies implement a dosage of 3 to 4 times a day, tapered weekly over 3 to 6 weeks.[32]
- Corticosteroids have many ocular side effects with prolonged use including elevated intraocular pressure, inhibition of wound healing, risk for recurrence of HED, and possibly increasing the risk for infection.

NSAIDs act by inhibiting the production of cyclooxygenase. In addition to being antiinflammatory, they also have an analgesic effect. There is still debate about the need for topical NSAIDs for all patients although it is often used.

- Ketorolac tromethamine 0.5%, diclofenac 0.1%, bromfenac 0.1%, and nepafenac 0.1% are the most commonly used NSAIDs.
- The side effects of ocular NSAIDs include delayed wound healing, corneal toxicity, and, rarely, corneal melting.[33]
- A Cochrane review evaluating the effectiveness of topical NSAIDs alone or with corticosteroids compared with topical corticosteroids alone found no differences in postsurgical inflammation or visual outcome, but NSAIDs did decrease the rate of CME compared with corticosteroids alone.[34,35]

Patient risk factors should be considered when choosing which medications to use postoperatively. A balance of efficacy and side effect profile should be taken into account.

- A corticosteroid with less IOP-raising effect may be more appropriate for patients with a history a glaucoma, whereas prednisolone or difluprednate should be considered for patients with a history of uveitis.
- The length of treatment with NSAIDs may be prolonged in patients with diabetic retinopathy who are at higher risk for CME, whereas an NSAID may be skipped altogether in patients with neurotrophic keratitis to avoid the risk for corneal toxicity.
- Although certain steroid drops have FDA approval for a certain dosage, this can be titrated per surgeon discretion. An example would be utilization of difluprednate twice a day instead of the standard four times a day.

ACUTE POSTOPERATIVE INFLAMMATION

Abnormal inflammation can present as inflammation that is either more severe than expected or lasts longer than expected. Acute postoperative inflammation is defined as pathologic inflammation that occurs within 6 weeks after surgery. There are four major etiologies for acute inflammation.

- Toxic anterior segment syndrome (TASS)
- Acute postsurgical endophthalmitis
- Retained lens fragment
- Reactivation of underlying uveitis

TASS is a rare sterile inflammatory reaction that occurs because of a reaction to toxins introduced into the eye through contaminated surgical equipment, intracameral medications, an optical variable device, or dyes such as trypan blue and indocyanine green.[36] The presentation of TASS is very similar to acute endophthalmitis. These two rare causes of severe inflammation are discussed in further detail in Chapter 14.

Retained lens and cortical fragments can be highly immunogenic. A granulomatous inflammation occurs via macrophage and leukocyte reaction to lens material. This reaction typically occurs at 2 weeks postoperatively, and the severity is correlated to the size of the fragment. If the lens fragment is not clearly visible, gonioscopy and ultrasound biomicroscopy (UBM) should be performed to look for fragments lodged in the angle or sulcus. For large fragments, surgical removal of the fragment is recommended.

CHRONIC POSTOPERATIVE INFLAMMATION

Chronic postoperative inflammation is defined as persistent or recurrent inflammation that occurs more than 6 weeks after surgery. Many of the same etiologies that cause acute inflammation should still be considered in chronic inflammation. A careful gonioscopy and UBM should be performed to look for retained lens fragments, which have been found to cause recurrent inflammation as long as 15 years after surgery.[37]

A misplaced or dislocated IOL is a common cause of chronic inflammation after cataract surgery. If this is in contact with uveal tissue such as the iris or ciliary body, the chafing causes pigment dispersion, which can cause significant intraocular inflammation and can lead to pigmentary glaucoma. Mechanical rubbing against vascular uveal tissue can also result in a microhyphema. This is called *uveitis-glaucoma-hyphema (UGH) syndrome*, although not all three signs need to be present. Key points to avoid UGH syndrome include the following:

- Any IOL can cause UGH syndrome. Incidents of in-the-bag UGH syndrome and 3-piece IOLs have been reported.[38,39]
- A more common cause, however, is a single-piece acrylic IOL causing UGH syndrome in the sulcus. A single-piece acrylic IOL should never be placed in the sulcus because the thick haptics can touch the back surface of the iris or the ciliary body.[40]
- It is important to carefully evaluate the location of the haptics at the postoperative dilated examination to confirm that they are secure in the capsular bag.

Haptics can be misplaced at the time of insertion (usually it is the trailing haptic that was not placed properly), or they may slip out of the bag postoperatively if the capsulorrhexis was too large or decentered or if there was an anterior capsular rent.

Key findings of a malpositioned IOL include the following:

- Pigment dispersion
- Transillumination defects
- Rebound inflammation
- Recurrent hyphemas

Three-piece IOLS are less likely to cause inflammation because of their thinner haptics. However, they can still cause UGH syndrome if they become displaced by a Soemmering ring or vitreous strands or if they are captured by the iris. UBM is very useful in determining IOL malposition if direct visualization is not possible. The offending IOL should be repositioned or removed. A dislocated haptic can be cut and extracted if the optic is well positioned and stable.

Indolent infectious endophthalmitis is another important cause of chronic inflammation after cataract surgery. Key findings include the following:

- The onset of symptoms is, on average, 4 to 5 months after surgery but has been reported up to several years out.
- The inflammation is granulomatous and typically mild and recurrent.
- Not all patients will have pain, but vision decrease is ubiquitous.
- The inflammation may progress to the posterior segment, causing a vitritis in some.
- A hypopyon is only present in a third of cases.[41]

Identifying the causative organism can be challenging. Obtaining a culture from an anterior chamber or vitreous sample should be done when there is any suspicion of chronic endophthalmitis. If the culture is negative but clinical suspicion is high, PCR or a vitreous biopsy can be done. Key pathogens include the following:

- *Propionibacterium acnes* is the most common cause and accounts for up to 48% of cases of chronic infectious endophthalmitis.[42] A white plaque behind the IOL is highly suspicious of *P. acnes* (Fig. 15.1).
- *Staphylococcus, Nocardia*, and *Corynebacterium* species have also been implicated.
- Fungal endophthalmitis accounts for up to 21% of cases of chronic infectious endophthalmitis, with *Candida, Aspergillus*, and *Curvularia* being the most common.

Treatment of chronic endophthalmitis is with intraocular injections of antibiotics or antifungal medications, with or without vitrectomy, IOL, and capsular bag removal. A culture result can help direct treatment, but usually the organism is unknown at the time of the first injection. A broad-spectrum antibiotic such as Vancomycin will cover the most common bacteria, including *P. acnes* and methicillin-resistant *Staphylococcus aureus*. The injection can be done intracamerally or intravitreally, depending on where the most intense inflammatory reaction is contained. Many studies found that recurrence rates are high with only intraocular antibiotic injections, particularly for *P. acnes* infections. Thus surgical intervention is recommended in cases of culture-positive *P. acnes*.

New onset of uveitis is a less common cause of chronic postoperative inflammation. If all other causes have been ruled out, a uveitis work up should be done.

PSEUDOPHAKIC CYSTOID MACULAR EDEMA

Pseudophakic cystoid macular edema (PCME), also known as *Irvine-Gass syndrome*, is a pattern of macular edema that develops after cataract surgery. The exact mechanism is not known, but historically it was noted that PCME was associated with posterior vitreous cell, suggesting that inflammation plays a role.

- Inflammatory mediators such as prostaglandins that are released into the anterior chamber during surgery can leak into the posterior chamber around the zonules.
- This leads to an increase in vascular permeability of retinal capillaries and causes leakage of fluid, which accumulates in cystic spaces in the macula.
- Vitreous traction caused by the fluid turbulence during cataract surgery may also contribute to the mechanisms of PCME. Observations that vitreous prolapse during cataract surgery increases the risk for PCME supports this theory.
- Angiographic studies show late leakage in a petaloid pattern, and OCT shows intraretinal fluid and macular thickening.

PCME most commonly causes decreased vision. Key findings include the following:

- Decreased contrast sensitivity. Photophobia and metamorphopsia have also been reported.
- In mild cases, patients may be asymptomatic or may not report any concerns because they are in the postoperative period.
- Patients who report a worsening of vision after initial improvement should have a high suspicion for PCME.
- Many practitioners who obtain a macular optical coherence tomography (OCT) at the 1-month follow up if the patient has worse vision than expected on visual acuity testing to confirm the diagnosis as direct visualization may miss the subtle clinical findings.

The incidence of clinically diagnosed PCME after phacoemulsification ranges from 0.1% to 3.8%, but OCT studies have reported that the incidence ranges from 4% to 41%.[43,44] The peak incidence is at 5 weeks postoperatively, and resolution can take weeks to months. Risk factors for PCME include the following:

- PCR
- Vitreous loss
- Retained lens fragments
- Malposition IOLs, iris fixated lenses, or anterior chamber lenses
- Iris trauma
- History of uveitis, epiretinal membrane, and central retinal vein occlusions
- Preoperative CME; patients who have a history of CME should have the underlying etiology optimized before cataract surgery
- History of diabetes or diabetic retinopathy

One key topic that has been debated is routinely using NSAIDs to prevent postoperative CME. The first-line treatment for prevention of PCME are NSAIDs and corticosteroids used independently or in combination. Prophylactic treatment with topical medications after routine surgery likely reduces the rate of PCME, but it does not improve the visual outcome beyond 3 months according to the study by Juthani et al.[45] Despite the lack of strong evidence, prophylactic treatment is widely used. There is no standardized course of treatment, which makes comparing studies especially difficult. NSAIDs may be slightly more effective than corticosteroids at the prevention of PCME.[24] A randomized controlled trial by the European Society of Cataract and Refractive Surgeons found that the use of bromfenac 0.07% alone or a combination of topical dexamethasone 0.1% and bromfenac was more efficacious for preventing PCME than dexamethasone alone.[46] Some studies have shown that pretreatment with an NSAID 3 days before surgery additionally decreases the risk for PCME.[47]

The natural course of PCME is not well studied. Cases of mild, acute PCME may resolve spontaneously, although treatment will hasten the resolution. Chronic PCME can lead to permanent vision limitation and is a cause of suboptimal vision after cataract surgery. PCME that is refractory to topical medications can be treated with sub-Tenon's, retrobulbar, or intravitreal injection of corticosteroid. The use of peri- and intraocular corticosteroids is mostly studied in diabetic macular edema, and their use has been applied to PCME in several case series with good results.[48] The risks associated with injection of corticosteroids including infection and elevated IOP must be considered. In diabetics, the addition of subconjunctival triamcinolone injection reduced the rates of PCME compared with topical medications alone. Intravitreal injection of antivascular endothelial growth factor agents has shown variable results in case series and remains controversial. Intravitreal bevacizumab had no significant effect.[49]

Key tips for prevention and management of CME include the following:

- Pretreat preexisting macular edema.
- Consider pretreatment with topical agents or other modes of antiinflammatory administration in high-risk patients.
- OCT macula before and after cataract surgery has been debated but should be obtained in any patient who complains of blurry vision after cataract surgery.
- Provide a trial of treatment with topical steroid and NSAIDs for 1 month then referral or treatment with intravitreal injection if the edema does not improve.

SUMMARY

Control of inflammation in cataract surgery is important to successful outcomes.

- Careful screening for higher risk individuals is vital.
- Decisions regarding pretreatment or intraoperative treatment can be made on a case-by-case basis.

- In the setting of postoperative inflammation not controlled by standard drop regimen, consideration of alternates more of antiinflammatory treatment may be needed.
- The best treatment for postoperative inflammation is prevention with careful screening, intraoperative techniques, avoiding complications, and postoperative drop regimen compliance.

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16

Incision Construction

Kirsten Wagner and Keith Walter

CONTENTS

KEY POINTS

- The main wound of entry for phacoemulsification cataract surgery has evolved over time.
- Clear corneal wounds have dramatically reduced surgical time, scleral tunnel-related complications, and postoperative recovery time.
- Through modifications of properties such as width, length, angle, manual versus femtosecond laser-assisted, potential complications of clear corneal incisions such as risk for endophthalmitis, wound leak, postoperative astigmatism, and wound burn are less common.
- Scleral tunnel incisions may still be appropriate in cases such as corneas with previous multiple radial keratotomy (RK) incisions.

INDICATIONS FOR CLEAR CORNEAL INCISIONS

Scleral incisions for phacoemulsification were traditionally placed in a superior location, and the sizes ranged from 3 to 7 mm. Scleral tunnel wounds evolved to become smaller and sutureless over time with the invention of foldable intraocular lenses, but they still required a peritomy. Complications related to length and depth of these tunnels can result in a filtration bleb, hyphema, Descemet's membrane detachment, and induced astigmatism.[1]

Initially, the utilization of clear corneal incisions was limited to those patients with preexisting filtering blebs, patients taking anticoagulants, or patients with cicatrizing disease such as ocular cicatricial pemphigoid or Stevens–Johnson syndrome. Subsequently, because of the natural fit of clear corneal cataract incisions with topical anesthesia, the indications for clear corneal cataract surgery expanded. Corneal entry avoids manipulation of conjunctiva, suture-induced astigmatism for most wounds that self-seal, and the need for cautery. There is less discomfort and bleeding and faster visual rehabilitation.[1] With the ability to avoid any injections into the orbit and use of intravenous medications, patients with cardiovascular, pulmonary, and other systemic diseases that might have been previously contraindicated for cataract surgery now become surgical candidates.

> Clear corneal incisions evolved from scleral tunnel incisions with advantages of no peritomy, less discomfort, and faster visual rehabilitation.

CLEAR CORNEAL SURGICAL TECHNIQUE

Single-plane incisions, as first described by Fine,[2] used a 3- mm diamond knife.

- A Fine-Thornton 13- mm fixation ring (Mastel Instruments, Rapid City, SD) (Fig. 16.1) stabilizes the globe and allows manipulation without creating conjunctival tears, subconjunctival hemorrhages, or corneal abrasions (Fig. 16.2).
- Aqueous humor is replaced by viscoelastic material through the side-port incision (Fig. 16.3).
- After pressurization of the eye with viscoelastic, a 300-micron groove may be placed at the anterior edge of the vascular arcade (Fig. 16.4); however, this is optional.
- If the groove has been placed, an incision is made by depressing the posterior edge of the groove with the diamond blade, flattening the blade against the surface of the eye.
- The knife is moved in the plane of the cornea until the shoulders—which are 2 mm posterior to the point of the knife—touch the external edge of the incision, and then a dimple-down technique is used to initiate the cut through Descemet's membrane.
- After the tip enters the anterior chamber, the initial plane of the knife is reestablished to cut through Descemet's in a straight-line configuration (Fig. 16.5).
- After phacoemulsification, lens implantation, and removal of residual viscoelastic, stromal hydration of the clear corneal incision can be performed in order to help seal the incision.[3] This is performed by placing the tip of a 26- or 27-gauge cannula in the side walls of the incision and gently irrigating balanced salt solution into the stroma (Fig. 16.6). This is performed at both edges of the incision in order to help appose the roof and floor of the incision. Once apposition takes place, the hydrostatic forces of the endothelial pump will help seal the incision.
- In those rare instances of questionable wound integrity, a single radial 10-0 nylon suture can be placed to ensure a tight seal. This can be removed at the slit lamp between postoperative week 1 to 2 in most cases.

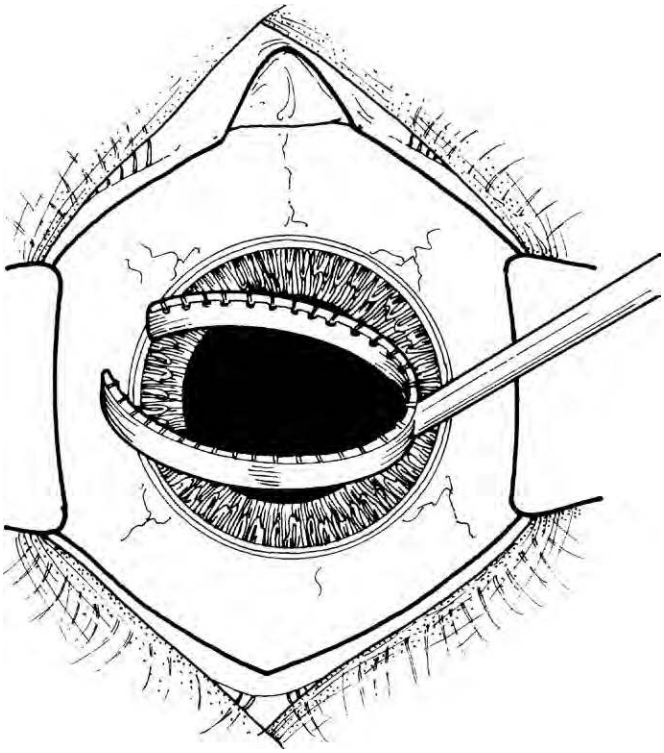

Fig. 16.1 The Fine-Thornton ring, shown in partial profile. Temporal limbus is seen inferiorly.

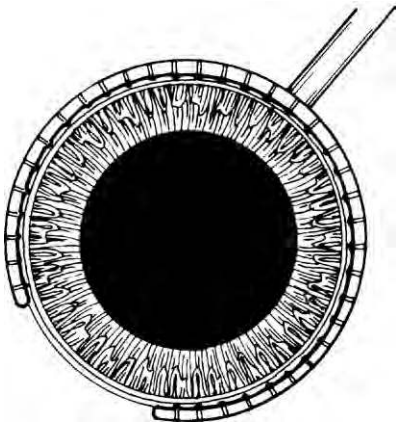

Fig. 16.2 Purchase of the globe by the Fine-Thornton ring.

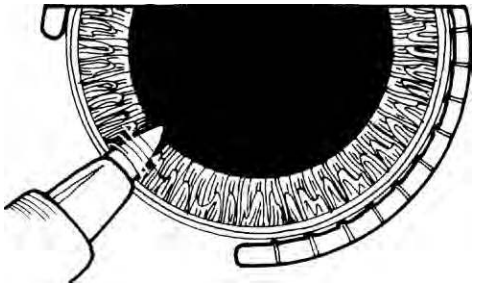

Fig. 16.3 Paracentesis being made.

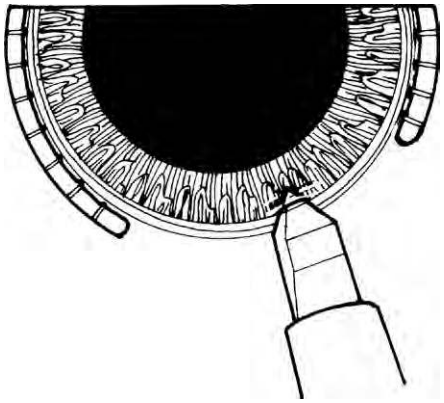

Fig. 16.4 Grooving of the peripheral cornea.

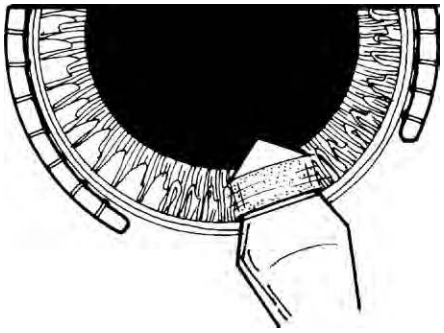

Fig. 16.5 Construction of the corneal tunnel.

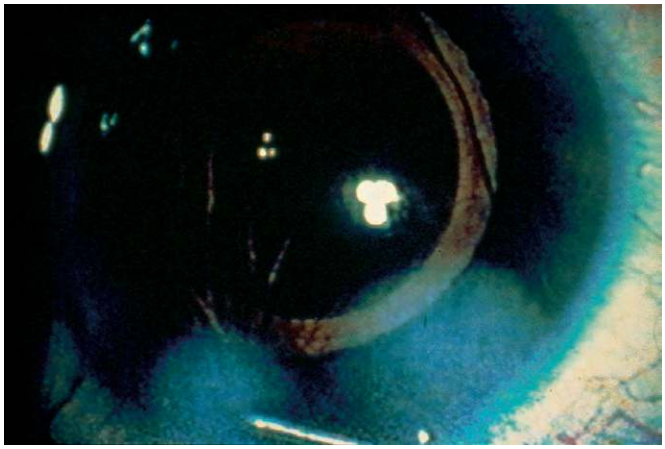

Fig. 16.6 Stromal hydration of the incision.

PROFILES OF CLEAR CORNEAL INCISIONS

Clear corneal incisions involving an incision in the plane of the cornea with a length equal to 2 mm are still being constructed in the same manner today. In 1992 the incisions were as wide as 4 mm but have more recently been reduced to a maximum width of 3.5 mm, if not sutured. Fig. 16.7 shows an artist's view of what the profile of clear corneal incisions were thought to look like. Part A shows the single plane incision and its apparent inherent lack of stability, as one surface can easily slide over another. Charles Williamson, MD, from Baton Rouge, innovated an alteration of that incision which involves a shallow, perpendicular groove prior to incising the cornea into the anterior chamber (part B). David Langerman, MD, deepened the perpendicular groove with the

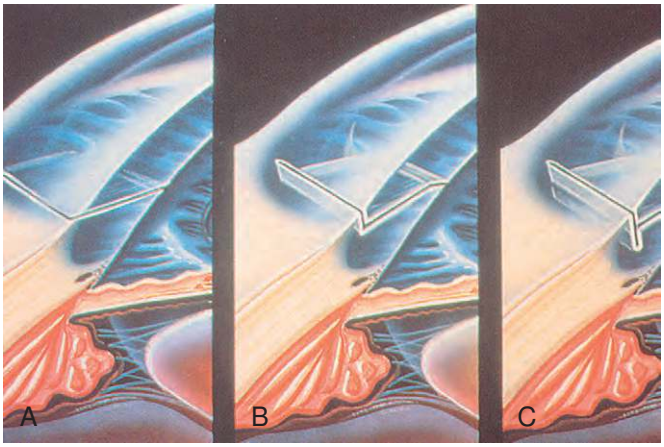

Fig. 16.7 Cross-sectional view of a single plane (A), shallow groove (B), and deep groove (hinged) (C) clear corneal incisions.

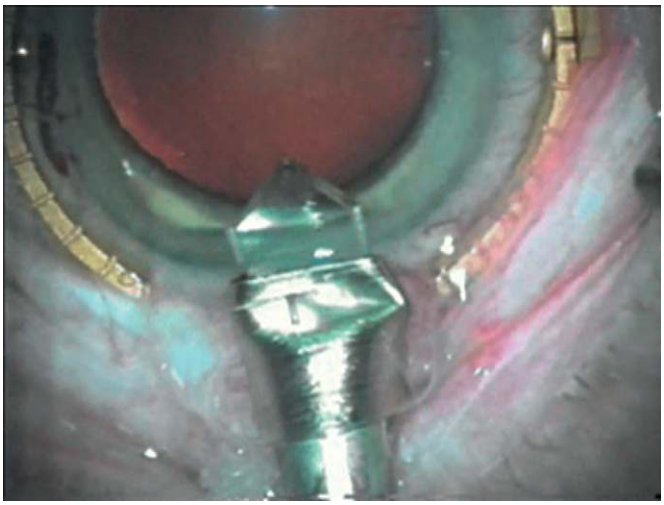

Fig. 16.8 Clear corneal incision construction with the blade completely inserted.

belief that it led to greater stability (part C). These grooved incisions have been abandoned by the authors in favor of a paracentesis-style incision because of the difficulties associated with a persistent foreign body sensation in the grooved incisions and the pooling of mucus and debris in the gaping groove. More importantly, the grooved incisions represent a disruption in the fluid barrier that intact epithelium creates, which allows for a vacuum seal as a result of endothelial pumping.

Initial incision construction technique began with a blade applanated to the surface of the eyeball with the point at the edge of the clear cornea, which advanced for 2 mm into the plane of the cornea before incising Descemet's membrane (Fig. 16.8). These early incisions were made with knives with straight sides; however, these knives were subsequently replaced by trapezoidal-shaped knives in order to allow the enlargement of the incision without violating the architecture by cutting sideways. From the onset of the use of clear corneal incisions, stromal hydration of the incisions, which thickens the cornea, forcing the roof of the incision onto the floor of the incision and facilitating endothelial pumping to the upper reaches of the cornea, was strongly advocated. Testing the seal of the incision with a Seidel test using fluorescein (Fig. 16.9) was also strongly advocated. These practices have not changed since 1992 except that we now infrequently depress the posterior lip of the incision.

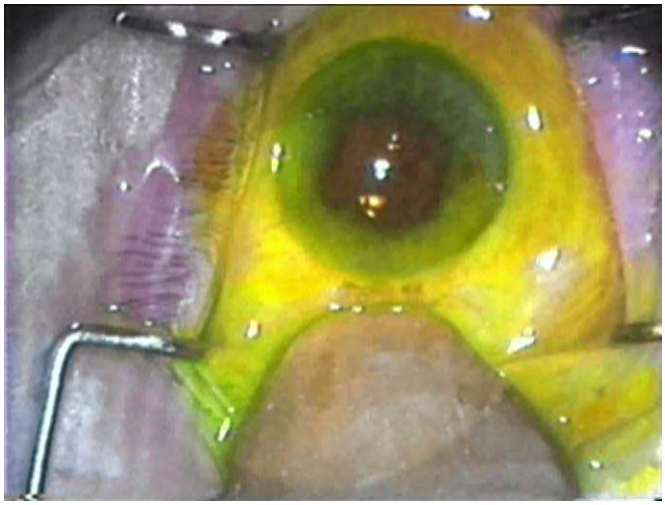

Fig. 16.9 Testing the seal of the incision with a Seidel test using fluorescein and tactile pressure.

Fig. 16.10 The Zeiss Visante Optical Coherence Tomography Anterior Segment Imaging System.

To obtain a better understanding of the architecture of clear corneal incisions, the authors conducted a study of the profiles of clear corneal incisions using the Zeiss Visante Optical Coherence Tomography (OCT) Anterior Segment Imaging System (Fig. 16.10). This technology has allowed the first view of the clear corneal incision in the living eye in the early postoperative period. All previous views were in autopsy eyes sectioned through the incision, which introduces artifacts. Fig. 16.11 shows an example of the corneal periphery in a control eye, which includes the anterior chamber angle. The regularity of the corneal epithelium blending in the conjunctiva and the clear corneal stroma blending into sclera can be clearly seen.

A variety of knives were used to create the clear corneal incisions during cataract surgery. All clear corneal incisions were made by one surgeon (IHF). OCT images of each operative eye were taken on the first postoperative day within 24 hours of cataract surgery and are representative of multiple images from multiple patients.

As seen in Fig. 16.12, which was taken on the first day postoperatively, the clear corneal incision is actually curvilinear, not a straight line, as seen in the artist's depiction of clear corneal incisions

Fig. 16.11 OCT image of a control eye showing the corneal periphery, including the anterior chamber angle.

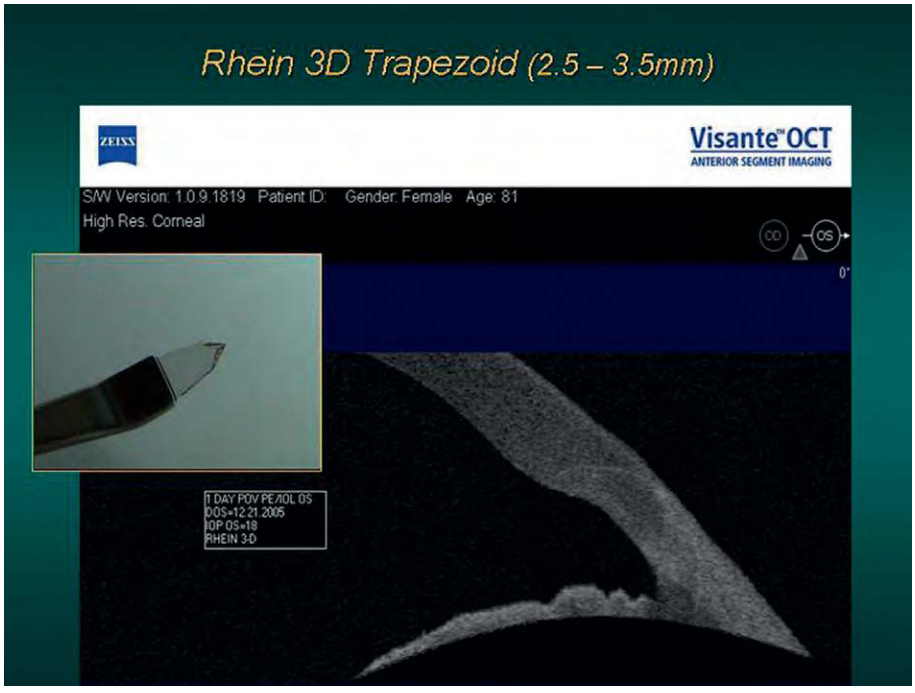

Fig. 16.12 OCT image of a clear corneal incision made with the Rhein 3D Trapezoidal 2.5- to 3.5- mm Blade. Image of the blade is inset.

(see Fig. 16.7). It is an arcuate incision which is considerably longer than the chord length originally estimated for the length of the incision. It is very important to note that the architecture of the incision allows for a fit not unlike tongue-and-groove paneling, which adds a measure of stability to these incisions and makes sliding of one surface over the other considerably less likely. Fig. 16.13 shows an incision that was made with a 300-micron groove at the external edge of the incision prior to incision construction. The incision itself still has a similar curved or arcuate configuration; but the gaping of the external groove, which is noted on the first day postoperatively, is accompanied by a similar offset of the internal lips of the incision, which appears to be somewhat less stable than a paracentesis-style incision.

These images also demonstrate the persistence of stromal swelling from stromal hydration on the first postoperative day, which many critics of clear corneal incisions believed disappeared within 1 or 2 hours.

Fig. 16.14 shows a clear corneal incision made with the Rhein Medical (Tampa, FL), the Rhein 3D Trapezoidal blade, 2 to 2.5 mm

Fig. 16.13 OCT image of a clear corneal incision with a 300-micron groove at the external edge of the incision. Image of the Rhein blade is inset.

Fig. 16.14 OCT image of a clear corneal incision made with the Rhein 3D Trapezoidal 2- to 2.5- mm Blade. Image of the blade is inset.

(#05–5088), for incision construction using single-piece acrylic lenses with a Royale injector (ASICO, LLC, Westmont, IL, #AE-9045). Once again, the very advantageous architecture of the incision is observed. It is interesting to note that the arc length is considerably longer than the chord length and is probably a hyper-square incision in that it is only 2 mm wide. As Figs. 16.15 to 16.18 demonstrate, all clear corneal incisions made with a variety of blades demonstrated a similar, arcuate architecture.

A variety of different blades can produce clear corneal incisions with the ideal 2 mm wide square architecture.

The BD Kojo Slit (BD Medical-Ophthalmic Systems, Franklin Lakes, NJ, #372032) is a blade that is curved in the direction of the width of the incision. This creates an arcuate incision paralleling the curvature of the peripheral cornea with a chord length whose width is considerably smaller than the incision itself, which may add a greater degree of

Fig. 16.15 OCT image of a clear cornea incision made with the Accutome Simplicity blade. Image of the blade is inset.

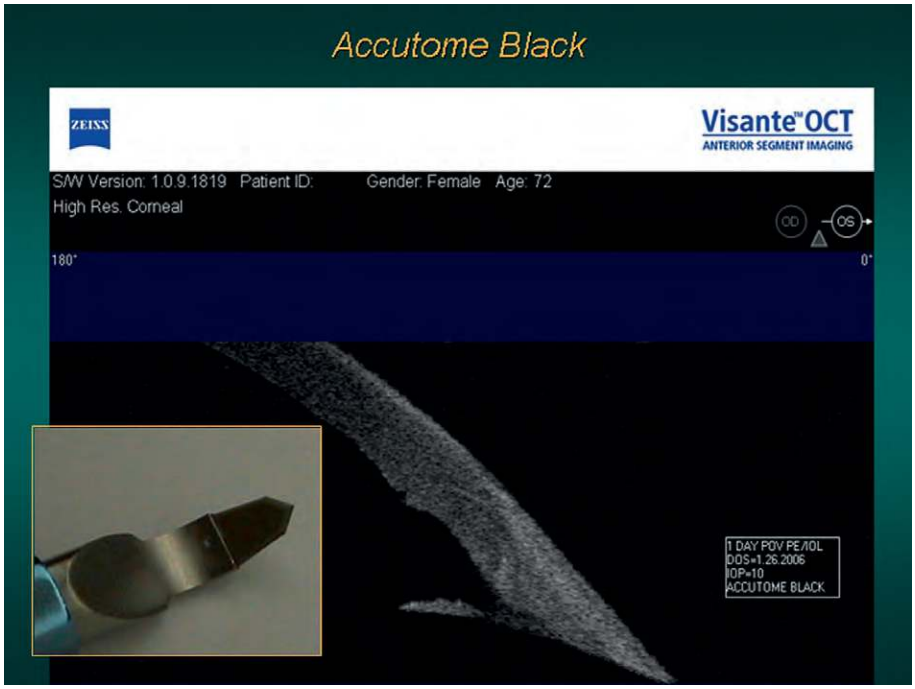

Fig. 16.16 OCT image of a clear corneal incision made with the Accutome Black Blade. Image of the blade is inset.

stability. The first few times that this blade is used, its unusual configuration makes it somewhat more difficult to create an incision in the plane of the cornea, and the incision can end up considerably shorter than anticipated (Figs. 16.19 and 16.20). However, as one learns how to use this blade, the desired architecture is much easier to achieve (Fig. 16.21).

One of the surprising findings was that proper incision construction resulted in a longer incision than the chord length that was measured and in greater stability (like tongue-in-groove paneling) of the incision. Another surprising finding was that stromal swelling does indeed last for at least 24 hours. These findings demonstrate those characteristics that have contributed to an added measure of safety in clear corneal incisions that can result in the absence of endophthalmitis[4].

FEMTOSECOND LASER–ASSISTED CORNEAL WOUND

The femtosecond (FS) laser is a newer technology used for cataract and refractive surgeries. The first reported clinical application of FS lasers for cataract surgery was in 2009 by Nagy et al. It is a near-infrared laser

Fig. 16.17 OCT image of a clear corneal incision made with the ASICO Clear Cornea Fixed Angle 2.8-2.8 mm Blade. Image of the blade is inset.

Fig. 16.18 OCT image of a clear corneal incision made with the Mastel Superstealth Blade. Image of the blade is inset.

at a 1053 nm wavelength. This wavelength can be focused to a less than 1.8 micrometer spot and does not cause trauma to adjacent tissues.[5] An advantage of this technology is that it employs precise cutting of tissue without any development of heat. FS laser can be used in four steps of cataract surgery: capsulotomy, lens fragmentation, astigmatic relaxing incisions, and clear corneal incisions, including the main wound and the side port or paracenteses.

The precise depth and shape of the clear corneal wound can be designed and reproduced by the laser. A benefit of using FS to create incisions during cataract surgery is decreased risk for wound gaps, Descemet's membrane detachment, and increased thickness at the incision site, and it allows for more efficient sealing than conventional clear corneal incisions.[5] Specifically, a wound can be made with an acute angle of 120, which can be made only with femtosecond laser

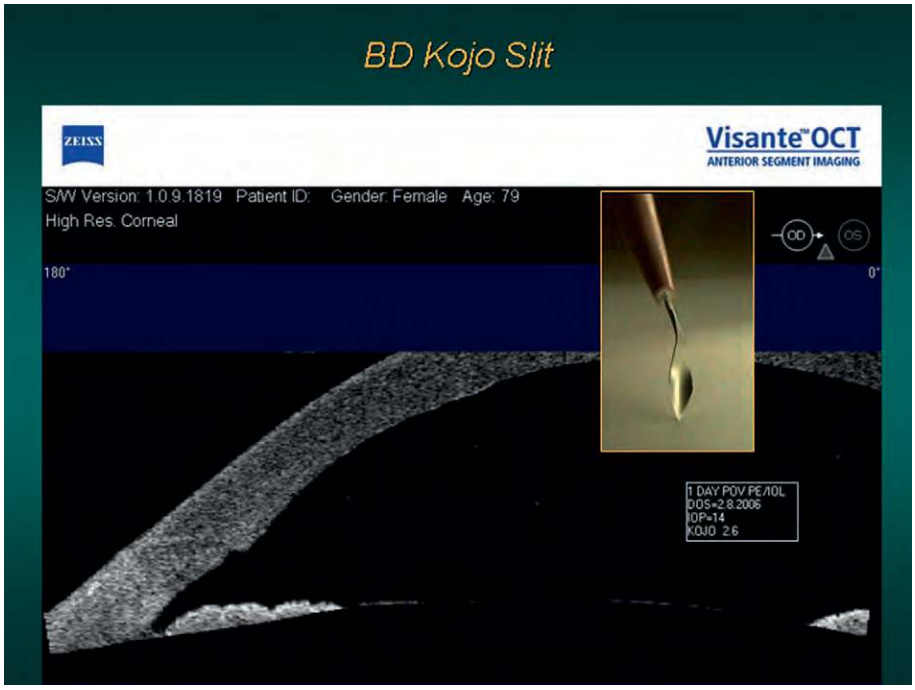

Fig. 16.19 OCT image of a clear corneal incision made with the BD Kojo Slit Blade during the learning curve. Image of the blade is inset.

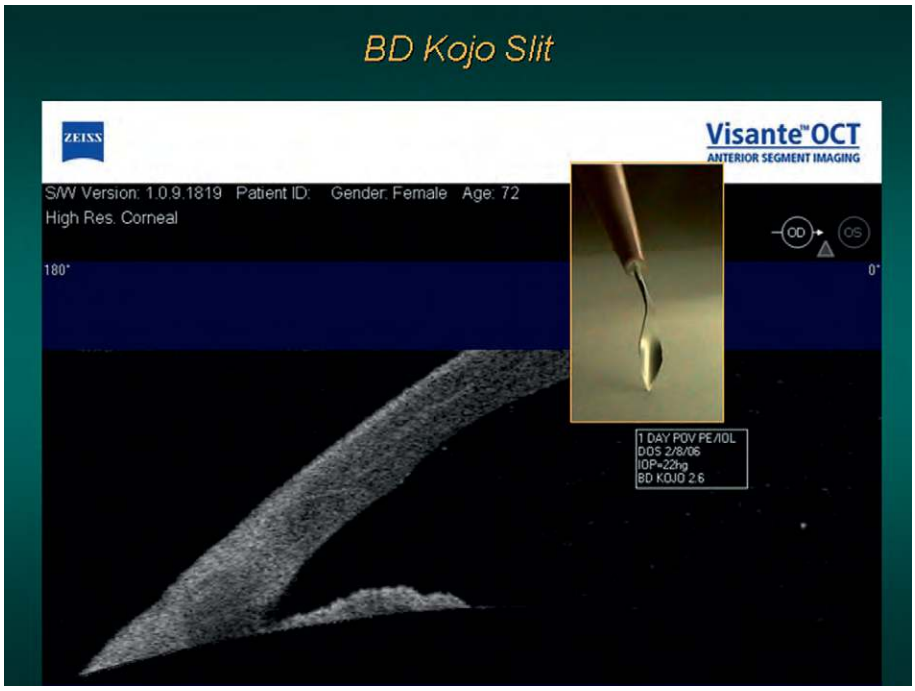

Fig. 16.20 OCT image of a clear corneal incision made with the BD Kojo Slit Blade during the learning curve. Image of the blade is inset.

(Fig. 16.22). This allows for a shorter and more consistent tunnel than manual creation of the wound. The square wound architecture by the FS has been shown to be far more stable and stronger than rectangular wounds (Video 16.1).[5]

An apparent limitation to the novice surgeon is that the FS-created wound is difficult to open with small tissue bridges and the inverse angle (Fig. 16.23). With experience and the assistance of a blunt cannula, the surgeon can easily master opening these wounds in most of these cases.

Femtosecond laser–created clear corneal incisions can be designed to meet the surgeon's exact specifications.

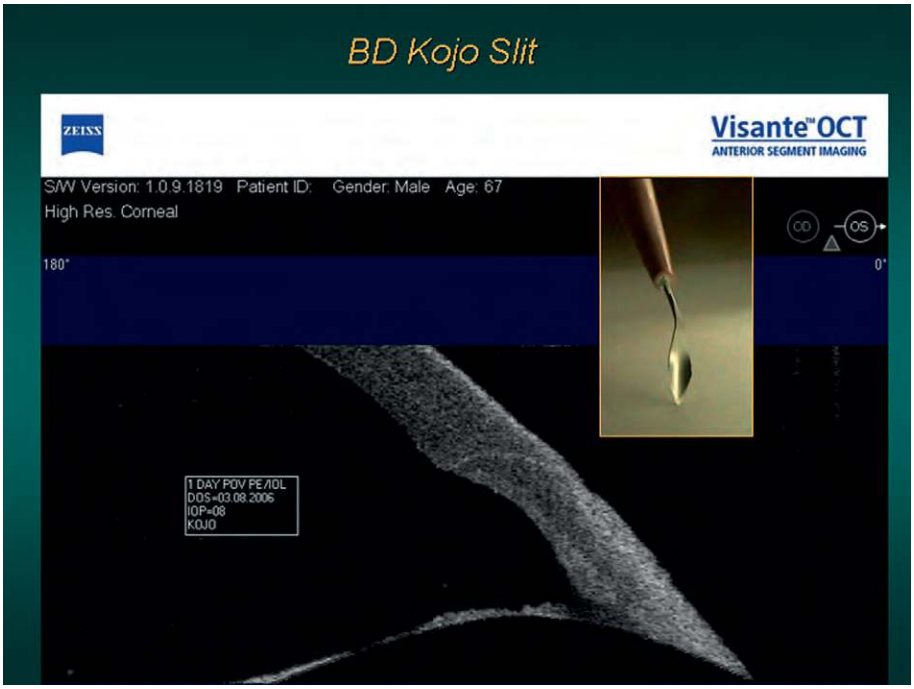

Fig. 16.21 OCT image of a clear corneal incision made with the BD Kojo Slit Blade after using the blade for 1 month. Image of the blade is inset.

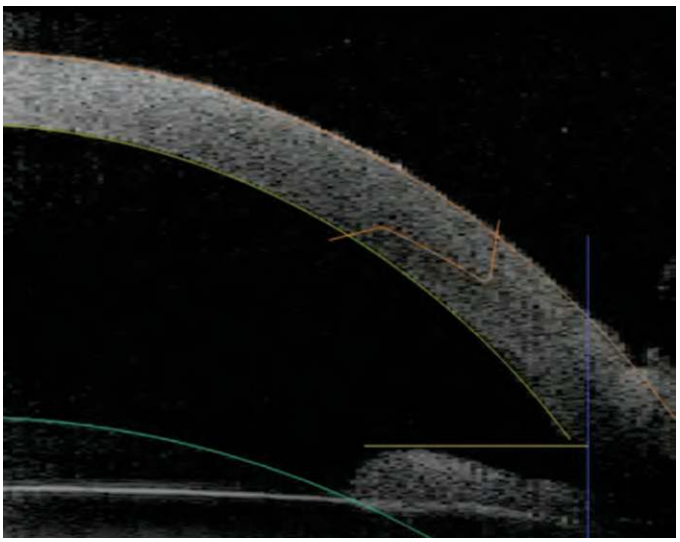

Fig. 16.22 Anterior segment OCT image of a clear corneal incision made with the Catalys (Johnson and Johnson, Santa Ana, CA).

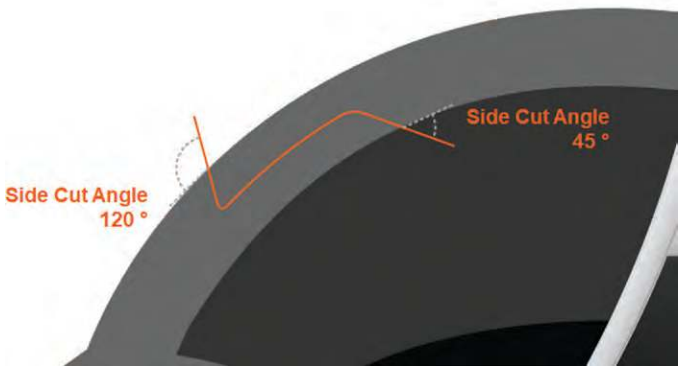

Fig. 16.23 Cartoon depiction of the anterior and posterior corneal wound angles that can be modified with the femtosecond laser.

INTRAOPERATIVE AND POSTOPERATIVE COMPLICATIONS

Clear corneal incisions, by nature of their architecture and location, have some unique complications associated with them. If one accidentally incises the conjunctiva at the time of the clear corneal incision, ballooning of the conjunctiva can develop, which may compromise visualization of anterior structures. When this develops, the use of a suction catheter may be used by the assistant to aid in visualization. Alternatively, a small cut-down of the ballooning conjunctiva can help release the trapped fluid. Early entry into the cornea might result in an incision of insufficient length to be self-sealing, and thus suturing of the wound may be required to ensure that a secure water-tight seal at the conclusion of the procedure. In addition, incisions that are too short or improperly constructed can result in an increased tendency for iris prolapse. A late entry may result in a corneal tunnel incision that is so long that the movement of the phacoemulsification tip would create striae in the cornea and compromise visualization of the anterior chamber.

Manipulation of the phacoemulsification handpiece intraoperatively may result in tearing of the roof of the tunnel, especially at the edges, potentially compromising the ability for the incision to self-seal. Tearing of the internal lip can also occur, resulting in compromised self-sealability or, in rare instances, small detachments or scrolling of Descemet's membrane in the anterior edge of the incision. A localized DM detachment can be treated with an injection of air into the AC at the end of the case with the patient positioned to appropriately tamponade the detached DM for a few hours postoperatively.

A complication of greater concern has been the potential for incisional burns.[6] When these phaco burns develop in clear corneal incisions, the shrinkage of the tissue can create severe distortion of the

wound architecture with difficulty in wound closure even with sutures, corneal edema, and severe induced astigmatism. In addition, manipulation of the incision can result in an epithelial abrasion and trauma to the roof of the incision, which can also compromise self-sealability. Without an intact epithelial layer, the corneal endothelium does not have the ability to help appose the roof and floor of the incision through hydrostatic forces.

Postoperatively, hypotony might result in some compromised ability for these incisions to seal. Wound leaks and iris prolapse are infrequent postoperative complications[7] and are usually present in incisions greater than 3.5 mm in width. When temporal clear corneal incisions of 3.2 mm or less have been compared with superiorly placed scleral tunnel incisions of the same size, similarly low numbers of induced astigmatism have been documented for the two incision locations.[8] When comparing locations of clear corneal incisions, superior axis incisions have demonstrated more meridional flattening than temporal incisions.[9] This has also been shown in the oblique superolateral clear corneal incision compared with a temporal incision. Therefore, if astigmatic neutrality is desired, a temporal clear corneal incision of <3 mm is recommended.

Contraindications for clear corneal incisions include the presence of radial keratotomy incisions that extend to the limbus that might be challenged by clear corneal incisions[10] and marginal degenerations associated with thinning of the peripheral cornea. In these cases, a scleral tunnel incision may still be preferable to a clear corneal incision.

Complications of clear corneal incisions include ballooning of the adjacent conjunctiva, local Descemet's membrane detachment, wound leak, and iris prolapse.

SUMMARY

Clear corneal incisions are now the most popular wound approach for cataract surgery throughout the world. Although there are still some indications for using a scleral tunnel technique, clear corneal incisions have evolved over time to be safe, astigmatically neutral, and maintain a stable anterior chamber. This has been demonstrated further in femtosecond laser–created clear corneal wounds. Both femtosecond and manual clear corneal wounds advantageously offer decreased surgical time and faster healing time for patients.

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Video 16.1: Use of femtosecond laser to perform capsulotomy, lens fragmentation, and creation of multi-planar main incision for cataract surgery.

17

Capsulotomy

Vance Thompson

CONTENTS

KEY POINTS

- The capsulotomy is key to optimizing long-term vision.
- The capsulotomy determines ultimate implant position.
- Implant centration and tilt are heavily influenced by the capsulotomy.
- Implant tilt and decentration with capsule contraction can be minimized by achieving 360 degrees of anterior capsular overlap with the capsulotomy.
- Centering the capsulotomy to create 360 degrees of capsular overlap of the anterior optic is key to long-term implant stability.
- Preventing fusion of the anterior capsulotomy edge to the posterior capsule by creating a barrier effect with the optic periphery lessens capsular fibrosis dramatically. This will decrease yttrium-aluminum-garnet (YAG) laser rate and reduce the laser energy required to open the capsule when it is affecting vision.
- A quality capsulotomy can be achieved manually or with modern-day, more automated technologies.
- The Purkinje images are very useful in helping to center both the capsulotomy and the implant.

INTRODUCTION

A perfectly performed capsulorrhexis leading to a successful replacement of the crystalline lens with an intraocular lens (IOL) implant for a patient in need is one of the most rewarding surgical experiences an ophthalmologist can have. It is also one of the most powerful and joy-filled experiences we can do for our patients. On the contrary, a complication in cataract surgery that leads to permanent visual side effects creates a cascade of events that hurts the patient physically and, although in different ways, both the patient and caring surgeon emotionally. During surgery, there are certain pinnacle events that can be the difference between a great surgery and a complication; arguably the capsulorrhexis is number one in a surgeon's mind during cataract surgery. It is the seminal step that can make or break a successful procedure. It has both short-term and long-term implications if performed improperly. Completed with attention to detail, the capsulotomy achieves the ultimate goal: a lifetime of quality vision because of a properly positioned and stable implant.

HISTORY

The anterior capsule opening, known as the *capsulotomy*, was a necessary step for the transition from intracapsular to extracapsular cataract surgery. Many surgeons are credited with its beginning that evolved to the can-opener technique that ruled for decades.[1] But it was the circular tear capsulotomy known as *capsulorrhexis* that led to increased surgical safety and visual accuracy.[2] The capsulorrhexis improved surgical safety because of the dramatically reduced incidence of anterior capsule can-opener tears extending into the posterior capsule and resulting in vitreous loss with resultant complications.[3,4] It also improved accuracy in the visual result because, when performed properly, it led to a more predictable and stable effective lens position.[5,6]

THE IDEAL CAPSULOTOMY

The three main techniques used in modern-day cataract surgery to perform the anterior capsule opening are manual capsulorrhexis, femtosecond laser-assisted capsulotomy, and Zepto Precision Pulse Capsulotomy (PCC; Fig. 17.1). The goal of all three is to create a well-centered, round, and precisely sized opening to overlap the anterior edge of the optic enough so that with capsule contraction the implant optic position stays where the surgeon placed it. These three aspects to the ideal capsule opening, centration, size, and roundness should be optimized whether the surgeon is performing the capsule opening manually (circular capsulorrhexis) or with a device that provides increased automation (femtosecond laser or

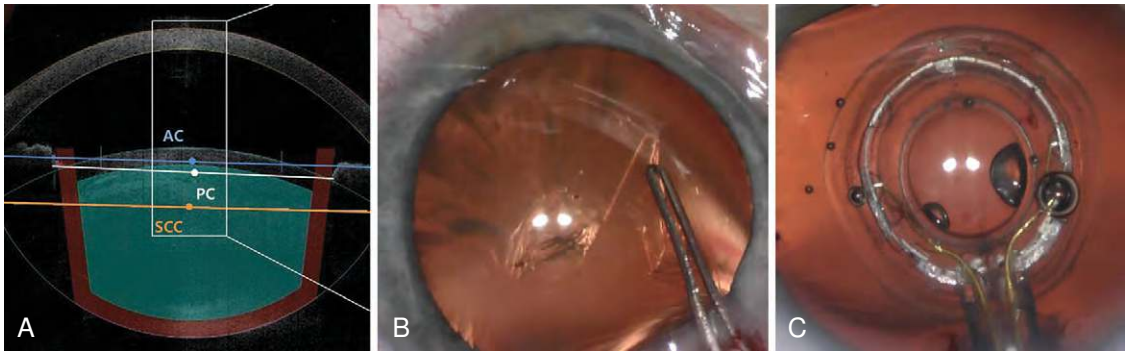

Fig. 17.1 Three common methods to perform a modern-day capsulotomy. (A) Optical coherence tomography–guided femtosecond laser. (B) Manual capsulorrhexis. (C) Zepto.

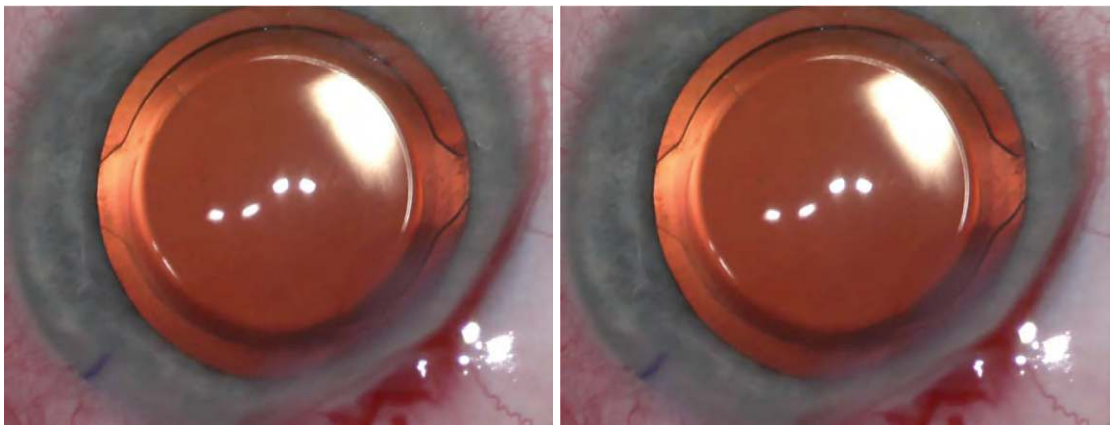

Fig. 17.2 The goal of the capsulotomy is to create a well-centered, round, and precisely sized opening to overlap the anterior edge of the optic enough so that with capsule contraction the implant optic position stays where the surgeon placed it (see Video 17.1.)

Zepto). The goal to consistently create the optimal 6.0-mm diameter IOL optic overlap is to create a capsule opening of 5.0 to 5.2 mm (Fig. 17.2). The capsulorhexis opening may contract in the postoperative period.[7]

EARLY AND LATE POSTOPERATIVE CAPSULOTOMY CONSIDERATIONS

Optimal centration of the optic with minimal tilt is our surgical goal. The capsule opening influences both in the short and long terms.[8] If the opening is not made properly or there is an anterior or posterior capsule tear, implant stability and centration is compromised.[9] If the opening is too small, capsular fibrosis and phimosis can become an issue and can cause an anteroposterior IOL shift or IOL decentration over time as a result of asymmetric capsular bag shrinkage.[10,11] If it is too large or decentered, the anterior capsule that is now peripheral to the optic can fuse to the posterior capsule and create an aggressive capsular fibrosis that gradually displaces, decenters, and tilts the lens.[12]

It is important for the surgeon to understand the role that lens epithelial cells can play in the capsular contraction dynamics.[13] These cells can be seen on retroillumination in cataract surgery (Fig. 17.3). The lens cuboidal epithelial cells reside in the anterior portion of the lens and serve multiple functions including differentiating into lens fiber cells.[14] Metabolically, in comparison to the fiber cells, the

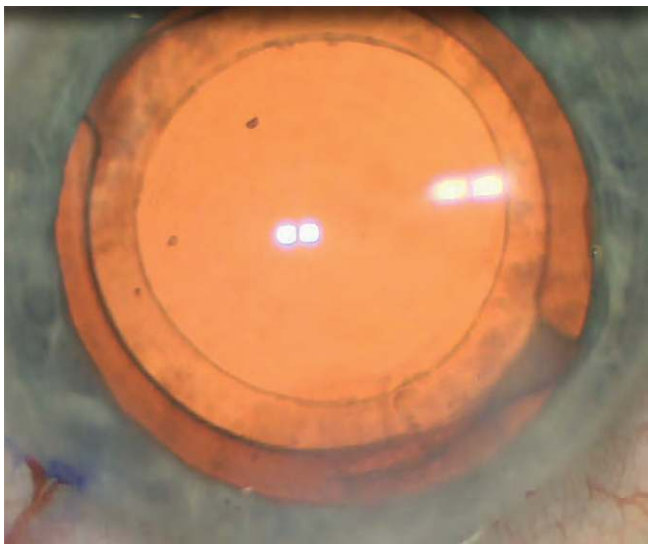

Fig. 17.3 Lens epithelial cells under the anterior capsule can be seen on retroillumination in cataract surgery. Polishing can lessen these cells, but they are difficult to totally remove. If the surgeon does not achieve 360 degrees of capsule overlap of the optic, these cells can promote fusion of the anterior capsule to the posterior capsule and create a sequence of events that progressively decenters and/or tilts the implant for the rest of the patient's life.

epithelium is the more active compartment of the ocular lens. In contrast to the normal lens, the cataractous lens is characterized by morphologic and distribution anomalies of the epithelial cells.[15] All lens epithelial cells are capable of undergoing cell proliferation, but in the adult lens the most activity is in the germinative zone above the lens equator (Fig. 17.4). As a result of the significant metabolic activity in the anterior subcapsular lens epithelial cells, a profound capsular reaction consisting of aggressive capsule opacification and fibrosis can occur if this layer is allowed to come into contact with the posterior capsule. Multiple studies have shown that apposition of the anterior capsule edge onto the posterior capsule near the posterior surface of the IOL optic can be dangerous.[12,16] The fusion of the anterior capsule to the posterior capsule can also be progressive over time and lead to a gradual extrusion of the implant out of its centered and nontilted position into a decentered and tilted visually disturbing position.[17] The author calls this *capsular fusion syndrome*; preventing it is one of the main goals in cataract surgery. Even though posterior capsule opacification (PCO) is very common after cataract surgery, it is worth minimizing how aggressive it is. There are basically two forms of PCO: a less aggressive "pearl-type" and a more aggressive "fibrotic-type."[12] Even though neodymium:yttrium-aluminum-garnet (Nd:YAG) laser posterior capsulotomy is relatively safe, the opening of the posterior capsule may be associated with numerous complications and can be much more challenging in the more aggressive fibrotic PCO. The key to maximizing the chance of limiting PCO to the less aggressive pearl type PCO is to prevent the anterior capsule from fusing to the posterior capsule.[12,17–21]

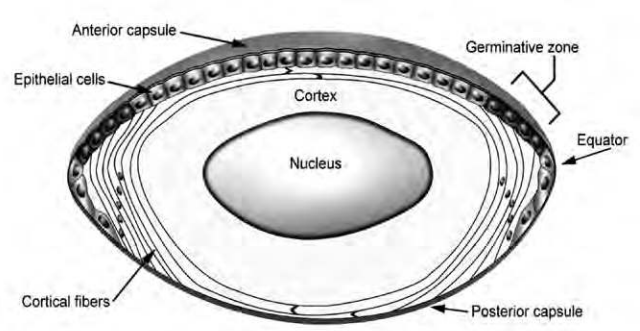

Fig. 17.4 All lens epithelial cells are capable of undergoing cell proliferation, but in the adult lens the most activity is in the germinative zone above the lens equator.

PREVENTION OF CAPSULAR FUSION SYNDROME

The key to preventing apposition of the anterior capsule to the posterior capsule is to create a round and even anterior optic overlap of the anterior capsule (see Fig. 17.2). To do this, the capsulotomy needs to be centered on or as close as possible to the patient's visual axis with the same care and attention to detail as centering the implant itself. By attention to detail and centering both the implant and the capsule opening on the visual axis, one maintains a very important relationship between the two that, coupled with a 5.0- to 5.2-mm diameter opening, creates a barrier effect that greatly lessens the chance of capsular fusion syndrome with its potential optic decentration and tilt. It is notable that centering on the patient's dilated pupil does not consistently create the desired centration because most people's visual axis is not centered on their pupil and it is common to be nasally displaced from the center of their pupil.[22–24] (Figs. 17.5 and 17.6).

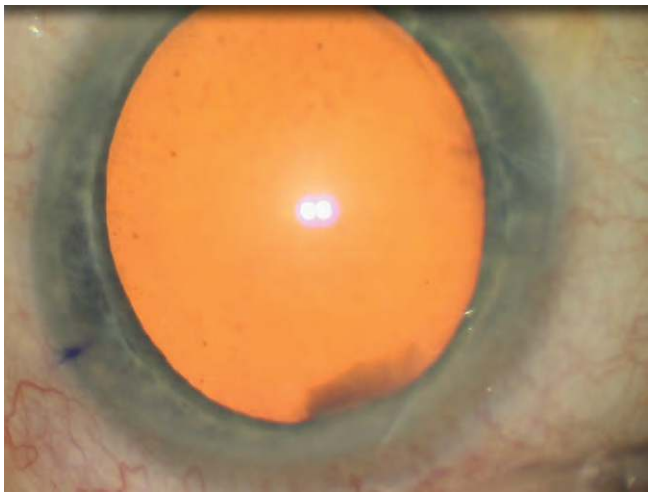

Fig. 17.5 Centering on the patient's dilated pupil does not consistently create the desired centration because most people's visual axis is not centered on their pupil and is common to be nasally displaced from the center of their pupil as shown in this patient's left eye with P1/P4 alignment.

THE PURKINJE I AND IV METHODS FOR VISUAL AXIS IDENTIFICATION AND CENTRATION

The preferred technique for centering cataract surgery, both the implant and capsule opening, has been previously described.[25] It is based on the fact that in eye surgery there are the beautiful, precise, and reproducible Purkinje light reflexes that are often underused but are so very helpful to center cataract surgery. There are basically four Purkinje images, and the two that are the most useful are the first Purkinje image (PI) and the fourth Purkinje image (PIV)[25] (Fig. 17.7). Others have nicely described centering cataract surgery on PI, also known as the *subject-fixated coaxially sighted corneal light reflex*[26] and involves the use of coaxial microscope optics, surgeon-instructed patient fixation on a coaxial light, and either a manual corneal 6.0-mm optical zone marker or the Zepto PPC device.[25] If patient fixation is precise in cataract surgery, centering on PI can be very accurate. But fixation is often affected by sedation or the patient inconsistently looking at a very bright light. Thus having a technique to serve as a surrogate for patient fixation is very helpful.[25] The preferred technique is based on the fact that, when a patient fixates on a bright light, there is a reproducible and accurate relationship between their P1 and P4 images. If the patient is having a difficult time looking at the light, the surgeon can manually adjust eye position with their .12 forceps to align P1 and P4 and have a very close approximation of their visual axis and center the capsulotomy on these closely aligned images (Fig. 17.7). Subtle variations in the degree of P1/P4 overlap at fixation are apparent between patients and reflects their individual ocular anatomies. The Purkinje method of centering the capsulotomy works very well when using techniques that allow for patient fixation and/or Purkinje image utilization. This works well for long-term optic centration and minimizing PCO by preventing capsular fusion syndrome.

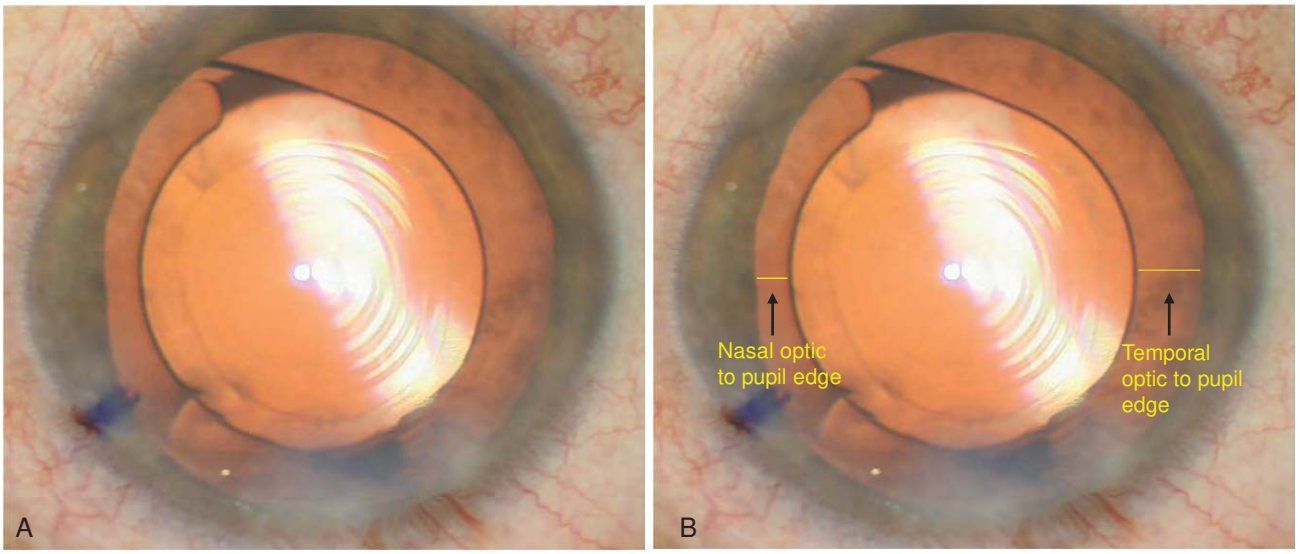

Fig. 17.6 (A.B) Note that in this left eye with great capsule overlap for long-term implant stability, the distance from the nasal optic edge to the pupil edge is much less than the greater distance temporally. If this Zepto capsulotomy would have been centered on the pupil, it would have been decentered with respect to the optic. This is why centering both the capsulotomy and the optic on the visual axis is more accurate than centering on the dilated pupil.

MODERN-DAY CAPSULOTOMY METHODS

There are multiple methods to achieve a quality opening in the anterior capsule. There are also multiple reasons surgeons gravitate toward one or more of these methods. The number one reason is surgeon comfort. Another reason can be financial. Third-party reimbursement in many parts of the world does not include extra technology such as a femtosecond laser or a PPC device like Zepto. Thus to use advanced technologies that help automate certain aspects of the capsulotomy, patient pay is a strong consideration.

Because the capsule is so delicate and its barrier function between the anterior and posterior segment so important, it is considered a paramount goal to maintain its integrity and minimize the chance of a tear or dialysis leading to vitreous loss and the cascade of complications that can follow.[27,28] Therefore, in addition to optimization of visual outcomes, the physical aspects of a well-performed capsulotomy are important for procedural safety. When choosing a technology for completion of the capsulotomy, surgeons must consider both the safety and efficacy to achieve their patients' long-term visual goals.

MANUAL REFRACTIVE CAPSULOTOMY

Manual capsulorrhexis is the most commonly used technique for capsulotomy creation. To perform it consistently and accurately requires significant expertise. The size, shape, and centration of the continuous curvilinear capsulorrhexis (CCC) can vary significantly from surgeon to surgeon.[2]

The capsulotomy is greatly facilitated with a guide to optimize centration, size, and roundness. The surgeon can estimate or use techniques and instruments to facilitate these goals. The corneal optical zone marker is a helpful tool for creating an epithelial imprint (see Fig. 17.8).

When using a guide, there are certain principles to adhere to:

1. The most important aspect of centering on patients' visual alignment is having them fixate on the microscope light and centering on PI (Fig. 17.9). You can use the P1/P4 aligned image as a double check of proper patient fixation (Fig. 17.10A and B). The surgeon needs to understand the microscope and which eye (either or both) best aligns for optimal capsule overlap. One method of doing this has been described.[25]

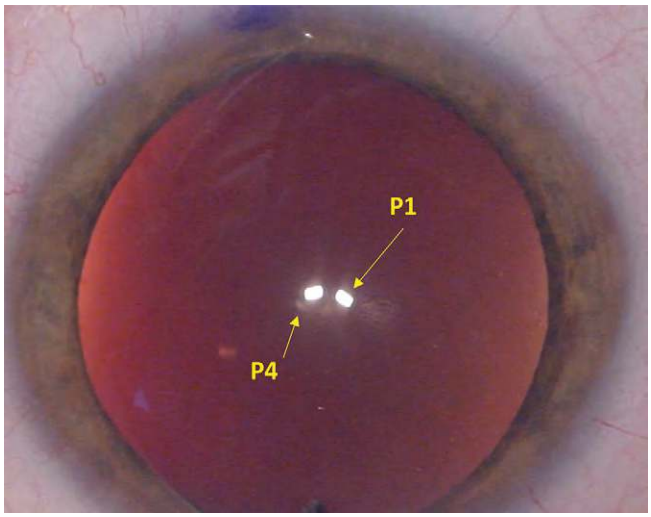

Fig. 17.7 There are basically four Purkinje images, and the two that I find the most useful are the first Purkinje image (PI) and the fourth Purkinje image (PIV). *P1* is the corneal light reflex and is the brightest and upright image. *P4* is dimmer, inverted, and reflected off the posterior capsule. With patient fixation, their relationship is very consistent as a representation of the patient's visual axis. If a patient cannot fixate, manually aligning P1 and P4 can serve as a very close approximation of the patient's visual axis.

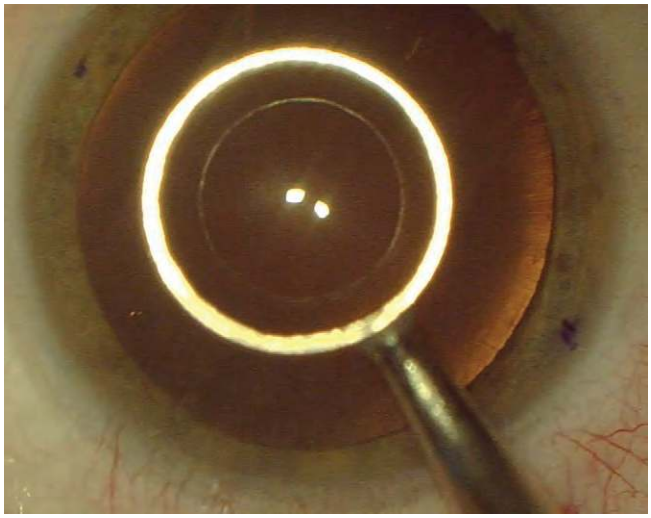

Fig. 17.8 The corneal optical zone marker is a helpful tool to guide a manual capsulotomy for size and centration.

2. Marking the optical zone first involves choosing a size. By using a 6.0-mm optical zone marker and going just on the inner aspect of the epithelial imprint, a 5.0- to 5.2-mm opening can be achieved (Fig. 17.11A–D).
3. The surgeon needs to put just enough pressure to create an imprint but not so much as to damage the epithelium, to create a defect that affects visualization in surgery, or to create a painful abrasion for the patient. This imprint is not difficult to do with practice and serves as a wonderful guide for performing capsulorrhexis.

The importance of patient fixation to create the mark is just as important when performing the capsule opening. The only way to count on your mark that you created with patient fixation is for the patient to be fixating while using the mark as a guide (see Fig. 17.11C and D). This is another reason to use the PI/PIV aligned Purkinjes because, during capsule opening, the light can start to blur and move for the patient, and continually realigning P1/P4 helps maintain alignment for proper capsule opening size, roundness, and centration (Fig. 17.12A and B). This method allows for a manual way to achieve beautiful overlap (Fig. 17.13A and B).

CURRENT STANDARD TECHNIQUES OF CAPSULORRHEXIS

There are three basic choices that a surgeon must make for establishing a standard technique:

- The instrument: a cystotome, capsulorrhexis forceps, or a combination
- The access: via the main incision or via a side-port paracentesis
- The medium: viscoelastic or irrigation with fluid

Using either the cystotome or the tip of a capsulorrhexis forceps, the anterior capsule is perforated near the center with the needle tip and then slitted in a curvilinear manner in such a way that the desired radius of the capsulorrhexis is reached in a blend-in manner. When about to reach the desired circumference, the capsule is lifted from underneath, close to the leading tear edge, and pushed upward and forward to propagate the tear. Soon, enough of a flap will be created to permit flipping it over and engaging it from its backside, its epithelial side, now facing up toward the cornea (Fig. 17.14). If using a cystotome alone, the needle engages the flap by exerting just enough pressure to create the friction necessary for engagement but not enough pressure for the needle tip to perforate. If using the forceps, the flap is grasped and the tear propagated. Having the capsular flap thus engaged, it is torn in a circular fashion by appropriately influencing the tear vectors (Fig. 17.15). The more distant the point of engagement is from the leading edge of the tear, the more centripetally one must tear; the closer the point of engagement is to the leading edge, the more directly the tear will follow the direction of traction. It is therefore most advisable to refixate the tear with the cystotome point frequently, close to the leading edge: a basic principle that governs the entire technique and its variations. When brought around full circle, the tear is blended into itself, automatically coming from outside in, which is a basic prerequisite to avoid a discontinuity.

This technique is most commonly performed with the anterior chamber filled with a viscoelastic substance.

TECHNICAL TIPS

- Starting the tear somewhere in the center in the capsule has the advantage of virtually eliminating the possibility of creating a discontinuity that would be caused by finishing the tear from inside out; this becomes especially valuable in cases with reduced visibility (e.g., small pupils, no red reflex). The tear must be performed over the full 360 degrees in the direction in which it was started.
- Puncturing the capsule within the contour of the capsulorrhexis has the disadvantage that it may cause a stellate burst (with extensions to the capsular periphery) if the needle is not perfectly sharp. If such a burst goes unnoticed (e.g., for visibility reasons) or if its extensions reach too far peripherally to be recovered, a peripheral tear will result at this location. In addition, with this technique, the risk for inadvertently completing the capsulorrhexis from inside out is slightly higher.
- On the other hand, by beginning with a puncture, the surgeon has two options as to where to proceed with the tear, developing it and bringing both ends together at the point of maximal control (Fig. 17.16). Most surgeons probably start somewhere in the capsular center.

Learning Capsulorrhexis

One of the major advantages of capsulorrhexis is that it can be learned by doing, without exposing the patient to any additional risk. Coming from whatever prior technique of anterior capsulotomy, the surgeon may begin along the given guidelines. If the tear starts moving into an unwanted direction, the surgeon can revert to the previous technique.

TECHNICAL TIPS

- When using Utrata-type forceps through the main incision, insidious loss of viscoelastic is very likely to occur. This leads to a flattening of the anterior chamber and, consequently, a forward movement of the lens. This, in turn, leads to an increase of the outward vector forces inherent in the lens capsule, making it increasingly more difficult to keep the tear from running outward. Knowing the danger means banning it: refilling the chamber with viscoelastic patiently as losses occur can prevent this most frequent source of losing control over the capsular tear. Use of a low-molecular–weight, retentive viscoelastic agent also reduces the amount of viscoelastic lost through the main incision.
- To practice, good surrogates for the lens capsule are cellophane, as used in shrink-wrap packages, or tomato skin. Pigs' eyes, with thicker and more elastic anterior capsules, can serve as excellent models for learning to master the difficulties in infantile and juvenile capsules.

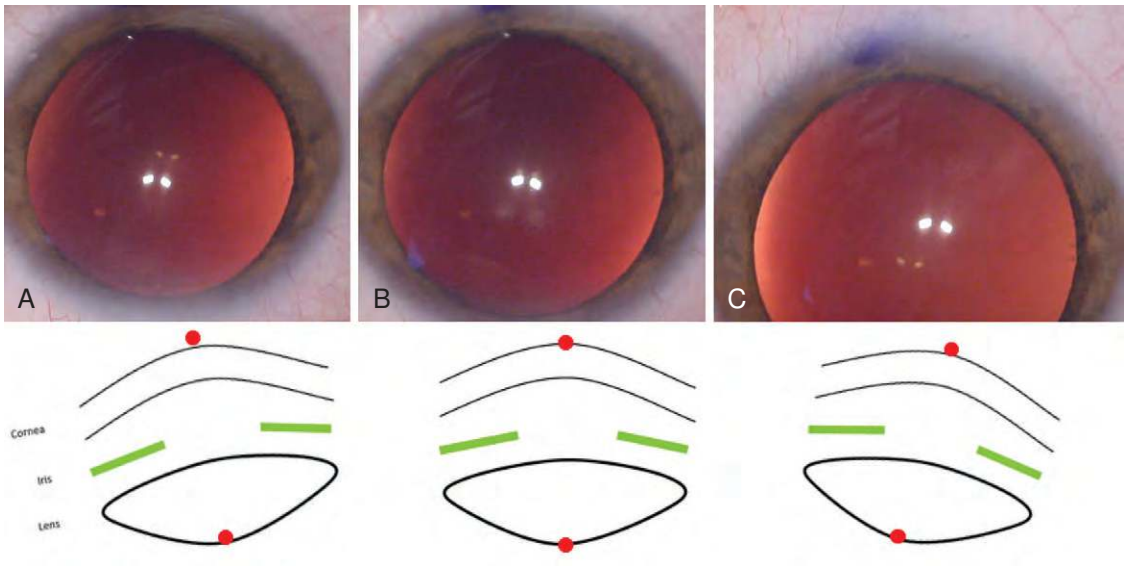

Fig. 17.9 Aligning on the visual axis starts with proper patient fixation. This patient was wandering but when she fixated (B), close alignment of P1 and P4 was achieved. These aligned images now can be used to center the capsulotomy and implant.

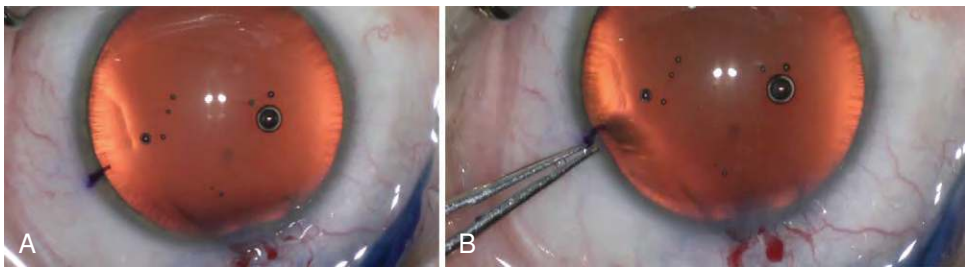

Fig. 17.10 (A) This patient was sleepy with sedation and had a hard time fixating. (B) Use of a 12 forceps to align P1 and P4 serves as a close approximation of the patient's visual axis, and surgery can proceed from there.

PRECISION PULSE REFRACTIVE CAPSULOTOMY

Using a PPC (Zepto device by Centricity, Inc.) is a first-in-class intraoperative method for producing a perfectly round 5.2-mm capsulotomy. Using coaxial microscope lights and optics with brief patient fixation, excellent centration of both capsulotomy and optic can be achieved[25] (Fig. 17.17).

Through the primary 2.2-mm or greater incision, the transparent PPC suction cup is inserted into the anterior chamber. The patient is instructed to fixate on the microscope light selected by the surgeon while the surgeon looks through the preferred eyepiece. The PPC device is then centered on the Purkinje PI/PIV aligned image, which marks the patient's visual axis, and a capsulotomy is performed. The PIV image should be aligned and mostly hidden behind PI when the patient is fixating on the coaxial light. The resulting capsulotomy preserves the visual axis information and acts as a surrogate reference marker to guide IOL centration on this axis (Figs. 17.18 and 17.19).

Capsulotomy edge strength has been studied with this device and in a paired cadaver eye study through an open sky technique. This study showed the Zepto edge to be stronger than both the femtosecond laser and manually created capsulotomy edge.[29] At 1 day postoperation, the edges of the cut collagen are easily visualized (Fig. 17.20). At 3 weeks postoperation, the Zepto-created capsulotomy demonstrates great overlap for a long-term stable implant (Fig. 17.21).

The Zepto PPC technique has been extensively studied, and its use is growing in our world for both routine and challenging cataract surgery cases.[30–33]

FEMTOSECOND LASER REFRACTIVE CAPSULOTOMY

Femtosecond laser-assisted cataract surgery automates multiple steps in cataract surgery including the capsulotomy, lens fragmentation, and creation of corneal incisions (the primary and secondary incisions and astigmatic keratotomy, when desired). There has been debate on how much it improves predictability and safety of the procedure and improves refractive outcomes.[34,35] In general, it has introduced a high level of predictability and reproducibility of the anterior capsulotomy with a higher degree of precision in size and shape than obtained manually[36–44] (Fig. 17.22). As a result, studies have shown improved refractive outcomes with more predictable and stable effective lens position and less IOL decentration or tilt when a femtosecond laser is used to create the capsulotomy.[45–47]

It is notable that, for white cataracts, the femtosecond laser has been shown to be a benefit in creating the capsulotomy but with a higher incidence of incomplete capsulotomy.[48,49] In comparison, the Zepto PPP has shown high success for complete capsulotomies in white cataracts and in other complicated cataract situations.[50,51]

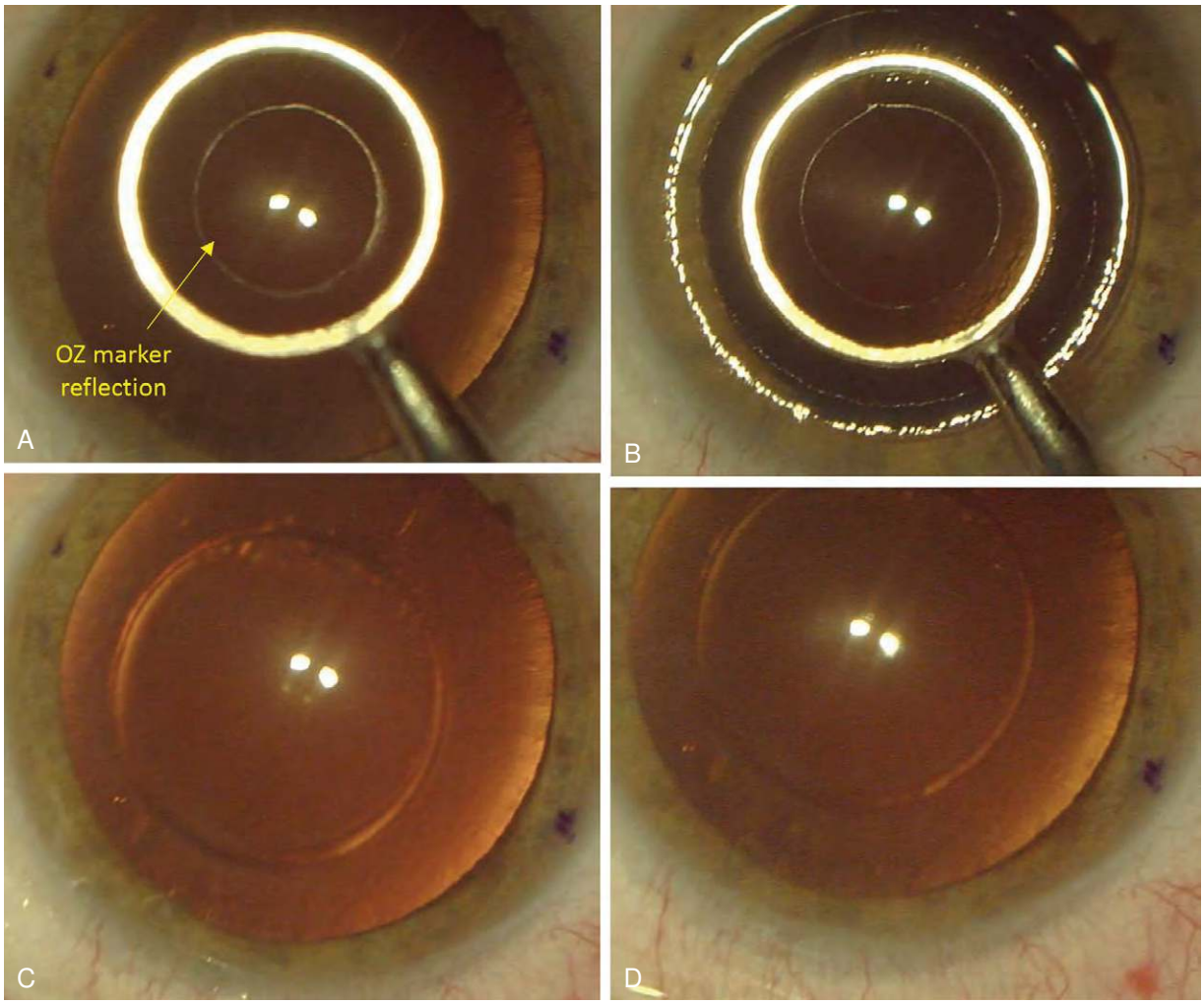

Fig. 17.11 A 6.0-mm optical zone *(OZ)* marker is used. With either patient fixation or manual P1 and P4 alignment, the marker is centered (using the OZ marker reflection off the tear film) over the Purkinje images (A), and an epithelial imprint is made (B). Once the epithelial imprint is made, it is only of value when the patient fixating or during manual P1/P4 alignment (D).

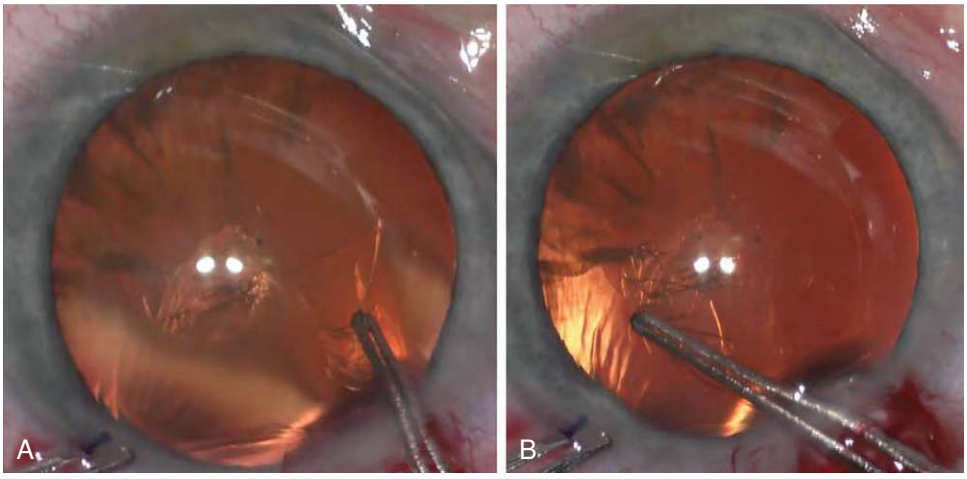

Fig. 17.12 As far as nuances that help with this technique, notice in (A) that P4 has drifted from its close approximation to P1. Using 12 forceps, P1/P4 is realigned as shown in (B), and the capsulotomy was completed. When performing a refractive capsulotomy manually, frequent realigning of the Purkinje images helps make a well-centered capsulotomy.

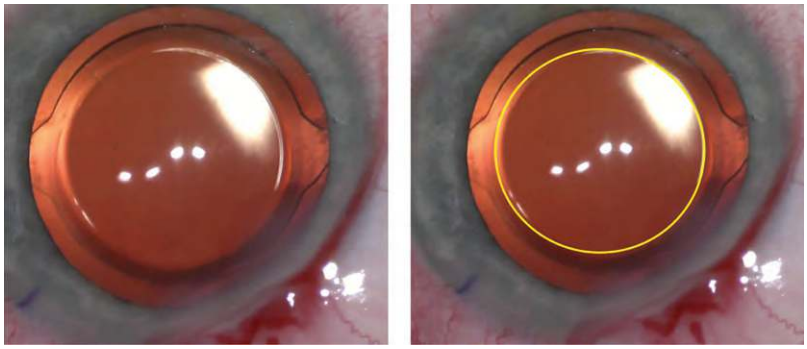

Fig. 17.13 The patient in the fig has 360 degrees of overlap of the anterior capsule over the optic and will have a stable implant (well centered with normal tilt) for the rest of life.

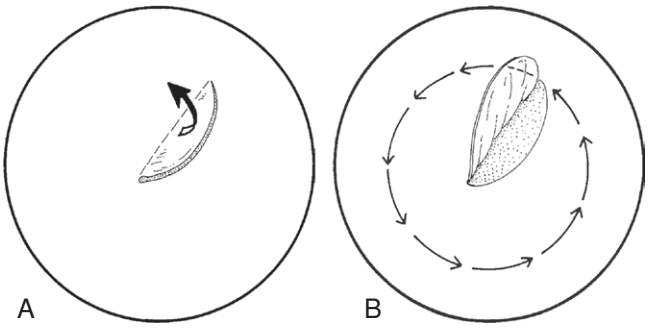

Fig. 17.14 (A) In the standard technique for capsulorrhexis, a central puncture with a cystotome followed by an arched curve creates a slit. The capsular flap is pulled and lifted at its edge. (B) Flap is inverted, and the underside of the capsule edge, now anterior, is engaged with the needle tip or forceps and pulled circularly.

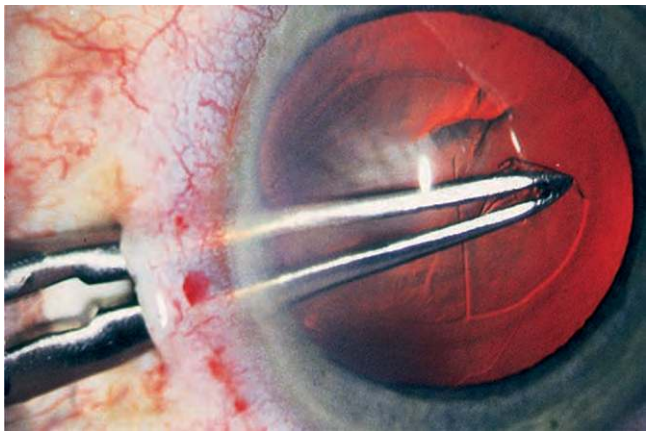

Fig. 17.15 Circular tear capsulorrhexis is illustrated using a capsulorrhexis forceps.

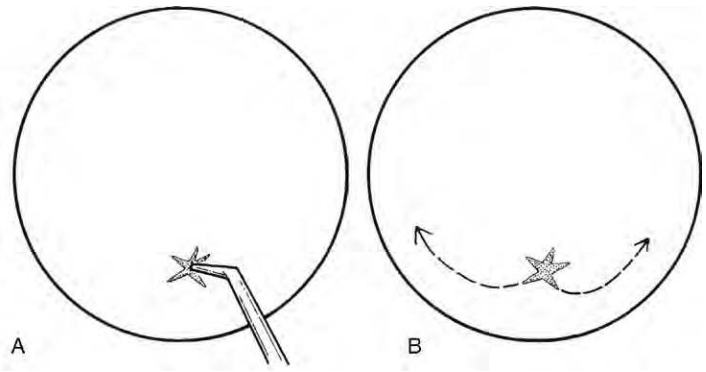

Fig. 17.16 (A) Use of a blunt needle to puncture the capsule in the periphery may create a stellate burst with outward pointing edges from which peripheral tears may originate. (B) After a stellate opening, a continuous curve capsulorrhexis can be achieved by tearing in both directions from the most peripheral edges of the stellate opening.

Because femtosecond lasers involve using suction to approximate the applanation cone against the cornea, a process referred to as docking, it is very important to minimize the chance of losing suction during the ablation (Fig. 17.23). Fortunately, if one does lose suction, the surgeon can carry forward with manual cataract surgery techniques and not have to cancel the surgery. This is in comparison to femtosecond laser flap creation in which the surgeon must use caution to reapply suction and finish the ablation in the same plane. In flap surgery, there is a chance the case will need to be canceled.

It is helpful in any femtosecond laser surgery to minimize this suction loss chance by optimizing our handling of the patient. Educating the patient right before the ablation is very helpful. The following sequence is helpful to calm patients and optimize their contribution to a quality femtosecond laser surgery result:

1. Tell them that they will feel pressure and that their vision will dim or black out, but they will find it is quite tolerable and that it does not last long at all.
2. Tell them there are basically three things they need to remember when they feel the pressure and their vision dims out:

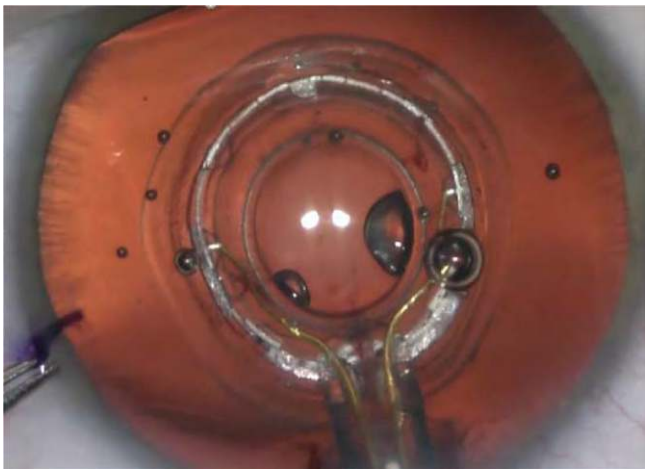

Fig. 17.17 The Zepto PPC uses a nitinol ring in a silicone cup to achieve suction of the capsule followed by a 4 msec electrical pulse to achieve a 360-degree capsulotomy. It can serve as both a capsulotomy device and a guide.

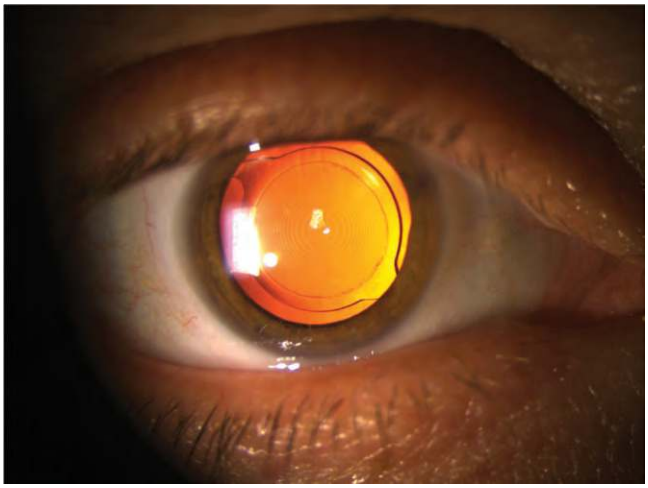

Fig. 17.20 Zepto capsulotomy day 1 postoperation showing the edges of the cut capsule collagen.

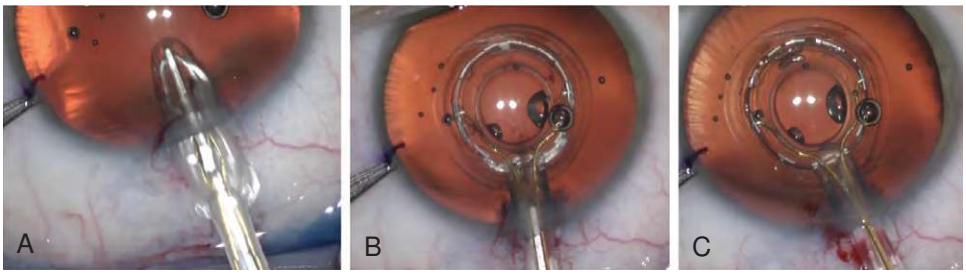

Fig. 17.18 Through the primary incision, the transparent PPC suction cup is inserted (A) and the patient is instructed to fixate on the microscope light selected by the surgeon while the surgeon looks through the preferred eyepiece. The PPC device is then centered on the Purkinje PI/PIV aligned image (B), which marks the patient's visual axis, and a capsulotomy is performed (C). The resulting capsulotomy preserves the visual axis information and acts as a reference marker (in addition to the Purkinje images) to guide IOL centration on this axis.

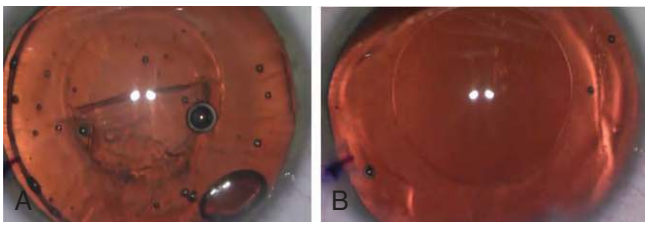

Fig. 17.19 The Zepto PCC performed in Fig. 17.17 is free floating (A) and is well centered and round before IOL implantation (B).

- Do not let the head drift down or back.
  - Explain that, while patients do understand holding still, at times they do not realize that they are slowly drifting away.
  - Explain that it is the slow drift that we want to prevent.
- Do not move anything, even fingers and toes.
  - Even finger and toe movement can move the whole body.
- Do not talk; talking creates movement.
  - Comfort them by telling them that there will not be any surprises and that there will be reminders of the above during the laser process.

Patients appreciate this coaching on the docking process. Talk in a calm voice, sometimes called *verbal anesthesia* or *vocal local*, during

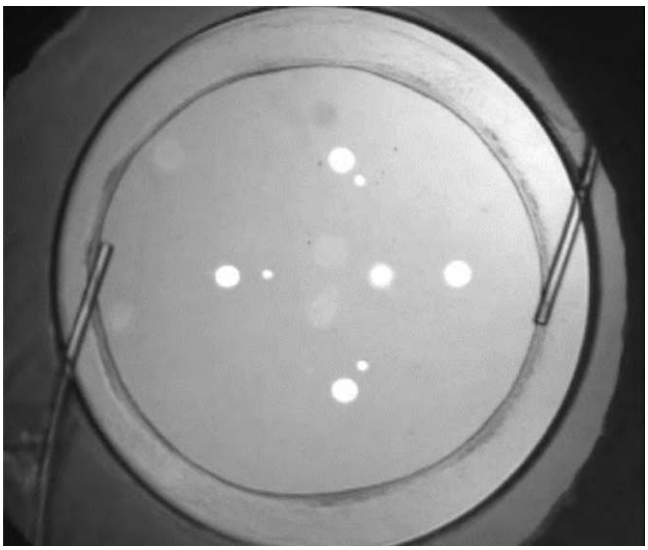

Fig. 17.21 Zepto capsulotomy 3 weeks postoperation in a light-adjustable lens patient showing a well-centered capsulotomy with great overlap and smooth edges.

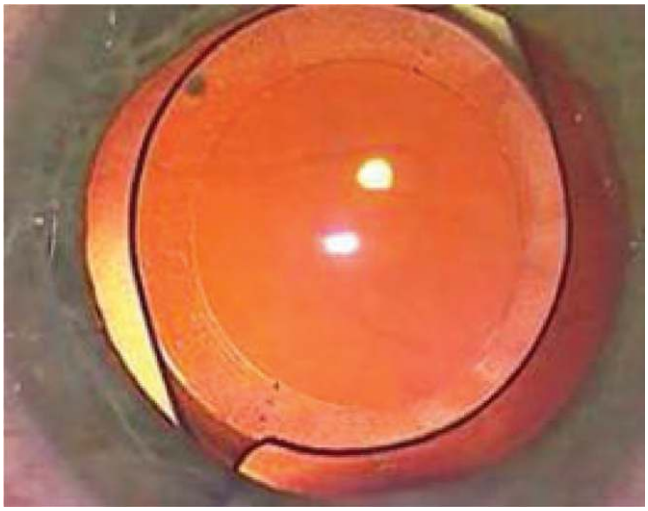

Fig. 17.22 Femtosecond capsulotomy with smooth edges. With OCT guidance and centering, the capsulotomy on the lens consistent 360 degrees of optic overlap can be accomplished with the femtosecond laser.

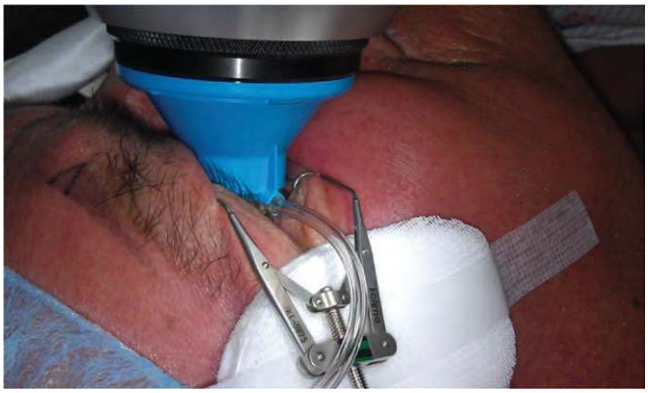

Fig. 17.23 Performing a capsulotomy with a femtosecond laser involves the important step of coupling the patient's eye to the laser in a process known as *docking*.

the whole process and never let them be in silence. By following these guidelines, you will find that it is very rare to lose suction during the femtosecond laser ablation.

All femtosecond lasers used for cataract surgery operate slightly differently. Regardless, all platforms first acquire OCT image before energy delivery. In most femtosecond lasers, this sophisticated image will give the surgeon the choice to center the capsulotomy on the pupil or the capsule. Because the implant will find its home close to the center of the capsule, and because we want to center the capsulotomy on the implant, centering the capsulotomy on the lens is the preference. Excellent 360 degrees of capsule overlap of the optic can be achieved with this method.

COMPLICATIONS AND SPECIAL SITUATIONS

Each step of cataract surgery prepares the surgeon for the subsequent steps. Early in the procedure, the capsulotomy must be performed well to avoid more significant complications such as a dropped nucleus or vitreous loss. Here is a list of the most common capsulotomy complications.

Complications

Article I. Radial Extension

As the manual capsulorrhexis is performed, poor control or posterior pressure can lead to radial extension of the edge toward the equator of the lens. If recognized promptly, the flap can safely be redirected toward the center. The most important step is to resolve the posterior pressure by reforming the anterior chamber with viscoelastic. Using the "Little" technique, the capsule flap is grasped, and force is applied in the same plane but opposite direction to redirect the flap centrally[52] (Fig. 17.24). If this technique does not work, the capsulorrhexis can be completed from the other direction, or the edge can be cut with intraocular scissors and then completed.

If the run-out extends to the lens equator, it will often stop at the zonules where forces are redistributed. However, without careful maneuvering, the run-out can radialize posteriorly, leading to nucleus drop and vitreous loss. A radial tear does not preclude placement of an IOL in the capsular bag, but careful insertion with positioning of the haptics 90 degrees from the tear should be performed.

Article II. Discontinuous Edge

Without a CCC, the forces are distributed focally into the area of discontinuity. This can quite easily result in an anterior capsular rent (Fig. 17.25). The major causative factors in this instance are completing the capsulorrhexis "from inside outward," nicking an originally intact margin with the second instrument during lens extraction, or breaking the rim with the activated phaco tip. A discontinuity in an otherwise intact CCC margin will, in most cases, extend into a radial tear into the capsular fornix; it will do so very readily because the distensive forces will concentrate on this single point of weakness. The risk for this radial tear extending around the capsular fornix into the posterior capsule increases with sparse and friable zonules and with all maneuvers that distend the anterior capsular opening, such as hydrodissection, expression of the nucleus, nuclear fracturing techniques that rely on pushing the nuclear sections widely apart, and IOL implantation maneuvers.

The femtosecond laser typically produces perfectly round capsulotomies by generating thousands of confluent perforations. On occasion, because of media opacities, suction loss, or improperly calibrated machinery, an incomplete capsulotomy is created. As such, it is critical that the surgeon ensures all capsular tags are released before removal of the capsulotomy to ensure that the edge is continuous. Even with a perfect capsulotomy, capsular discontinuity can occur. If the edge of the capsulorrhexis is struck with the phaco tip, a discontinuous edge can form.

TECHNICAL TIPS

The most important rule is to always close the circle from outside inward. This will automatically occur when starting the tear somewhere in the center of the capsule, as described earlier (Fig. 17.26). If the flap breaks off during the course of the tear, the surgeon must be sure to grasp the remaining flap and continue the outward pointing tear edge. When a discontinuity happens, timely recognition is of key importance. Its edge must instantly be grasped with forceps and blunted off by blending into the main contour. When a tear has occurred into the capsular fornix, utmost caution is warranted not to extend the tear further by avoiding the previous risk factors. A relaxing counterincision opposite the first tear may be considered. A radial tear does not preclude capsular bag implantation if manipulations are appropriately gentle. The lens haptics should be placed at 90 degrees from the radial tear. Such a tear is a relative contraindication for implantation of plate haptic IOLs.

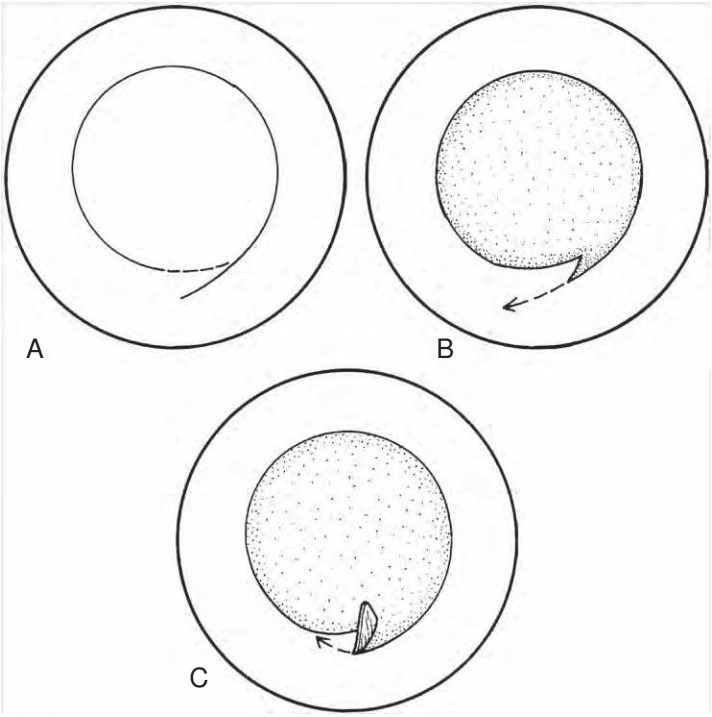

Fig. 17.24 (A) Illustration of a capsulorrhexis that is progressively enlarging so that it finishes from the inside toward the outside. (B) Discontinuity in the capsule is created by an inside-to-outside finish. From that point, a peripheral tear may originate. The same situation results when a previously intact capsulorrhexis margin is cut with an instrument or with the phacoemulsification tip. (C) Discontinuity in the capsule is created by an inside-to-outside finish. From that point, a peripheral tear may originate. The same situation results when a previously intact capsulorrhexis margin is cut with an instrument or with the phacoemulsification tip.

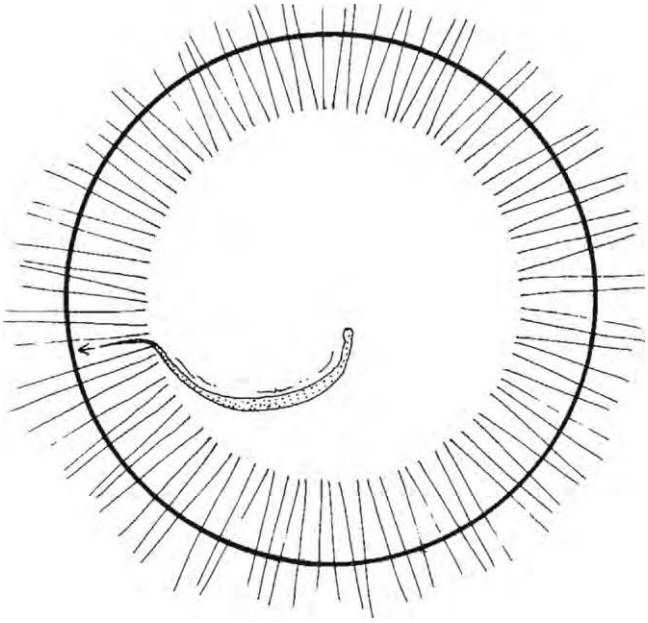

Fig. 17.25 When a capsular tear encounters a zonular fiber, the resulting zonular forces direct the tear peripherally toward the equator.

Article III. Improperly Sized

Capsulotomy size is important for both the safety of the procedure and refractive stability postoperatively. When a capsulotomy is too small, hydrodissection may result in an incomplete fluid wave and fluid trapped behind the nucleus. The excessive pressure that can only be relieved posteriorly by rupturing the capsule, and with a posterior capsule rupture this early in the case, the odds of dropping the nucleus are high.[28] With a small capsulotomy, there is a significant risk for developing postoperative capsular phimosis requiring Nd:YAG anterior laser capsulotomy.[10,11] If the surgeon realizes that the diameter of the CCC is becoming smaller than desired, he or she may just continue the tear in a spiral manner until the desired diameter is reached (Fig. 17.27).

When a capsulotomy is too large, there is inadequate overlap of the optic, predisposing the lens to decentration and tilt.[12]

Article IV. Capsular Block

It is critical to evacuate all of the viscoelastic from behind the IOL at the completion of the case. If left behind, viscoelastic will quickly hydrate, leading to significant posterior pressure that can shift the lens-iris diaphragm anteriorly, resulting in angle closure. To relieve the pressure, the Nd:YAG laser can be used to create a small capsular opening peripheral to the optic anteriorly. If there is inadequate visualization, a posterior capsulotomy may be necessary, resulting in evacuation of viscoelastic into the vitreous. This can lead to intraocular pressure, cystoid macular edema, and prolonged healing.

Special Situations

1. NO RED REFLEX

When there is no adequate reflex from the fundus to retroilluminate the surgical site for visualization, other clues must be used to "detect" the capsular margin to control the tear at every moment. The introduction of capsular dyeing, usually with trypan blue, is certainly the most notable progress in solving problems of visualization of the anterior capsule. Additional help can be contributed by other technical details; for instance, inclining the eye slightly with regard to the observation and illumination paths can sometimes

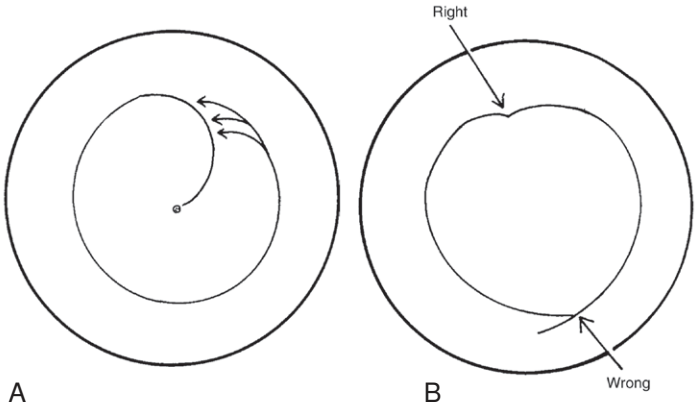

Fig. 17.26 (A) Starting the capsulorrhexis from the center makes it virtually impossible to end in an inside-out fashion. Creating a continuous margin is much more likely. (B) When a capsulorrhexis is completed correctly, a small centrally pointing tag is created. When the capsulorrhexis is incorrectly finished, a discontinuity occurs.

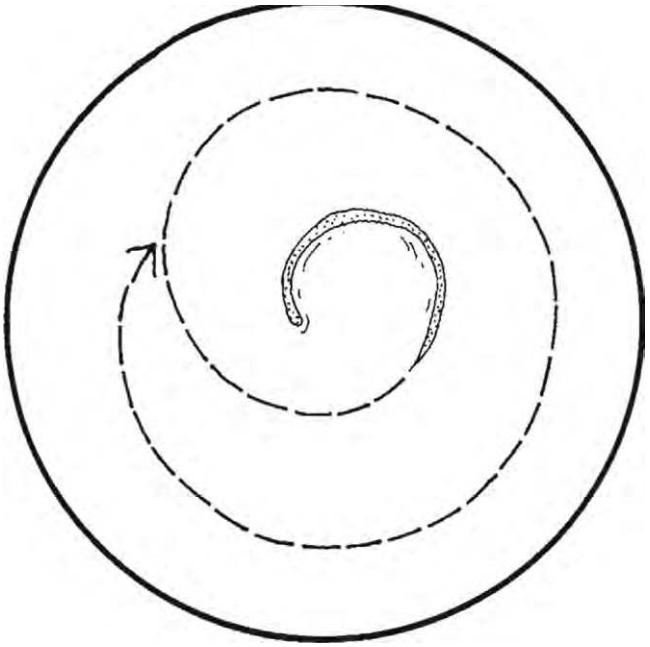

Fig. 17.27 In performing the capsulorrhexis, the surgeon may realize that the original arc is too small. The capsulorrhexis can be expanded by "spiraling" outward to the desired diameter and then "closing the circle."

produce enough of a red reflex to safely proceed. Also, side illumination, in addition to, or instead of, coaxial illumination, can be helpful. Often, one can benefit from the orange skin-like specular reflex of the coaxial light source on the capsule. Constant manipulation of the eye position in such a way that the progressing tear edge remains in that reflex zone outlines the tear very clearly. Also, one should always choose as high a magnification as possible that does not interfere with the necessary overview. Finally, proceeding slowly in small steps and with frequent regrasping will help the surgeon not to lose control of the flap.

2. **THE SMALL PUPIL**

   In addition to precluding visualization of the capsular area where one wishes to place the tear, the small pupil, in most instances, also causes reduction of the red reflex. Therefore all of the previous measures are advisable as needed. When the pupil is smaller than the desired capsulorrhexis diameter, one may combine different principles. With experience, the surgeon will be able to tear a capsular flap "blindly," larger than the pupil diameter. Starting from the capsular center within the visible pupillary area will ensure completion from "outside in." If one chooses to start the capsulorrhexis from the peripheral circumference, the needle may be used to retract the pupillary margin to the desired eccentricity, sliding along it while creating the initial slit and developing the flap away from the site of entry. Previous dyeing of the capsule with trypan blue can be helpful in judging the flap diameter. Measures to increase the pupillary diameter may include injection of atropine and/or epinephrine into the anterior chamber; filling the chamber with viscoelastic; peeling off the fibrous lining of the posterior aspect of the pupil, which so often limits its dilation; dilation of the pupil with self-retaining hooks or dilators (e.g., Malyugin ring), or only local dilation of the pupil with a second instrument through a second paracentesis, sliding along the pupillary edge with the progression of the tear.

3. **POSITIVE PRESSURE**

   Positive pressure tends to force the tear outward. Therefore these cases require an intentionally small diameter to begin with, which can be widened as soon as the pressure is relieved, and continuous, pronounced centripetal traction in small steps, regrasping frequently close to the tear edge. Loosening the lid speculum, adding more viscoelastic to help flatten the lens and exerting counterpressure by pushing the lens back with viscoelastic are helpful techniques to counteracting the positive pressure.

4. **INFANTILE/JUVENILE CAPSULE**

   The special challenge in infantile and juvenile capsulotomy is the increased elasticity of the lens capsule. When placing tension on an anterior capsule flap, it will first distend considerably before propagating the tear; once the tear starts, it has a great propensity to get lost outward because of the tractional "preload" and the elasticity, creating a pronounced outward pulling vector force. It is therefore advisable to aim for a tear that is smaller than one really wishes it to be because it will become wider by itself. The capsulorrhexis tear should progress slowly, in small steps, and with frequent regrasping and directing the tearing more centripetally than for a typical adult cataract. The disadvantage of the extreme elasticity, however, has a positive side also. Should a discontinuity in the capsulorrhexis margin occur, it is, for the same reason, less likely to progress peripherally when due caution during surgery is maintained.

TECHNICAL TIPS

- The intumescent lens combines the difficulties of positive pressure with those of a lack of red reflex. Filling the anterior chamber with a thick viscoelastic is advisable to block opaque liquefied cortex from leaking into the aqueous humor and compromising visibility. Usually a forceps technique is preferable because the cortex is liquefied and therefore presents no resistance to a needle tip. The second major problem is the increased pressure within the capsule as a result of the swollen lens, which increases the risk of uncontrollable extension of the partially completed capsular opening to the periphery. The surgeon must try to counteract this tendency by filling the anterior chamber with a high-viscosity viscoelastic to the extent of indenting the anterior lens pole. Sometimes one can decompress the lens by making a small puncture in the central anterior lens and aspirating some of the liquid content through the puncturing needle
- The only situation in which capsulorrhexis is impossible in principle is the totally fibrosed capsule. Cases of heavy fibrosis or fibrous plaques extending so far peripherally that one cannot tear around them without hitting zonules mandate the use of scissors to cut through the fibrosis. The scissor cut should end just barely at the margin of the fibrosis, and from there on into regular capsule the opening should be continued as a tear.
- With proper recognition, complications involving the capsulotomy can be rescued, resulting in a safe surgery with excellent outcomes.

POSTERIOR CAPSULORRHEXIS

Leaving the posterior capsule intact is one of the major objectives of extracapsular surgery. Nevertheless, this goal cannot always be attained. Examples are a dense, nonremovable posterior capsular opacification that will doubtlessly interfere significantly with vision; an infantile cataract in which rapid opacification of the posterior capsule is inevitable and Nd:YAG laser capsulotomy is impractical or, most frequently, accidental posterior capsular rupture. In all of these cases, the opening in the posterior capsule should have the same quality, if possible, as that of the anterior capsulorrhexis, namely being not further extendable because of a continuous smooth margin. This can be obtained by applying the same technique of capsulorrhexis as that of the posterior capsule. In cases of intentional posterior capsule opening, the posterior capsule should be nicked centrally with a needle tip. Viscoelastic is injected through the first tiny triangular defect to separate and posteriorly displace the anterior vitreous face, and the posterior capsular triangle is grasped by capsular forceps and torn out as a curvilinear posterior capsulorrhexis.

When an unintended capsular defect occurs, extension can be limited by the same technique as long as the original posterior capsule rent is limited enough to permit this. This technique will then preserve a capsular bag into which an IOL can be implanted securely, maintaining all the advantages of intracapsular implantation.

SUMMARY

Giants in our field have emphasized the clinical significance of the capsulotomy and the surgical importance of achieving 360 degrees of overlap of optic by the anterior capsule. Its importance is recognized, but it is still a challenge to achieve on a consistent basis. Methods such as P1 and P4 alignment of manual, Zepto, and OCT-guided femtosecond laser can help the surgeon achieve this all-important centration of the capsulotomy. Centering both the capsulotomy and the implant on the visual axis is key to ideal optical performance and long-term patient satisfaction. Early recognition of complications is essential for proper management to retain the ability to place an IOL. Each step of cataract surgery prepares the surgeon for the next step; the capsulotomy is the first major step to set the dynamics for the rest of the case.

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Video 17.1: Capsulotomy.

18

Hydrodissection and Hydrodelineation

Ashvin Agarwal, Priya Narang, and Ashraf Freddie Ahmad

CONTENTS

KEY POINTS

- Avoid overdistention of the capsular bag with fluid while performing hydrodissection.
- Perform hydrodissection from the main corneal wound rather than side port incision.
- Viscodissection might reduce the incidence of posterior capsule rupture in posterior polar cataracts.

INTRODUCTION

Hydrodissection (Fig. 18.1) is one of the crucial steps of the phacoemulsification procedure, the efficacy of which often decides the outcome of the surgical maneuver. In 1984 Faust coined the term *hydrodissection*[1] followed by Apple et al.[2] who analyzed the technique in a study on human cadaver eyes in a laboratory setting. In 1990 Koch et al.[3] described multilamellar hydrodissection wherein fluid is injected in multiple lamellas of the lens, thereby creating multiple layers of cortex and a central small nucleus. In 1992 Howard Fine clinically documented and described the procedure as cortical cleaving hydrodissection[4] in a subgroup of patients and reported that fluid, when injected beneath the anterior capsule, generates a visible fluid wave that traverses the equator, progresses further and separates the posterior capsule from the cortex, and finally emanates from the anterior capsular rim from the opposite side.

The term *hydrodelineation*, described by Anis,[5] involved separating the epinucleus from the central dense nuclear mass or the endonucleus (Fig. 18.2).

HYDRODISSECTION SURGICAL TECHNIQUE

The type of cannula chosen for hydro procedures may vary from round tip to flat tip, with diameters ranging from 30 g to 25 g. These cannulas are typically attached to a 3- or 5-mL syringe, which offers enough hydrostatic force and volume to achieve the desired fluid wave. Many surgeons prefer to use right-angled or J-shaped cannulas because they allow for easier and more precise cleavage of the subincisional cortex. The Chang cannula has a 27-g bore with a 90-degree angled flat tip with a beveled opening. This allows the fluid wave to be properly propagated around the lens for both hydrodissection and hydrodelineation. Furthermore, these angled tip cannulas allow immediate rotation of the nucleus after the hydrodissection step without having to change instruments. The importance of the cannula is to allow adequate passage beneath the capsular rim and facilitate the formation of a fluid wave while minimizing fluid egress from the capsular rim.

1. Use the cannula to decompress the anterior chamber by applying downward pressure on the posterior lip of the main corneal incision to allow egress of excess viscoelastic. This maneuver creates additional room inside the anterior chamber to accommodate the fluid that will be subsequently injected inside the capsular bag.
2. With the hydrodissection cannula, tent up the edge of anterior capsular rim and allow the tip to pass around 1 to 2 mm below the anterior capsular rim.
3. Once the cannula is properly placed and the anterior capsule is elevated, gentle and continuous irrigation results in a fluid wave that passes circumferentially in the zone just under the capsule, cleaving the cortex from the posterior capsule. As more fluid is injected, the fluid wave can be seen traversing and emanating around the lens (Fig. 18.3).
4. Care should be taken to avoid overinflation and overdistention of the bag with fluid as excess fluid can lead to elevated pressure in the capsular bag, increasing the risk for rupture and/or iris prolapse.
5. At this point, if fluid injection is continued, a portion of the lens may prolapse through the capsulorrhexis and into the anterior chamber. This is desirable if the surgeon is using a supracapsular technique for nuclear disassembly or in cases of weak zonular support. However, for most nuclear disassembly techniques, lens prolapse is undesirable.
6. If unintended lens prolapse occurs, the surgeon can reposition the lens in the posterior chamber with injection of viscoelastic and gentle posterior pressure. Lens prolapse can be avoided if the capsule is decompressed by depressing the central portion of the lens with the side of the cannula in a way that forces fluid to come around the lens equator from behind, thereby allowing fluid to exit from the capsular bag via the capsulorrhexis.
7. The capsulorrhexis will then constrict to its original size, and the lens will mobilize in a way that it can spin freely within the capsular bag.
8. Hydrodissection can be performed in multiple quadrants to ensure total cortical cleaving and free rotation of the nucleus.

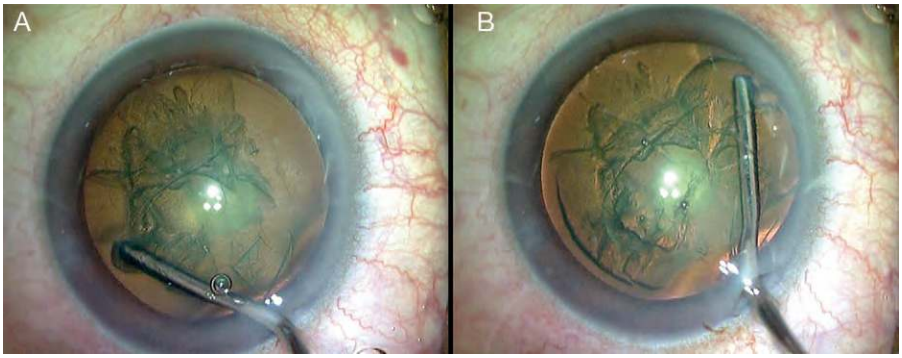

Fig. 18.1 Clinical images of hydrodissection. (A) The cannula is being placed beneath the capsular rim. (B) Multiple quadrant hydrodissection being done.

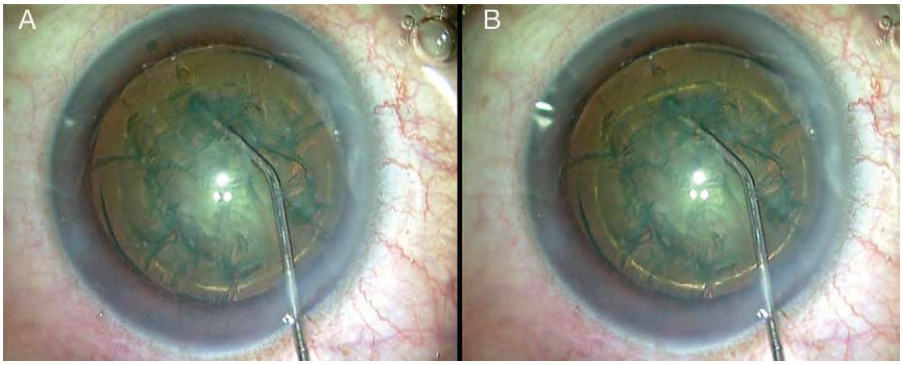

Fig. 18.2 Clinical images of hydrodelineation. (A) The cannula is placed in the lens, and fluid is injected to separate the endonucleus from the remaining lens cortex. (B) Golden ring is visualized.

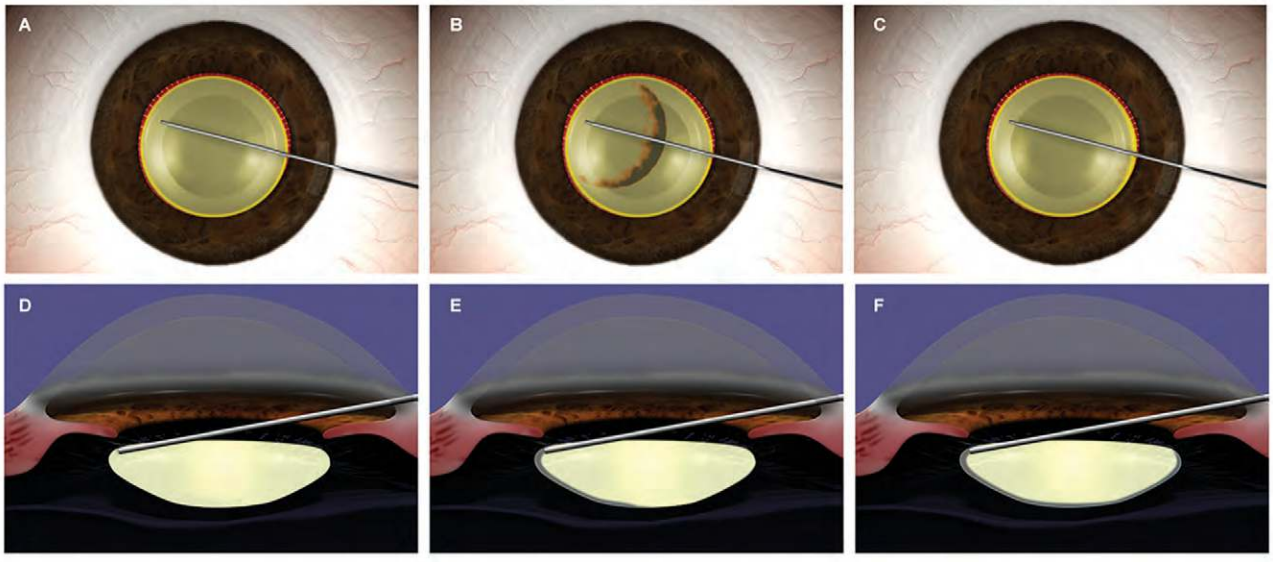

Fig. 18.3 Animation describing hydrodissection procedure. (A and D) A 30-g cannula is placed beneath the anterior capsular rim for performing hydrodissection. (B and E) Fluid is injected beneath the anterior capsular rim. Fluid wave is appreciated sweeping across the equator to the posterior pole of the lens. (C and F) Hydrodissection is complete, and the fluid wave traverses all around the equator and separates the cortex from the lens capsule.

9. In cases of zonulopathy, avoid excessive downward pressure on the lens during decompression. A bimanual technique can be used to rotate the lens in these cases to reduce excessive force on the remaining intact zonules. In severe zonulopathy, it is often safest to place capsular hooks and/or a capsular tension ring to stabilize and mobilize the capsule prior to proceeding with nuclear disassembly.

There are certain situations in which special consideration should be made when performing hydrodissection. For example, in femtosecond laser-assisted cataract surgery, laser is applied for fragmentation causing gas buildup to occur, which increases the tension in the capsular bag. Therefore it is important to titrate the force with which hydrodissection is performed and avoid aggressive fluid injection,

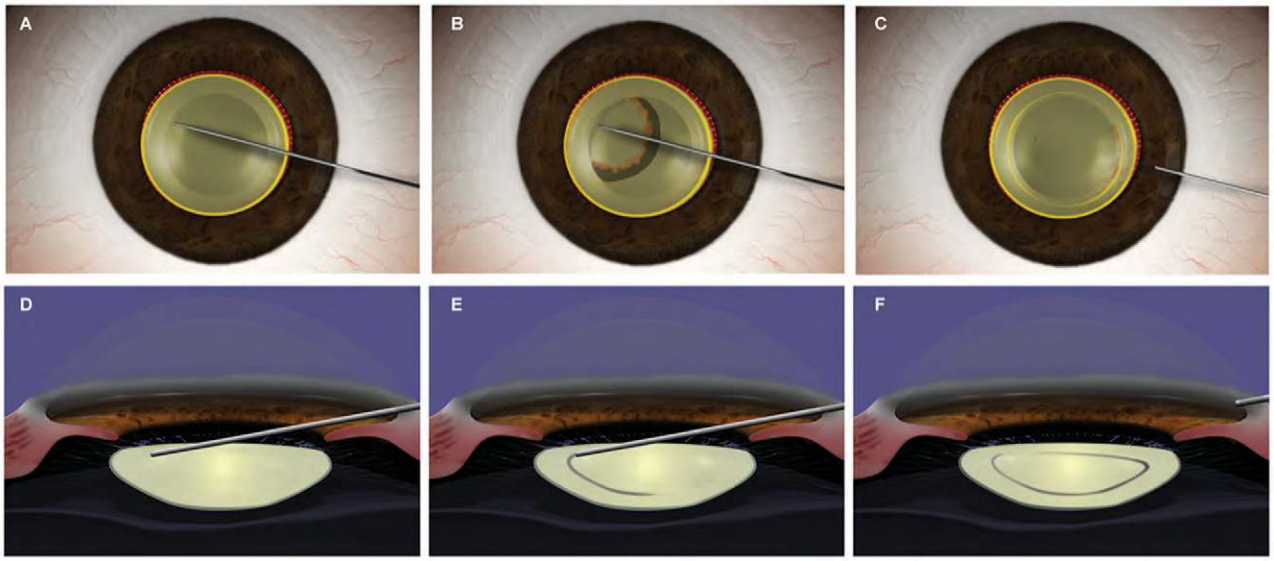

Fig. 18.4 Animation describing the hydrodelineation procedure. (A and D) The cannula is embedded into the lens cortex, and fluid is injected. (B and E) This creates a plane separating the epinucleus from the endonucleus. (C and F) Hydrodelineation is complete, and golden ring is appreciated.

which can lead to capsule rupture. In cases of intraoperative floppy iris syndrome or short eyes, hydrodissection is a high-risk step for iris prolapse as increased intracapsular pressure can precipitate iris prolapse from the main incision. The risk for iris prolapse can be mitigated by initially creating a longer main incision. Additionally, hydrodissection can be carried out from the sideport to maintain pressure dynamic in the anterior chamber.

HYDRODELINEATION SURGICAL TECHNIQUE

Using the same hydrodissection cannula as previously described, the cannula is placed in the nucleus, off center to either side, and directed at an angle downward and forward toward the central plane of the nucleus. At this point, the cannula is directed tangentially to the endonucleus, and a gentle but steady pressure on the syringe allows fluid to enter the path of least resistance, which is the junction between the endonucleus and the epinucleus. This often creates a golden ring that is considered to be pathognomonic of complete hydrodelineation (Fig. 18.4).

DISCUSSION

Total removal of cortical material is essential during irrigation-aspiration and an effective hydrodissection performed in the initial stages contributes significantly to its success. The passage of the fluid wave through the margin of the capsulorrhexis along the internal posterior capsular envelope helps to dissect the cortex and nucleus from the entire posterior capsule and ensures free and total rotation of the nucleus. Lens rotation after hydrodissection allows for cleavage of the equatorial epithelial cells. This has been shown to decrease the rates of posterior capsule opacification in the postoperative period.[5,6]

Multiquadrant cortical cleaving hydrodissection has also been described to facilitate removal of cortex.[7] Fluid injection into the body of the lens leads to a successful hydrodelineation.[3] In cases with suspected posterior capsular defect, such as in a posterior polar cataract, hydrodissection should be avoided and a careful hydrodelineation should be performed to separate the nucleus from the epinuclear shell without disturbing the cortex and enlarging the potential posterior capsule defect. Viscodissection has been advised for such cases in which a dispersive viscoelastic is injected, instead of fluid, between the cortex and the capsule to attain a cleavage plane. The benefit of such a maneuver is reduced risk for posterior capsule rupture as it acts as a cushion for the posterior capsule and additionally tamponades the vitreous in inadvertent rupture.[8,9] Vasavada et al.[10] described "inside-out" delineation to precisely delineate the central core nucleus. After creation of a central trench, a right-angled cannula is made to penetrate the central lens from the right wall of the trench. Fluid is injected and delineation is achieved as the fluid wave traverses from inside to outside.

Patients with ocular conditions like traumatic cataract, previously vitrectomized eyes, and pseudoexfoliation should be handled with caution during hydro procedures caused by associated weakness of the zonules and the posterior capsule.

Although the hydro procedures are simple to perform, their importance in the successful outcome of cataract surgery cannot be underestimated. Surgeons should master this step to optimize their success for every subsequent step of the surgery.

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PART IV

Nuclear Disassembly

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Basic Principles of the Phacoemulsifier

Kenneth L. Cohen

CONTENTS

OVERVIEW

Components of the Phacoemulsifier

The goal of the phacoemulsifer is to use ultrasound energy to emulsify the cataract and aspirate the lens material while maintaining a well-formed anterior chamber (AC). The balanced salt solution (BSS) in the irrigation bottle maintains the intraocular pressure (IOP) based on active or passive fluid dynamics (Fig. 19.1). The balance between inflow and outflow is a function of the irrigation bottle height, the pinch valve being open or closed, inflow through the silicone sleeve with irrigation ports, outflow controlled by the pump, leakage from incisions, and the fluidic circuit of the BSS. The foot pedal functions control emulsification, inflow, and outflow.[1]

The foot pedal has two modes: with and without phaco power (Fig. 19.2). Without phaco power (IA mode), the foot pedal has three positions: 0 resting, 1 irrigation (I), and 2 irrigation and aspiration (I,A). With phaco power (phaco mode), the foot pedal has four positions: 0 resting, 1 I, 2 I,A, and 3 I,A and phacoemulsification power (U/S).[2] With an open pinch valve and irrigation fluidic circuit and no occlusion at the aspiration port, fluid exits the AC via the pump and a drain (see Fig. 19.1). In most cases there is some leakage from wounds (main or paracentesis). Because this variable depends on incision construction and technique, for purposes of illustration, the slight amount of wound leakage that happens in most cases will not be included in the descriptions here after.

KEY POINTS

Components

- Phacoemulsifier controls power; pump controls irrigation and aspiration
- Ultrasonic handpiece
- Irrigation sleeve
- Phaco needle
- Irrigation bottle
- Foot pedal

Function

- Ultrasound energy to emulsify cataract
- Pump: outflow to aspirate lens material
- Inflow from irrigation bottle
- Foot pedal position. Phaco mode: 1. Irrigation, 2. Irrigation and aspiration, 3. Irrigation, aspiration, and phacoemulsification power. Irrigation/aspiration mode: 1. Irrigation, 2. Irrigation and aspiration
- Fluidic circuit to maintain well-formed eye

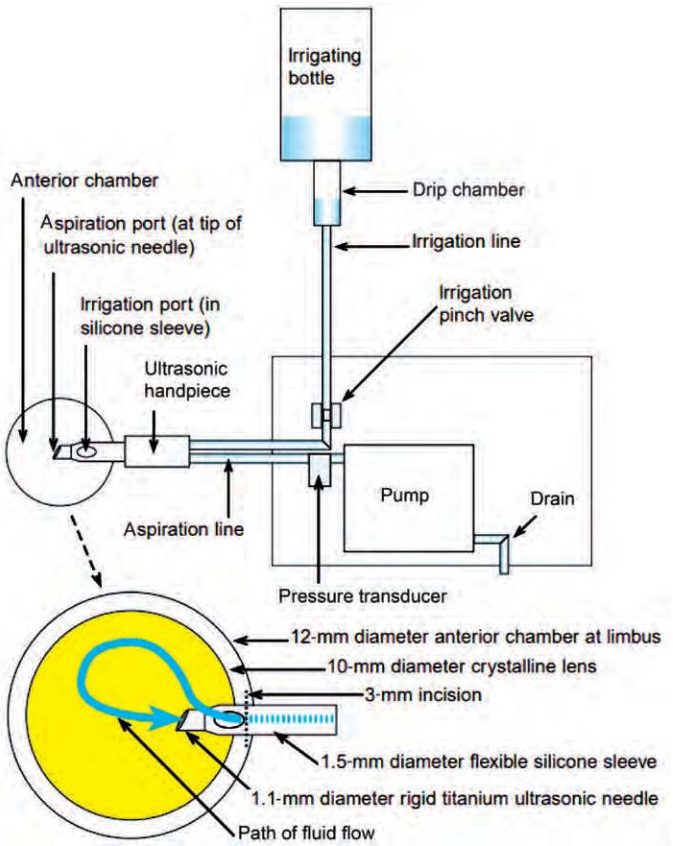


Fig. 19.1 Organization of the phacoemulsifier's fluidic circuit. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

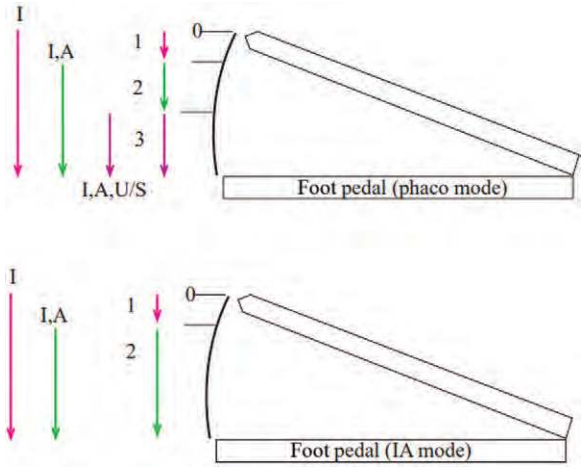


Fig. 19.2 Phaco mode of the foot pedal had four positions. Irrigation-aspiration mode of the foot pedal has three positions: 0: resting; 1: irrigation (I); 2: irrigation and aspiration (I,A); 3: irrigation and aspiration (I,A) and ultrasound (U/S). (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

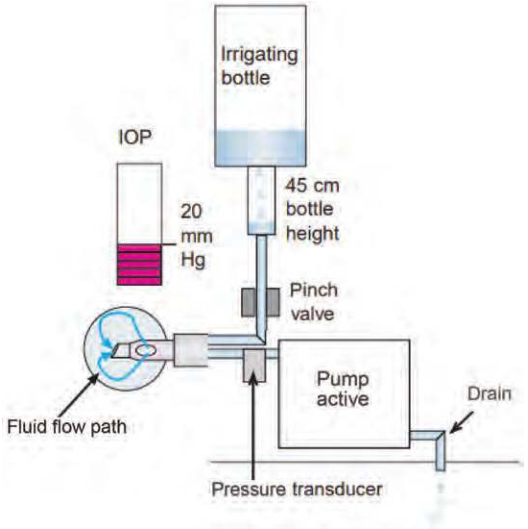


Fig. 19.4 With an open fluidic circuit and an active pump causing aspiration, the IOP decreases. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

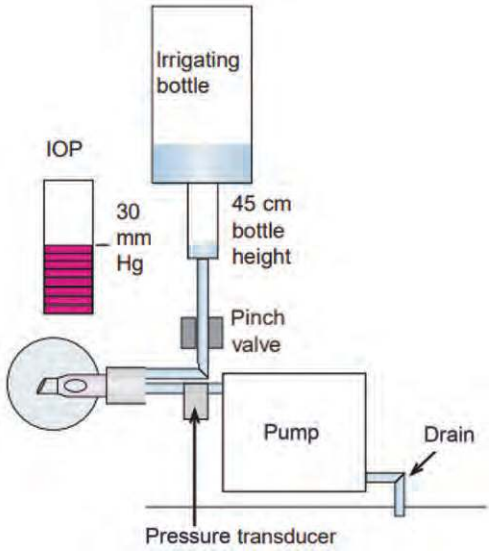


Fig. 19.3 With the pinch valve open and no flow, the bottle height controls the IOP. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

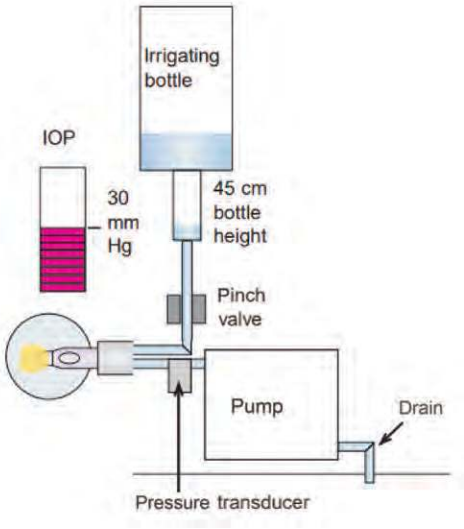


Fig. 19.5 With total occlusion of the aspiration port and an open pinch valve, the bottle height controls the IOP. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

INTRAOCULAR PRESSURE, FLOW, AND ASPIRATION

With an open fluidic circuit and no outflow (no aspiration), the bottle height controls the IOP, (e.g., 45 cm or 17.7 inches = 33 mm Hg) (Fig. 19.3). Increasing the bottle height increases the IOP. With an open fluidic circuit and outflow, the IOP decreases depending on the amount of outflow, which is measured in cubic centimeters per minute (Fig. 19.4 active pump). The pump setting controls the outflow. The faster the outflow, the greater the decrease of the IOP. With active, pump-controlled outflow, partial occlusion of the aspiration port will increase the IOP. Total occlusion of the aspiration port will increase the IOP to that controlled by the bottle height (Fig. 19.5).[3–7] With the pinch valve closed, the IOP is 0 mm Hg (Fig. 19.6).

KEY POINTS

Control of Fluidic Circuit

- Open fluidic circuit: pinch valve open, no aspiration; bottle height controls IOP (height 45 cm = 17.7 inches = 33 mm Hg; increase bottle height increases IOP
- Open fluidic circuit and active aspiration (cubic centimeters per minute) IOP decreases as cubic centimeters per minute increases
- Pump setting controls outflow
- Partial occlusion of aspiration port with constant pump setting will decrease outflow and increase IOP
- Total occlusion of aspiration port with increased IOP to that controlled by bottle height

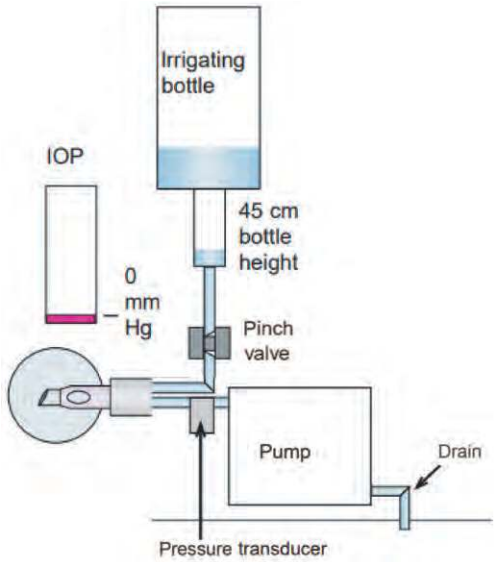


Fig. 19.6 With the pinch valve closed, the IOP will be 0 mm Hg. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

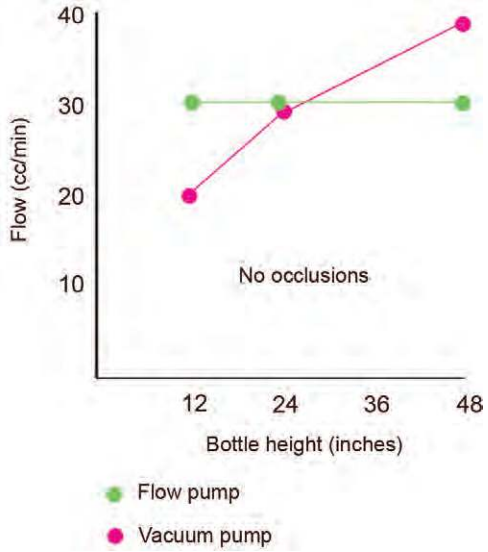


Fig. 19.8 Raising the bottle height does not affect the flow, measured in cubic centimeters per minute (*cc/min; green*), of the flow pump. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

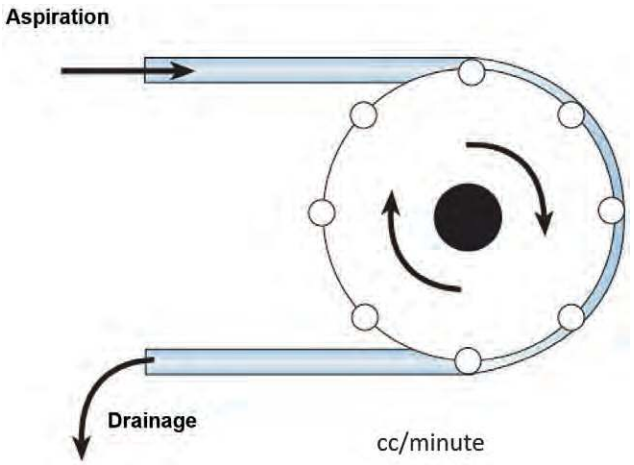


Fig. 19.7 The surgeon sets the rotational speed, measured in cubic centimeters per minute, of the flow pump. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

FLOW PUMP/PERISTALTIC, ASPIRATION, AND VACUUM

The flow pump (peristaltic pump) is set to a commanded rate that is measured in cubic centimeters per minute. The flow pump indirectly controls the vacuum. The flow pump wheel rotates at a specific speed determined by the commanded rate (Fig. 19.7). The flow pump is a fluidic resistor, and raising the bottle height will not increase the outflow rate (Fig. 19.8). Even with no occlusion at the aspiration port, an activated flow pump will create a small pressure differential between the AC and the aspiration line. With partial occlusion of the aspiration port, there is increased fluidic resistance, decreased outflow, and increased vacuum within the aspiration line. The pump pushes harder against the aspiration line to maintain the same rotational speed. With total occlusion of the aspiration port, vacuum increases to the maximum commanded level set by the surgeon, and the pump stops rotating (Fig. 19.9).[6–8]

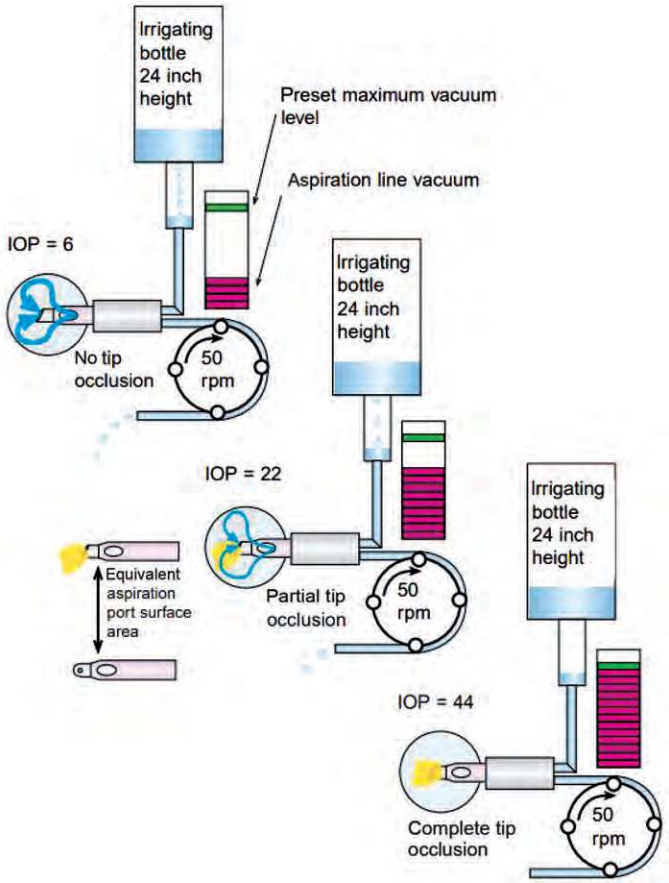


Fig. 19.9 The rotational speed, measured in cubic centimeters per minute, of the flow pump creates a pressure differential between the AC and the aspiration line. With partial occlusion of the aspiration port, the vacuum in the aspiration line increases. With total occlusion, the vacuum in the aspiration line is at the surgeon's commanded level, millimeters of mercury. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

KEY POINTS

Control of Aspiration and Vacuum (Flow Pump/Peristaltic)

- Surgeon sets maximum commanded aspiration flow rate, which is measured in cubic centimeters per minute
- Surgeon directly controls aspiration flow rate with foot pedal
- Pump rotates as set speed to create flow
- Pump active without occlusion creates pressure differential between IOP and aspiration line
- Bottle height does not affect aspiration flow rate
- Surgeon sets maximum vacuum, measured in millimeters of mercury
- Vacuum at pump directly affected by occlusion at aspiration port
- Partial occlusion of aspiration port creates vacuum
- Complete occlusion of aspiration port raises vacuum to preset maximum at pump

VACUUM PUMP/VENTURI, ASPIRATION, AND VACUUM

The most common type of vacuum pump uses the venturi effect. The venturi effect is based on Bernoulli's principle whereby the flow of compressed air through the pump creates a vacuum in the rigid drainage cassette (Fig. 19.10). This vacuum pressure differential pulls BSS into and through the aspiration line. The surgeon sets the maximum commanded vacuum level (in millimeters of mercury) and uses the foot pedal to linearly command a vacuum level, which indirectly controls the aspiration flow rate (Fig. 19.11). Total occlusion of the aspiration port is not required for the vacuum in the pump to increase to the maximum set commanded level (see Fig. 9.11).[6–8] The vacuum pump is not a fluidic resistor. Therefore without total occlusion, increasing the bottle height will increase the rate of outflow (see Fig. 19.8).

KEY POINTS

Control of Aspiration and Vacuum

- Surgeon sets commanded maximum vacuum, measured in millimeters of mercury
- Surgeon directly controls vacuum at pump with foot pedal
- Aspiration flow rate indirectly controlled by commanded vacuum
- Bernoulli's principle: increase vacuum then increase flow rate
- Partial occlusion of aspiration tip decreases flow in the AC but does not affect vacuum at pump

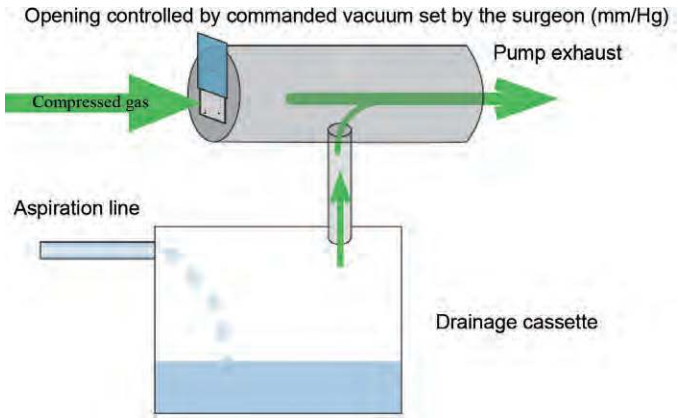


Fig. 19.10 The venturi effect is the pressure differential created by compressed gas flow, which pulls BSS through the aspiration line into the cassette. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

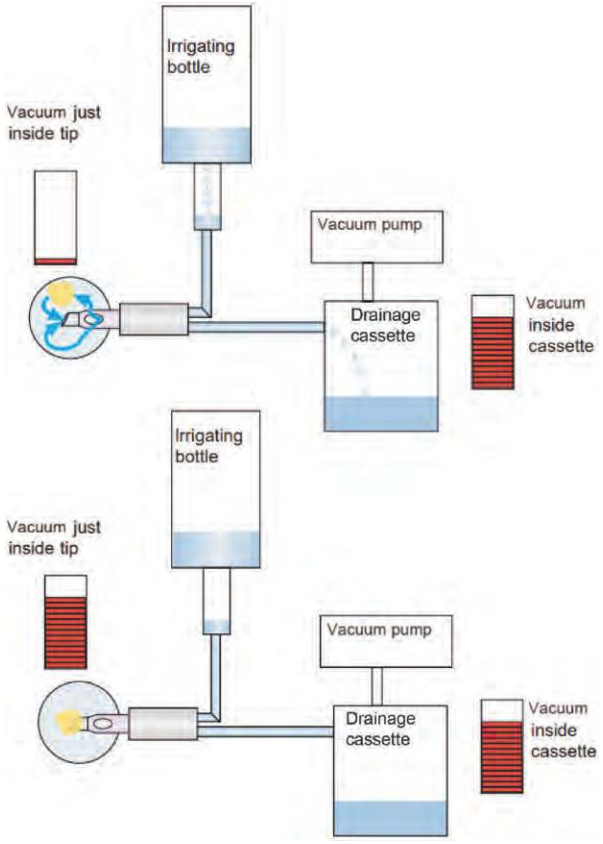


Fig. 19.11 With depression of the foot pedal, the surgeon controls the vacuum, measured in millimeters of mercury, in the pump. Occlusion of the aspiration port raises the vacuum just inside the phaco needle. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

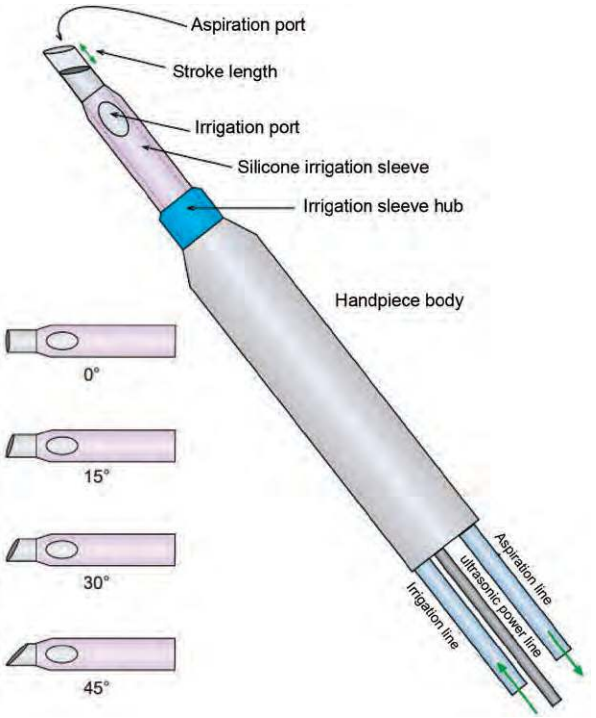


Fig. 19.12 The movement of the phaco needle creates emulsification. Three lines attach to the phaco handpiece, irrigation, aspiration, and ultrasonic power line. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

- Total occlusion of aspiration tip raises vacuum in aspiration line to vacuum at pump
- Without occlusion of aspiration tip, bottle height will affect aspiration flow rate, which is measured in cubic centimeters per minute

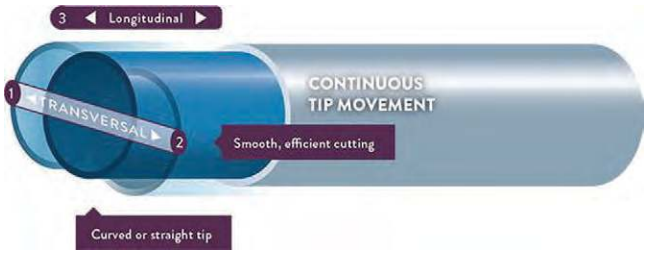


Fig. 19.13 Transversal movement is three-dimensional ellipse created by both longitudinal and side-to-side movements, and a bent or a straight phaco needle can be used to generate the transversal movement. (From Johonson and Johnson.)

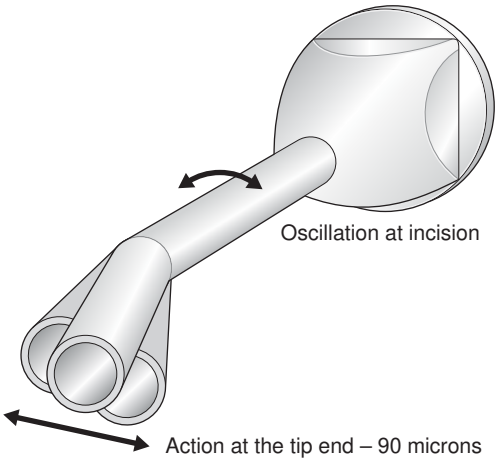


Fig. 19.14 Torsional movement is two-dimensional created by rotation at the incision and requires a bent phaco needle to be effective.

ULTRASOUND POWER AND THE PHACO NEEDLE

The phaco needle attaches to the phacoemulsifier handpiece and moves to create emulsification of the cataract (Fig. 19.12). The rate of linear movement generally is from 25,000 to 60,000 Hz/sec, depending on the specific phacoemulsifier model. Varying the stroke length, under linear control by the surgeon's footpedal, controls the ultrasound power. Depending on the phacoemulsifier, the stroke length is up to 100 microns. Using the maximum axial stroke length equates to 100% phaco power. Forty percent phaco power means that the tip only moves for 40% of the total stroke length in the ultrasound mode. The phaco needle may have additional nonlongitudinal movements, such as ELLIPS (transversal) (Fig. 19.13) and OZil (torsional) (Fig. 19.14), depending on the phacoemulsifier. The three-dimensional transversal movement, a prolate-spheroid movement like an egg cut in half, is created by both side-to-side and longitudinal movements and is generated with either a straight or a bent phaco needle. Two-dimensional rotation at the incision generates the torsional movement, up to 90 microns, and requires a bent phaco needle.

The phaco needle has an aspiration port. Phaco needles come in a variety of configurations and with varied diameters and lumen sizes. There are three functional lines connected to the phacoemulsification hand piece handpiece (see Fig. 19.12). The power line from the phacoemulsifier power unit, the aspiration line from the pump, and the irrigation line from the bottle are connected. Irrigation flows into the AC through two ports in a silicone sleeve that fits over the phaco needle.[1,9–11]

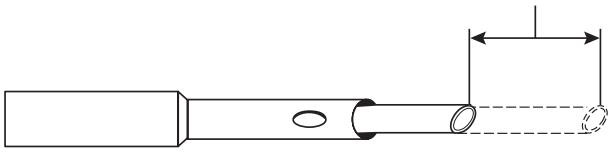


Fig. 19.16 Longer longitudinal stroke length generates increased jackhammer force.

Fig. 19.15 Increasing ultrasound power in foot position 3 increases the axial distance traveled by the phaco tip, thereby increasing the mechanical impact at the tip. This principle is illustrated by comparing the force generated by a hammer with a short stroke length (A) compared with a longer stroke length (B).

KEY POINTS

Function of the Ultrasonic Handpiece

- Phaco needle moves to emulsify lens
- 25,000 to 60,000 Hz/sec
- Surgeon sets percent power, which commands the linear stroke length
- Stroke length up to 100 microns
- Phaco needle has aspiration port
- Silicone irrigation sleeve
- Phaco handpiece has power line, irrigation line, and aspiration line attached

THE FOUR FORCES THAT CREATE EMULSIFICATION

The percent power is the linear stroke length of the phaco needle, up to 100 microns, depending on the phacoemulsifier. This linear movement emulsifies the cataract using mechanical impact, jackhammer effect, at 25,000 to 60,000 Hz/sec, with acceleration of the phaco needle up to 72 km/h (Figs. 19.15 and 19.16).

Movement of the phaco needle produces an acoustic shock wave (Fig. 19.17). This acoustic wave at up to 5400 km/h oscillates the nucleus, breaking down intermolecular bonds.

The forward acceleration of the phaco needle causes a fluid wave. The fluid wave pushes lens particles and fluid away from the moving phaco needle at up to 72 km/h (see Fig. 19.17). This fluid wave is able to break up softer lens material.

Transient cavitation is a controversial component of the emulsification forces (Fig. 19.18). Forward linear movement of the phaco needle pushes and compresses the fluid. Backward linear movement of the needle creates a low-pressure area with formation of cavitation bubbles. The phaco needle's linear movement cycle causes the cavitation bubbles to enlarge and eventually implode, releasing energy that creates microjets of fluid and creates a cavity (see Fig. 19.18). These microjets travel up to 400 km/h and hit the lens material, supposedly contributing to emulsification.[12,13]

KEY POINTS

Linear Movement of the Phaco Needle

- Mechanical impact of phaco needle, up to 72 km/h, jackhammers lens material

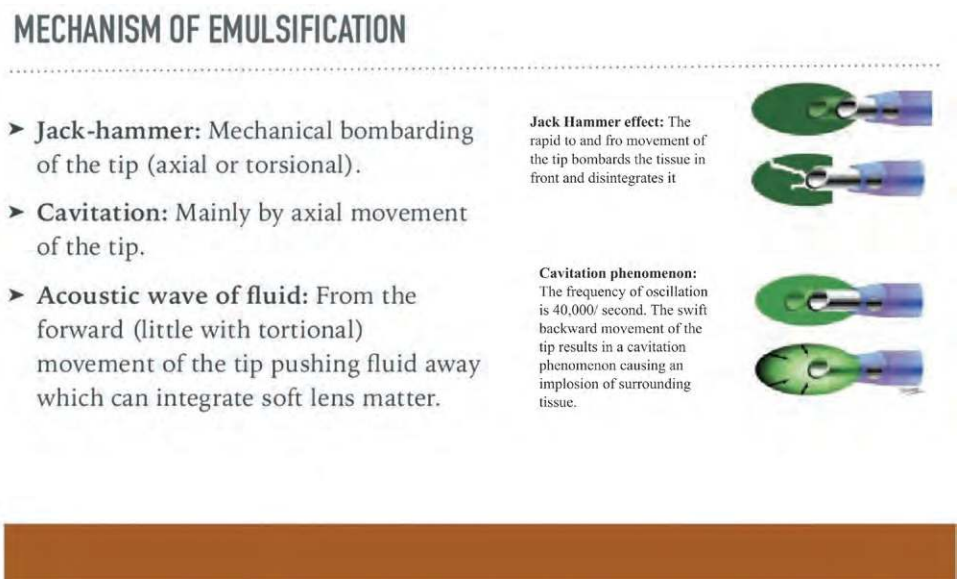


Fig. 19.17 Linear movement of the phaco needle causes a fluid wave and a shock wave that breaks up softer cataract material. (From Dr. Haitham Al Mahrouqi.)

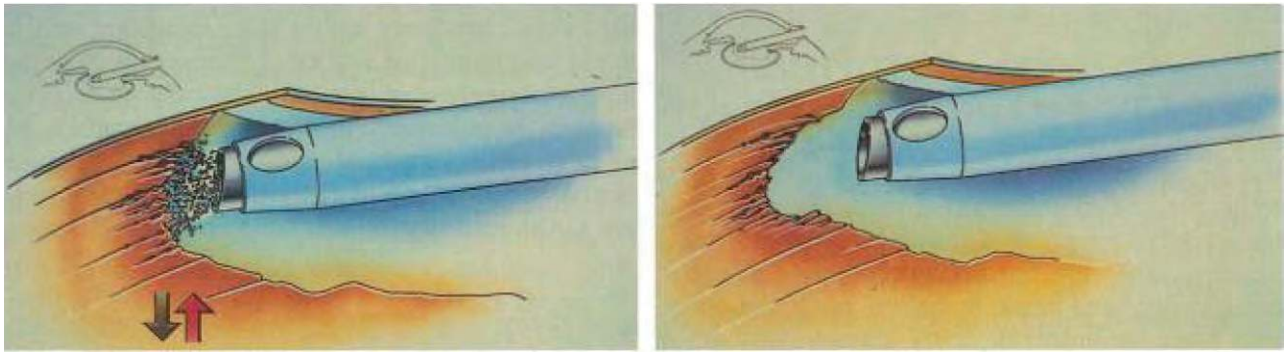


Fig. 19.18 Linear movement of the phaco needle causes a low-pressure area in which cavitation bubbles occur. The bubbles expand and then implode, creating a cavity in the cataract. (From Dr. Ronald L. Pacifico's article, Ultrasonic Energy in Phacoemulsification.)

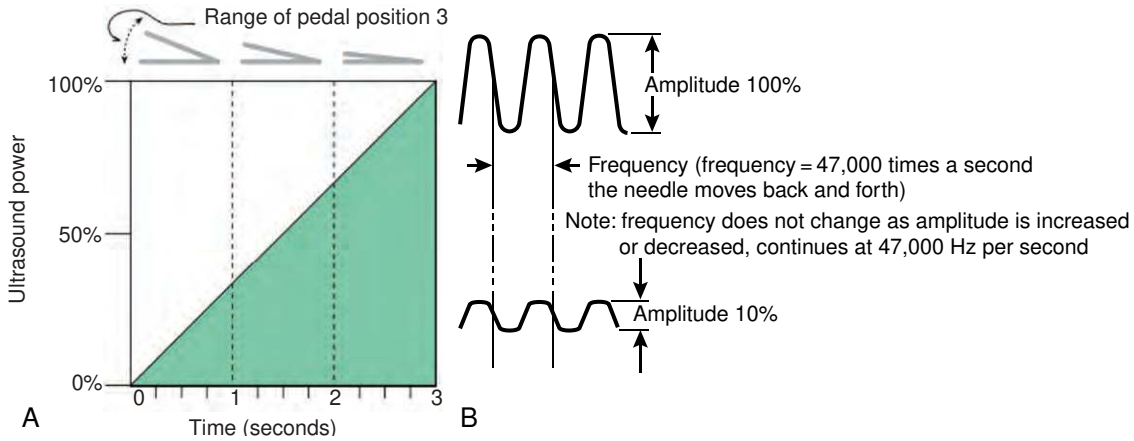


Fig. 19.19 (A and B) With depression of the foot pedal in phaco mode, position 3, the linear amplitude of the stroke length increases. The ultrasound power, jackhammer effect increases, and the set frequency remains constant. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

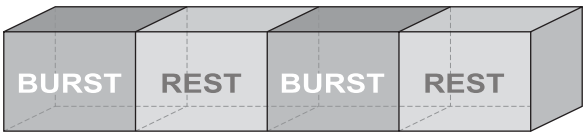


Fig. 19.20 A duty cycle is the percent phaco on time for the total time = burst time + rest time. The burst and rest are for the same length of time resulting in a 50% duty cycle.

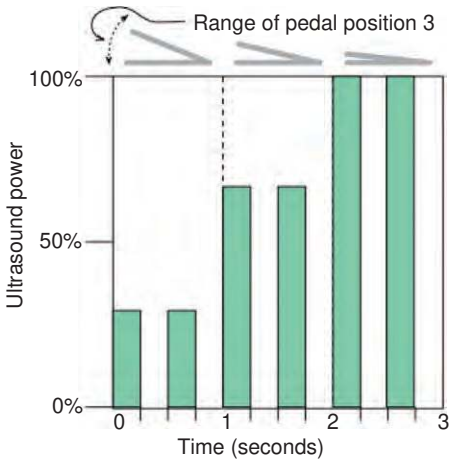


Fig. 19.21 Pulse phaco: duty cycle of 50% with 2 pulses per second. Phaco on is 250 milliseconds and phaco off is 250 milliseconds for a 50% duty cycle over 500 milliseconds; ultrasound power increases linearly with foot pedal depression. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

- Acoustic shock wave up to 5400 km/h breaks intermolecular bonds
- Fluid wave pushes lens particles
- Transient cavitation bubbles implode, which releases energy as microjets of fluid

Continuous, Pulse, and Burst Modes for Phacoemulsification[3]

- Continuous phaco: With phaco mode and the foot pedal in position 3, the phaco needle moves linearly, forward and back, at its fixed frequency without stoppage. Further depression of the foot pedal in position 3 can increase the percent power by increasing the

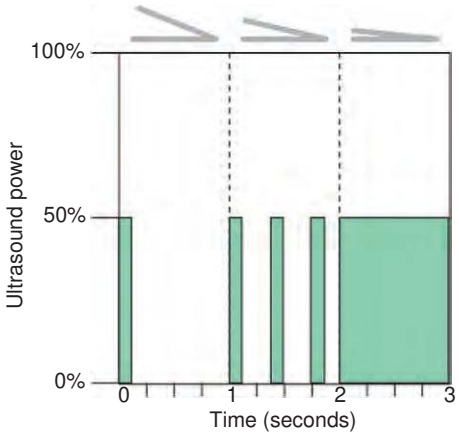


Fig. 19.22 Burst phaco: phaco on is 125 milliseconds. Off time becomes shorter with foot pedal depression in phaco mode; ultrasound power is fixed. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

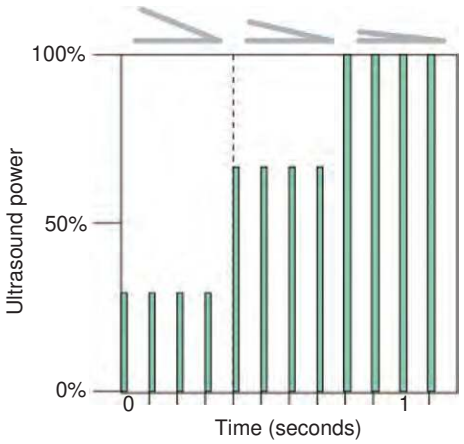


Fig. 19.23 Hyperpulse: the on and off times are very short. This is a 25% duty cycle with the on time 25 milliseconds and off time 75 milliseconds over 100 milliseconds. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

stroke length of the phaco needle and thus the jackhammer effect (Fig. 19.19A and B). Maximum power is set by the surgeon.

- Pulse phaco: With phaco mode and the foot pedal in position 3, the phaco needle moves linearly and cycles on and off at a set frequency. The surgeon sets the duty cycle, which is the percent of the time that phaco is on compared with off during one complete cycle of phaco (Fig. 19.20). The surgeon also can vary the frequency (pulse rate), cycles per second, or pulses per second. In addition, the surgeon can set the maximum percent phaco power that can be commanded with depression of the foot pedal in position 3 (Fig. 19.21).
- Burst phaco: With burst mode and the foot pedal in position 3, the phaco needle moves linearly for a very short time (milliseconds). The surgeon sets the amount of "on" time for each burst commanded by the foot pedal reaching position 3. The foot pedal also controls and varies the rest interval, or "off" time, between identical bursts of a fixed percent of phaco energy. As the surgeon depresses the foot pedal, the rest interval between the bursts becomes smaller (Fig. 19.22). The surgeon also sets and varies the duration of "off" time separating the "on" bursts.
- Hyperpulse phaco: Hyperpulse mode is very short bursts of phaco power followed by short rest periods (Fig. 19.23). The surgeon sets the duty cycle, expressed as pulses per second. There is linear control of ultrasound power by the foot pedal. Hyperpulse reduces heat generation by shortening the duration of each "on" period.

MODULATION OF ULTRASOUND

KEY POINTS

Continuous Phaco Mode

- Phaco needle moves linearly without stoppage
- Increase stroke length with depression of foot pedal in position 3

Pulse Phaco Mode

- With foot pedal depression in position 3, the phaco needle moves linearly
- With a preset number of equally spaced pulses over a preset time interval, with a 50% duty cycle
- % power can increase with depression of foot pedal

Burst Phaco Mode

- Phaco needle moves linearly for a short period of time (milliseconds)
- Surgeon sets phaco on time, which is fixed
- Depression of foot pedal shortens off time
- Surgeon sets shortest off time

Hyperpulse Phaco Mode

- Phaco needle moves linearly and is cycled on and off for very short times
- Surgeon sets pulses per second
- Surgeon sets maximum percent phaco power
- Depression of foot pedal increases percent phaco power

POSTOCCLUSION SURGE

Postocclusion surge occurs with occlusion break from a completely occluded phaco aspiration port that causes the vacuum in the aspiration line to reach the highest level preset by the surgeon. In this situation, there is potential energy stored in the aspiration line. There is the effect of compliance of the aspiration tubing defined as the inverse of stiffness. The vacuum causes higher compliance tubing, of which the walls are less stiff, to partially collapse. The vacuum pulls air bubbles out of the aspiration fluid (Fig. 19.24A). When phaco power emulsifies the aspirated nucleus or the nuclear fragment is dislodged from the phaco tip, this breaks the occlusion. The potential energy of the collapsing air bubble and the expanding tubing causes a momentary abrupt increase in fluid outflow. The sudden increased fluid outflow momentarily exceeds passive infusion inflow, causing a rapid shallowing of the AC (see Fig. 19.24B). To combat postocclusion surge, the bottle height should be raised and/or the vacuum should be lowered. Adjusting the aspiration flow rate is less effective, as it more directly controls the IOP with unoccluded flow.[14,15]

KEY POINTS

Fluidics

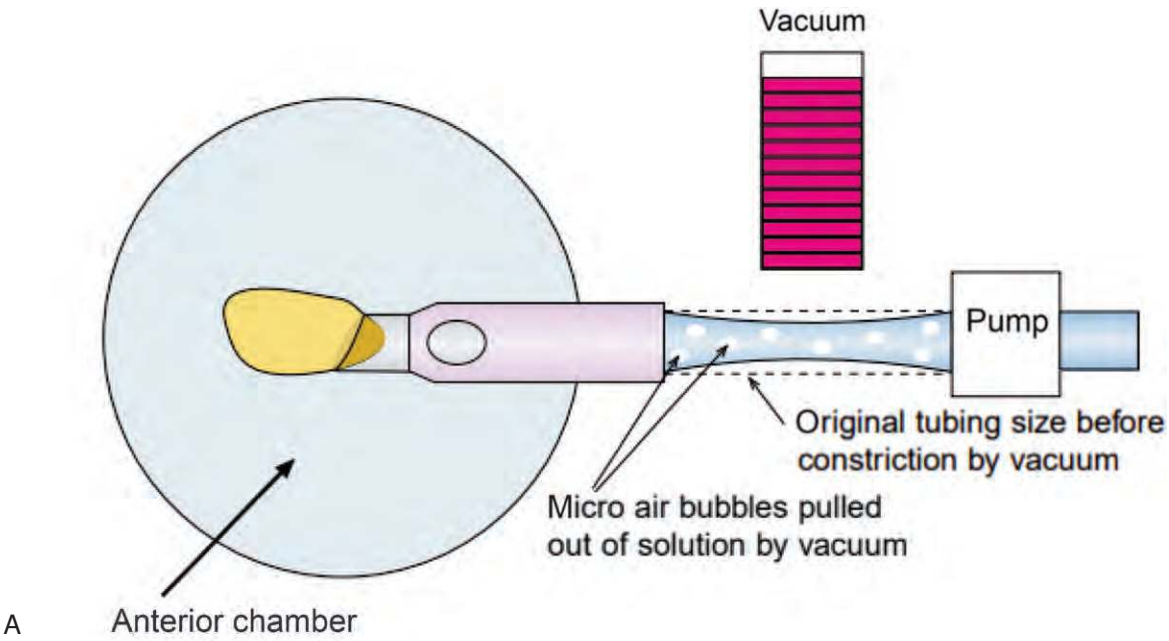
- Completely occluded aspiration port of the phaco needle
- Maximum vacuum is aspiration line commanded by surgeon
- Vacuum creates potential energy in aspiration line because partial collapse of aspiration line
- Upon break of occlusion, release of potential energy causes increased outflow
- Increased outflow not compensated by increased inflow
- Collapse of the AC
- To minimize, first raise bottle height and consider lowering maximum commanded vacuum.

CORNEAL INCISION CONTRACTURE/CORNEAL WOUND BURN

Corneal incision contracture (CIC), more commonly known as corneal wound burn, is a serious complication that can occur during routine phacoemulsification. The oscillatory movement of the phaco needle rapidly generates significant heating of the phaco needle. If the temperature reaches 60° C, the corneoscleral collagen contracts and distorts the incision. The needle is cooled by the simultaneous flow of irrigation fluid along its exterior and aspiration of fluid through its lumen. A wound burn is most likely to occur if the aspiration line becomes completely clogged with emulsified nucleus. If no fluid exits the eye, passive infusion of irrigation fluid cannot occur. Deploying ultrasound without the internal and external fluid flow alongside the phaco needle rapidly generates enough heat to burn the adjacent tissue.

Wound burn may range from whitening of the incision (indicating mild heating) to severe contraction and coagulation (Fig. 19.25A). White, milky lens material floating in the AC may indicated occlusion of the aspiration line and imminent wound burn (see Fig. 19.25B). Once the incision temperature reaches 60° centigrade, CIC occurs within seconds. Common predisposing causes for a clogged aspiration line or phaco needle are viscoadaptive or high viscosity ophthalmic viscosurgical device (OVD) used in conjunction with a brunescent nucleus. If there is a mismatch of incision size, phaco needle size, and irrigation sleeve, creating a too tight an incision, there will be cutoff of fluid to cool the phaco needle.[16]

The surgeon needs to be ever mindful. Before initiating phaco energy, use the foot pedal in position 2 to ensure irrigation and aspiration are functioning. Immediately let up on the foot pedal if the sound of the phacoemulsifier indicates occlusion despite the absence of a fragment at the phaco tip.[17]



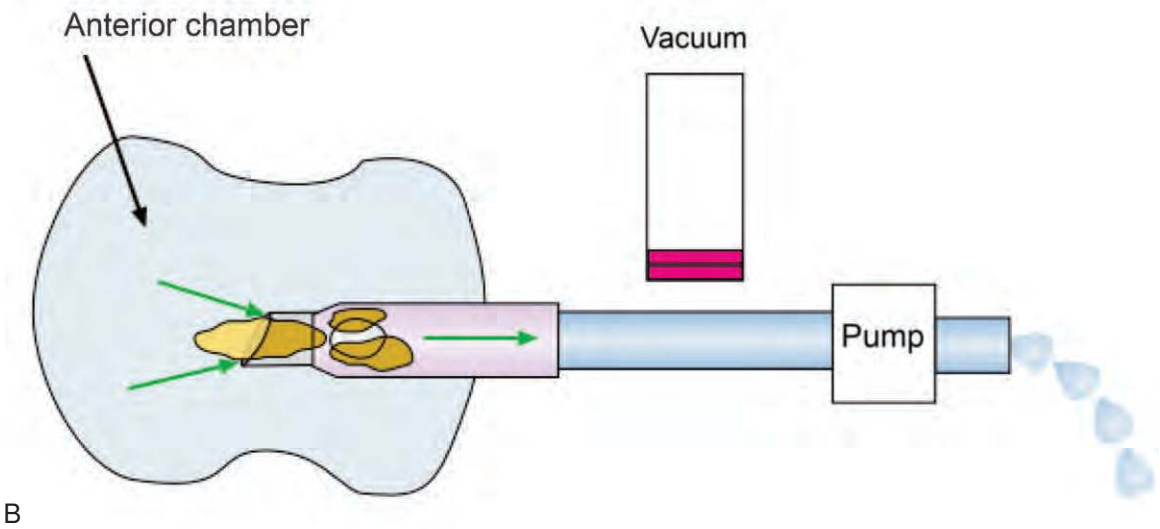


Fig. 19.24 (A and B) With complete occlusion of the phaco aspiration port, potential energy in the aspiration line causes transient increased outflow with break of occlusion. The increased outflow is not compensated by increased inflow, causing shallowing of the AC. (From Phacodynamics: Mastering the Tools and Techniques of Phacoemulsification Surgery, Fourth Edition, by Dr. Barry S. Seibel.)

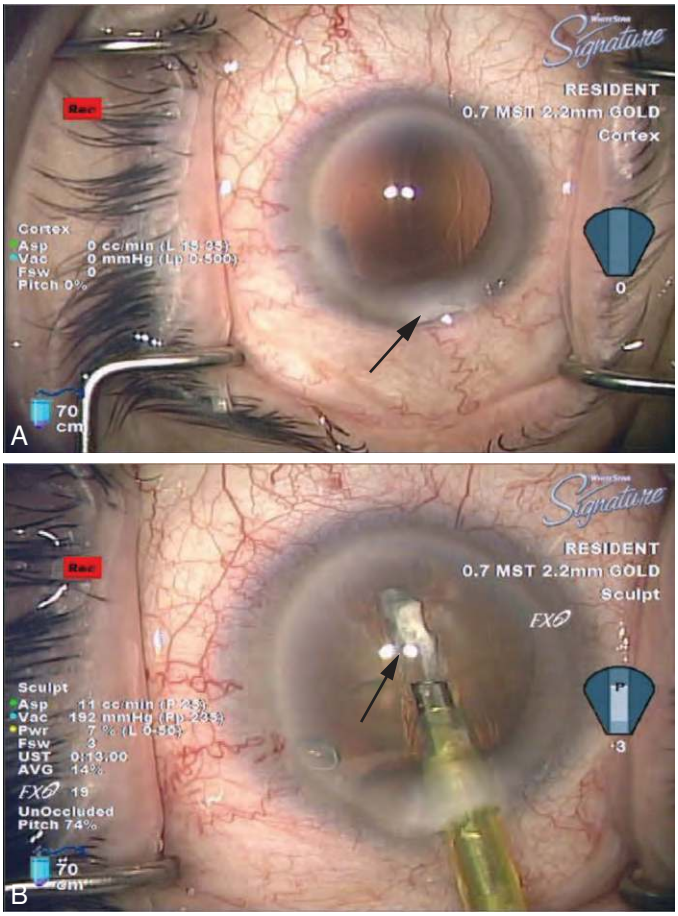


Fig. 19.25 (A and B) Whitening of the incision *(arrow)* and white lens material *(arrow)* in the AC.

KEY POINTS

Be Mindful

- Signs: whitening of incision and nonaspiration of lens material in the AC
- Etiology: total or partial obstruction of aspiration and/or transient lack of inflow increases temperature in incision
- Pathology: At 60° C, collagen contracts within seconds and distorts incision
- Predisposing causes: viscoadaptive or high viscosity OVD, lens material clogging aspiration, tight incision limiting inflow
- Before initiating phaco power, irrigate and aspirated to ensure fluid inflow and outflow in the AC

Components

- Irrigating bottle
- Irrigation line with pinch valve
- Ultrasonic handpiece
- Phacoemulsification needle with aspiration port
- Silicone sleeve with irrigation ports
- Aspiration line
- Pressure transducer
- Pump
- Drain
- Foot pedal

IOP, Flow, and Aspiration
- Pinch valve open and no flow, bottle height determines anterior-chamber IOP
  - 45 cm = 33 mm Hg
  - 17.7 inches = 33 mm Hg

Control of Flow (cc/min)
- Foot pedal position 1 = irrigation
- Foot pedal position 2 (irrigation/aspiration mode and phaco mode) = irrigation and aspiration
- Foot pedal position 3 (phaco mode) = irrigation, aspiration, and ultrasound

Control of IOP
- Increase bottle height increases IOP with no aspiration
- Increase aspiration flow rate lowers IOP without occlusion of aspiration port
  - IOP differential in the AC and aspiration line
  - Partial occlusion of aspiration port increases IOP
  - Complete occlusion stops aspiration flow with IOP controlled by bottle height

Control of Vacuum (mm Hg) Flow Pump and Vacuum pump
- Set maximum vacuum

Flow Pump and Vacuum Pump: Direct Versus Indirect Control of Flow
- Distal followability to bring lens material to phaco needle for emulsification
  - Increase flow
  - Move phaco needle closer to lens material
- Proximal followability alternates vacuum, occlusion, phaco, flow and aspiration of emulsate
  - Flow and vacuum work together to keep lens material on phaco needle for emulsification

Understanding Flow and Vacuum Pumps: They Are Different
- Flow pump directly controls flow (cc/min) and vacuum (mm Hg)
  - Acts as a fluidic resistor
  - Surgeon sets commanded flow at cubic cenimeters per minute, a speed at which the pump head pushes against aspiration line
  - Bottle height does not affect flow rate
  - Surgeon sets commanded maximum vacuum level (mm Hg)
- Vacuum pump indirectly controls flow (cc/min)
  - Bernoulli equation
  - Surgeon sets commanded maximum vacuum (mm Hg)
  - Force (vacuum) pulls fluid into aspiration line
  - Vacuum directly controlled, which indirectly controls aspiration (cc/min)
  - No fluidic resistor
  - Increased bottle height will increase flow rate

Ultrasound Power
- Phaco needle move linearly (stroke length) and has aspiration port
- 25,000 to about 60,000 Hz/sec linear movements depending on phacoemulsifier
- Ultrasound power, percent, is measured and controlled by adjusting linear stroke length
- Up to approximately 100 microns depending on phacoemulsifier
- Three lines into phaco handpiece: power line, aspiration line, irrigation line
- Phaco needle may have additional movements depending on phacoemulsifer
- ELLIPS transversal movement functions with
- Straight phaco needle
- Bent phaco needle
- OZil torsional movement requires
- Bent phaco needle

Silicone Sleeve
  Placed over phaco needle
  Irrigation ports
Postocclusion Surge
  Occurs with total occlusion of phaco needle aspiration port
    Vacuum builds to high preset level between machine pump and an occlusion at
    aspiration port
  Stiffness: extent with which an object resists deformation caused by applied force
  Compliance: inverse of stiffness, flexibility; ability to resist recoil toward original dimensions on
    application of distending or compressing force
    Volume change divided by change in pressure
  High vacuum partially collapses aspiration tubing and creates air bubbles pulled from fluid
  Upon occlusion break, additional flow in aspiration line caused by reexpanding aspiration tubing and collapsing air bubbles; this additional flow causes shallowing of the AC
  How to control postocclusion surge
    First, raise bottle height to provide increased inflow pressure
    Second, lower vacuum level
What is Ultrasonic Power?
  Increase power is increase linear stroke length of phaco needle
  Acoustical wave: 5400 km/h causes nucleus to oscillate and breaks down intermolecular bonds
  Mechanical impact: accelerates forward up to 72 km/h; impacted 25,000 to 60,000 Hz/sec
  depending on phacoemulsifier
  Fluid wave: from linear acceleration of phaco needle; pushes fluid and lens particles away from
  from phaco needle up to 72 km/h; opposes followability and aspiration
  Cavitation: low pressure area (gas bubble) formed when rapidly pushing liquid forward; bubbles
  collapse causing a shock wave; controversy as to clinical importance of cavitation
Continuous pulse and burst phaco modes
  Continuous phaco mode
    With foot pedal depression in position 3, the phaco needle moves linearly
    forward and back with no stoppage
    Percent power can increase with depression of foot pedal
  Pulse phaco mode
    With foot pedal depression in position 3, the phaco needle moves linearly
    with a preset number of equally spaced pulses over a preset time interval, with a 50% duty cycle
    Percent power can increase with depression of foot pedal
  Burst phaco mode
    With foot pedal depression in position 3, the phaco needle moves linearly with a burst
  of preset percentage of power at decreasing time intervals
  Foot pedal depression decreases the time interval between bursts
  Percent power constant

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Advanced Principles of Phacoemulsification Platforms

Jeff Pettey, Barry S. Seibel, Kevin M. Miller, and Sumit (Sam) Garg

CONTENTS

KEY POINTS

- Phacodynamics are applied differently by the available phaco platforms.
- Advances in technology are targeted at increasing surgeon cusomization and control.

Although Charles Kelman first pioneered small incision cataract surgery six decades ago, the original phacoemulsification machine would be considered primitive by today's standards. Dr. Kelman was the first of many surgeon innovators who collaborated with industry to transform and advance that original technology into today's modern phaco machines that are vastly superior in terms of safety and efficiency. Essentially all of today's phaco machine manufacturers offer platforms with good ultrasonic efficiency and fluidics, although the machines differ in terms of the strategies used to achieve this objective.

Phacoemulsifiers from different companies share many common features. All regulate the intraocular pressure (IOP) environment, movement of fluid into and out of the eye, vacuum level at the tip of the needle during occlusion, and energy applied to piezoelectric crystals within a handpiece. This chapter highlights more specialized and differentiating features of the three most common phacoemulsification platforms used in the United States.

THE ALCON CENTURION

Kevin Miller, MD

The Alcon Centurion builds on decades of experience in the phacoemulsification market with its most recent innovations addressing advanced fluidics control with pressurized infusion and an IOP sensor located within the handpiece. Other unique innovations such as torsional phacoemulsification are discussed in detail below.

Graphical User Interface

The Alcon Centurion (Fig. 20.1) has a user-friendly graphical user interface. The set-up screen guides the surgical technician through the steps of preparing the machine for surgery, which includes inserting a bag of balanced salt solution (BSS) into a bag compartment, connecting tubing to the bag, attaching a fluidics management system (FMS) cassette to the front console, plugging in an ultrasound handpiece connector, and attaching irrigation/aspiration (I/A) tubing to the handpiece (Fig. 20.2A). The "surgical" screen allows users to visualize global parameters across the top, the steps of the procedure across the bottom, and settings for phacoemulsification energy and fluidics across the midsection (see Fig. 20.2B). Selecting any icon on the screen opens an additional submenu, which enables further adjustments to surgical settings (see Fig. 20.2C).

Ultrasound Motion: Torsional Phacoemulsification

Standard phacoemulsifiers work in longitudinal mode. An alternating voltage is applied to a stack of piezoelectric ceramic crystals at their resonant frequency. The crystals expand and contract in response to the applied voltage. The crystals are mechanically coupled with a metallic hollow-bore needle and forward excursion of the needle creates a jackhammer effect when it contacts tissue such as cataractous lens material. Reverse excursion creates cavitation bubbles within water at the kilohertz frequencies and peak tip velocities employed during phacoemulsification. Although cavitation has long been discussed as an important component of nuclear emulsification, its actual contribution remains unclear.[1] Reverse movement of the needle, however, does generate heat and free radicals.[2–4] Additionally, longitudinal phacoemulsification repulses lens fragments and contributes to chatter.[5,6]

Exclusive to the Alcon platform is a unique ultrasound motion at the tip. If a different frequency is applied to the ceramic crystal stack, its coupled ultrasonic horn is designed to produce oscillatory or torsional (horizontal) motion rather than longitudinal motion. If a straight needle is attached to a crystal stack under this resonant condition, the effect on the tip is somewhat akin to an oscillating drill bit. However, if an angled needle is attached, torsional movement of the shaft of the needle is turned into a horizontal sweeping motion at the tip (Fig. 20.3A). The length of the shaft beyond the bend determines the amplitude of the horizontal stroke. Some studies have found that at equivalent applied energies, torsional phacoemulsification produced considerably less heat at the incision than longitudinal phacoemulsification.[7,8] It is proposed that torsional phacoemulsification is more efficient because the

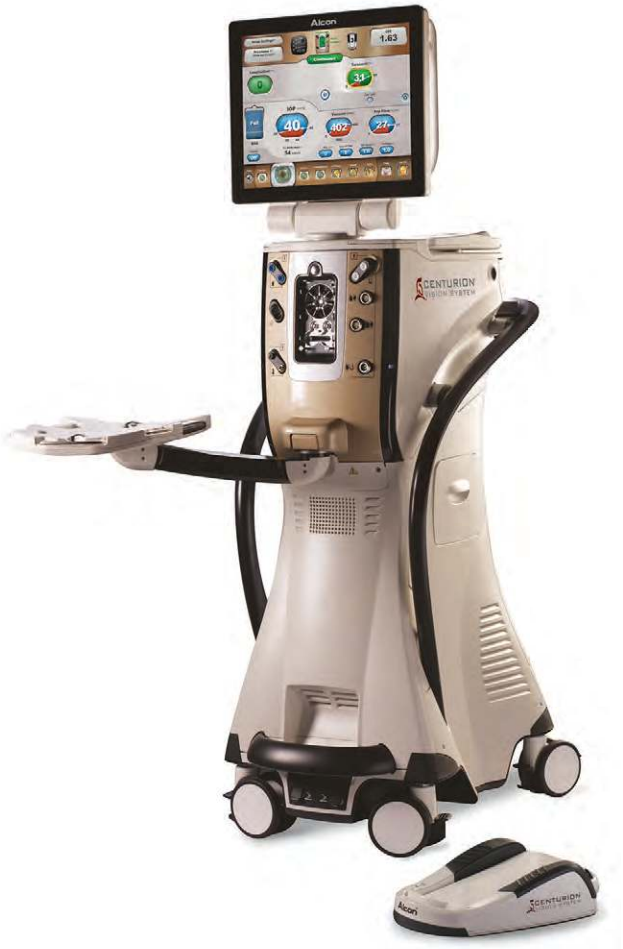

Fig. 20.1 Photo of the Alcon Centurion Vision Enhancement System.

sweeping tip maintains connection to the nuclear fragment while the needle cuts during the stroke to the left and the stroke to the right.[9] It also produces considerably less repulsion of nuclear pieces.[10]

To help surgeons transition from a straight phacoemulsification needle to a bent Kelman needle, Alcon developed a needle with a double bend profile in the distal shaft that retains a straight alignment between the proximal shaft and the distal tip while generating side-to-side motion. This Intrepid Balanced tip improves horizontal cutting at the tip compared with the curved Kelman needle while reducing shaft motion within the incision (see Fig. 20.3B).

Fluidics Control: Active Fluidics

A distinguishing feature of the Alcon Centurion phacoemulsifier is its approach to infusion pressure. Traditional phacoemulsifiers use gravity to regulate the IOP environment during surgery. The height of the fluid column between the infusion source, which is a bottle or bag of BSS, and an eye determines the IOP under zero flow conditions. An infusion bottle 75 cm above an eye, for instance, produces an IOP of 55 mm Hg. The relationship between bottle height and IOP is simple: IOP (mm Hg) equals bottle height (cm H_2O) times 0.74. However, this relationship holds true only when there is no flow through the infusion line. As soon as the aspiration pump begins turning and fluid is drawn from the eye, replacement fluid begins to flow from the BSS reservoir through the infusion line into the eye. Leakage of fluid through corneal or scleral incisions adds to the rate of flow of replacement fluid.

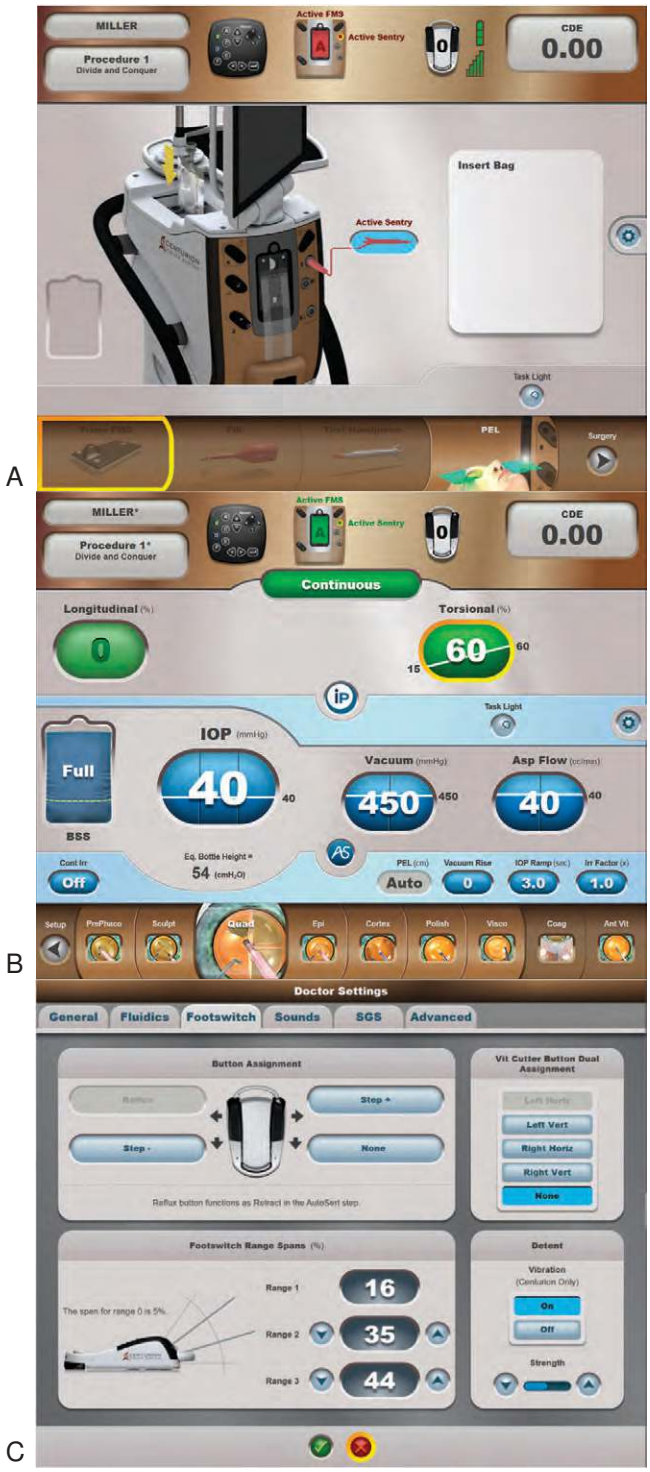

Fig. 20.2 (A) The Centurion "set up" screen. (B) The "surgical" screen. (C) A submenu example. The foot pedal submenu was selected.

Flow of fluid through the irrigation line causes IOP to drop. The change in pressure from the infusion reservoir to the eye equals the rate of flow through the infusion line times the resistance of the line. The greater the rate of flow, the greater the drop in IOP (Fig. 20.4). The surgical effect on IOP can be seen when the handpiece is placed into an eye and unoccluded aspiration is commenced. If outflow outstrips inflow, the anterior chamber shallows, the iris–lens diaphragm rises, and the

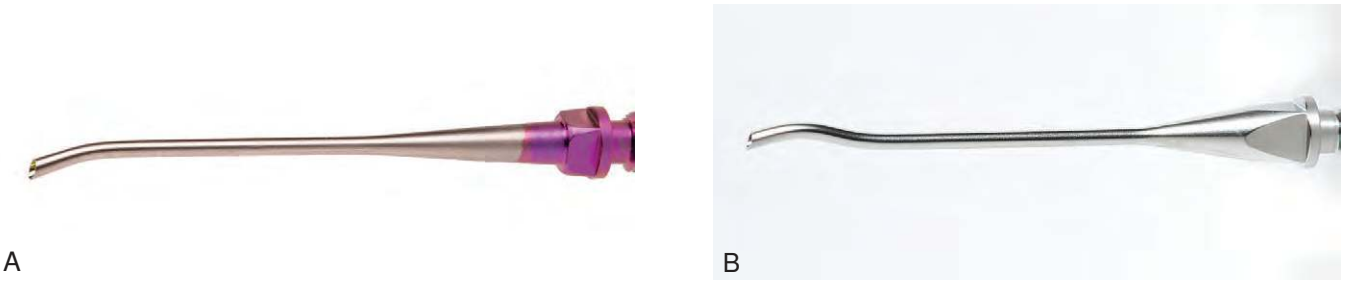

Fig. 20.3 These images show (A) a curved Kelman needle and (B) an Intrepid Balanced tip.

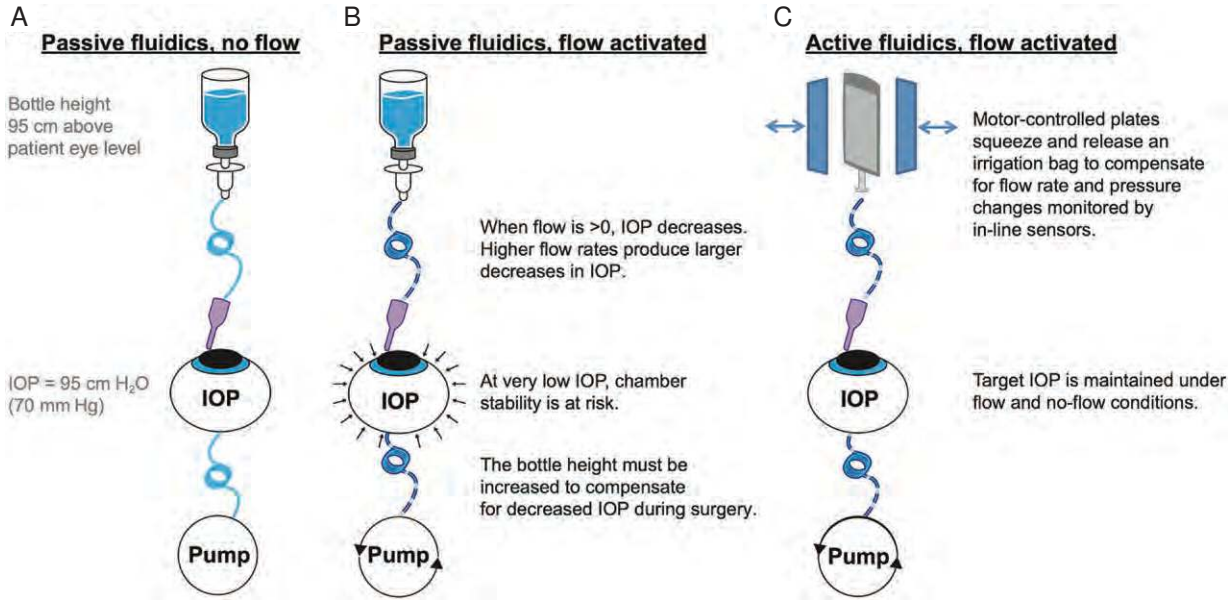

Fig. 20.4 This illustration shows the difference between passive and active fluidics. (A) Fluid dynamics shown under zero-flow conditions in a passive or gravity feed system. (B) Passive fluid dynamics shown with aspiration and irrigation flow activated. *IOP* decreases as a result. (C) An actively controlled fluidics configuration shown with aspiration flow activated. Pressure plates are used to compress a bag of BSS to maintain a target IOP. (From Nicoli CM, Dimalanta R, Miller KM. Experimental anterior chamber maintenance in active versus passive phacoemulsification fluidics systems. *J Cataract Refract Surg*. 2016;42:157–162.)

pupil constricts. As soon as the pump is turned off, the anterior chamber deepens as the IOP suddenly rises. To avoid fluctuations in inflow Alcon employs a dynamic process to adjust the pressure in the infusion line to maintain constant IOP. This is the basis of Active Fluidics. A pressure sensor on the infusion line determines the actual pressure at the point where BSS enters the FMS cassette (Fig. 20.5). This sensor then feeds that pressure information back to stepper motors in the infusion bay, which in turn squeeze a compressible bag of BSS dynamically and rapidly to maintain a constant IOP at the infusion line sensor.[11,12]

The effect of active fluidics can be seen if the Centurion system is used in gravity feed mode at an aspiration flow rate (AFR) of 60 cc/min and infusion pressure drops 50 mm Hg between the BSS bottle or bag and the eye. If a surgeon works with this system at a target IOP of 50 mm Hg, he or she will experience anterior chamber collapse at an AFR of 60 cc/min. With Active Fluidics turned on, however, the target IOP of 50 mm Hg will be maintained regardless of AFR (Fig. 20.6).[12] For the target IOP to be accurate, the instrument needs to know the position of the eye with respect to the infusion line pressure sensor. Thus the surgeon or a scrub technician needs to set the patient eye level (PEL) accurately on the console at the beginning of each surgery.

The Centurion Active Fluidics FMS and the peristaltic pump inside the console also contain additional improvements that reduce the

Fig. 20.5 This image shows the functional side of the Centurion FMS. Dual aspiration channels are shown at the top of the cassette. Irrigation and aspiration line pressure sensors are shown at the bottom of the cassette.

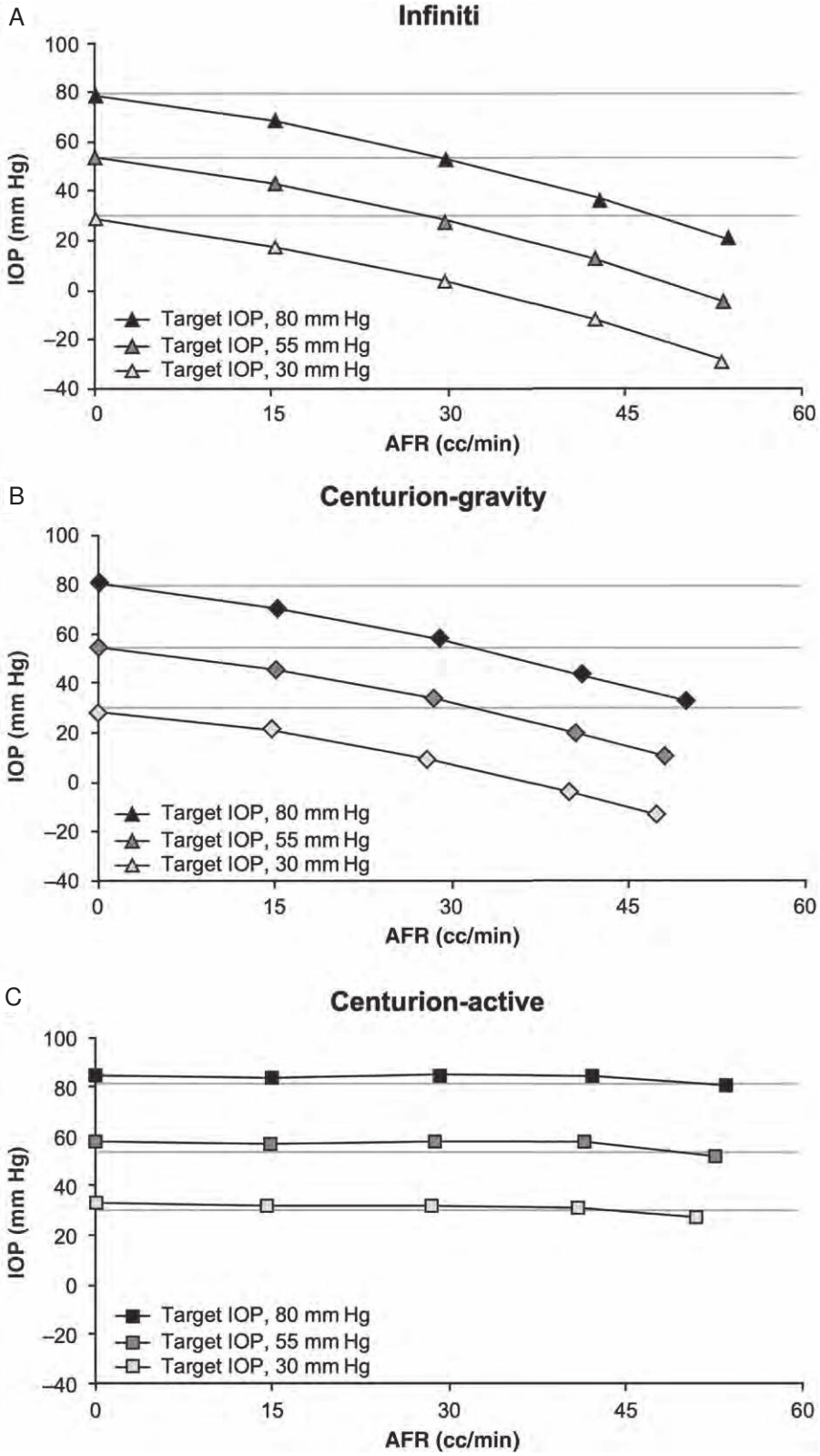

Fig. 20.6 This experimental study shows how IOP declines as a function of increasing AFR in the (A) Infiniti and (B) Centurion systems when used in the passive infusion fluidics mode. When the Centurion is used in the Active Fluidics mode, however, there is no drop in IOP as AFR is varied up and down. IOP is maintained at the designated level regardless of fluid movement through the infusion line. (Published in Nicoli CM, Dimalanta R, Miller KM. Experimental anterior chamber maintenance in active versus passive phacoemulsification fluidics systems. *J Cataract Refract Surg*. 2016;42:157–162.)

Fig. 20.7 This image of the Centurion console shows the seven rollers associated with the peristaltic pump.

ripple effect on aspiration line pressure. Instead of a single channel milked by four rollers, the Active Fluidics FMS cassette has two flow channels (see Fig. 20.5, *top*) that are milked by seven rollers (Fig. 20.7). The rollers are out of phase with respect to each other as they pass over the two channels. The result is less vacuum ripple in the aspiration line.

An additional feature of the Active Fluidics system is its ability to turn off continuous irrigation if rapid infusion flow is detected in the absence of AFR. Another is the ability to ramp up infusion pressure slowly (IOP Ramp). The latter capability is helpful when myopic patients undergo topical anesthesia cataract surgery. A final benefit of the Centurion is the Vacuum Rise function. This debuted on the Infiniti system as "Dynamic Rise." Positive values of +1 to +4 and negative values of −1 and −2 could be set on the Infiniti system. It was designed to allow a phacoemulsification tip to latch onto a cataract fragment when the machine sensed it was nearing full occlusion. A positive Dynamic Rise value could be set to kick the AFR up momentarily by a certain amount. A +1 setting kicked it up 25%. A +2 setting kicked it up 50%. A +3 setting kicked it up 100% or to 60 cc/min, whichever was lower, and a +4 setting kicked the AFR up to 60 cc/min. On the minus side, a −1 setting at near occlusion instantaneously decreased the AFR by 25% and a −2 setting reduced it by 50%. The Centurion is so responsive that the plus settings were discontinued. However, the minus settings were preserved. Minus settings are helpful when a surgeon is sculpting. When the tip of a needle reaches the end of a trough, the surgeon does not want to achieve full occlusion and a quick vacuum rise. With a minus setting of −1 or −2 enabled, the aspiration pump instantaneously slows down 25% or 50% as soon as the aspiration pump senses that occlusion is near complete. This keeps the tip from achieving full occlusion and punching through the epinucleus and cortex.

Handpiece: Active Sentry System

The Active Sentry system adds new features to Active Fluidics and overcomes additional obstacles to safe and efficient phacoemulsification. One of the problems of Active Fluidics is that the PEL must be set accurately for the IOP to be calibrated properly. Additionally, there is a speed of sound problem. Events occurring at the tip of the phacoemulsification handpiece, such as occlusion break surge or other IOP

Fig. 20.8 This is a graphic of the Centurion Active Sentry system.

alterations, take a certain number of milliseconds to travel back to the cassette where they can be detected by the pressure sensors.

In the Active Sentry system, the irrigation pressure sensor is moved from the FMS to the handpiece (Fig. 20.8). This enables several capabilities that were previously impossible. First, the handpiece eliminates the need for user entry of PEL, so it no longer has to be set on the console. If a surgeon needs to raise or lower a patient's head or the entire bed during a procedure, there is no need to recalibrate the PEL. Second, the handpiece pressure sensor turns the speed of sound problem into a speed of light issue. The pressure sensor in the handpiece can detect IOP events at the very moment they occur and feed that information back to the stepper motors in the infusion bay, so that not only is the IOP control more accurate, but also it is considerably more responsive. The Active Sentry FMS cassette was redesigned with a new QuickValve vent. Now, if the Active Sentry handpiece pressure sensor detects an occlusion break, it will signal the vent valve to open proportionally and vent fluid into the aspiration line so that less fluid has to be pulled from the eye to fill the recoiling aspiration line tubing.[13] Because it vents in a controlled way, a cataract fragment at the tip is less likely to disengage, which would result in a loss of efficiency. This venting process significantly lowers surge volume (Fig. 20.9). Finally, Active Sentry makes it possible to compensate automatically for the effects of average incision leakage.

In summary, the graphical user interface, torsional phacoemulsification, Active Fluidics, and Active Sentry make the Alcon Centurion a unique phacoemulsifier for the international market.

BAUSCH & LOMB STELLARIS

Barry Seibel, MD

The Bausch & Lomb Stellaris Elite represents the company's culmination of decades of progress that has particularly evolved the technologies of Dual Linear Pedal Control and vacuum-based fluidics that now include pressurized Adaptive Fluidics.

Graphical User Interface

The Bausch & Lomb video overlay embeds real-time machine parameters onto the surgical video. Prior graphic video overlays typically show a series of dials or bar gauges such as one might see on a car, but these are very difficult to visually corroborate with the actual surgery. The Stellaris Elite uses a functional video overlay that is patterned after the bars for vacuum and ultrasound depicted in (Fig. 20.10); the bars show not only the amount of commanded parameter, but more importantly, they show the actual movement of the unique Dual Linear foot pedal. Once the surgeon understands this orientation and because of the relatively large size of the bar gauges that emanate from an origin at the top left of the screen, attention can then be turned to the surgery at the

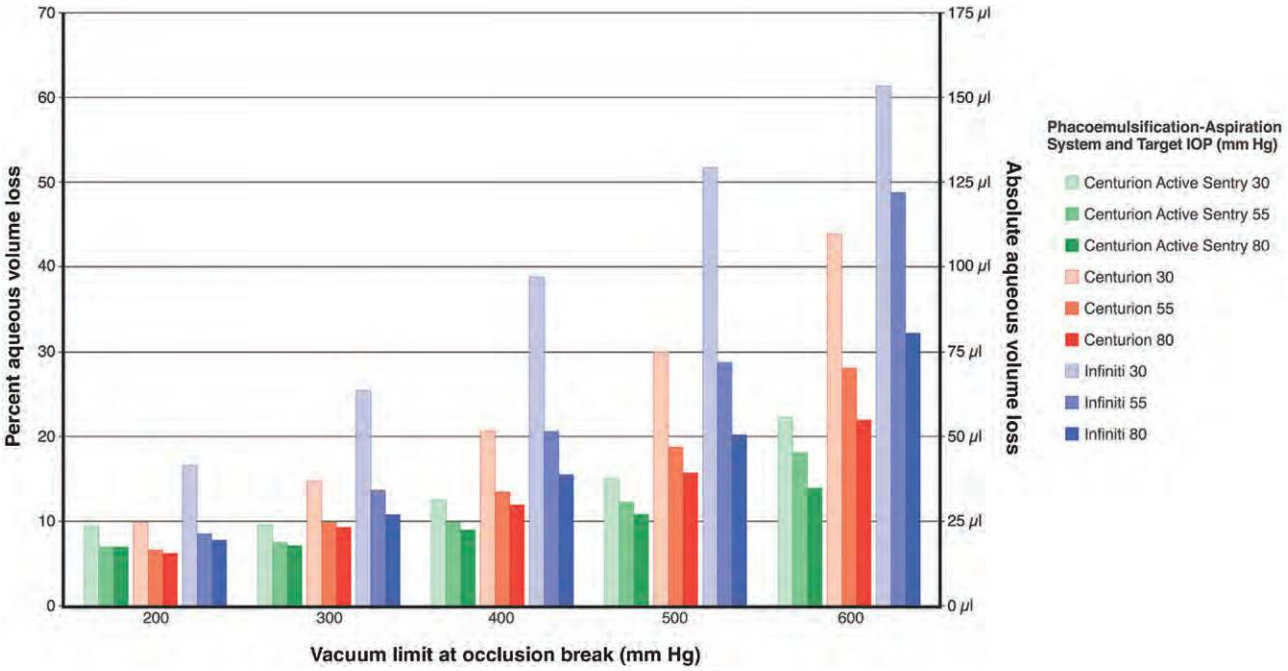

Fig. 20.9 This graph shows percent aqueous volume losses in a phakic eye model as a function of vacuum limit at the time of occlusion break, target IOP (30, 55, or 80 mm Hg), and phacoemulsification system in use. The Centurion with Active Fluidics outperformed the Infiniti, and the Centurion with Active Sentry outperformed the Centurion with Active Fluidics. (Published in Thorne A, Dyk DW, Fanney D, Miller KM. Phacoemulsifier occlusion break surge volume reduction. *J Cataract Refract Surg*. 2018;44:1491–1496.)

center of the screen with peripheral vision providing real-time information about both the parameters and the foot pedal position. This Graphic User Interface therefore provides much enhanced functionality with regard to reviewing cases, teaching, and learning.

Ultrasound Motion

For ultrasound, Bausch & Lomb has continued to refine their longitudinal technology with multicrystal design to maintain commanded power/stroke length when encountering variable loads of different nuclear densities. Other platforms have added nonlongitudinal technology that, in several papers, has been shown to be advantageous compared with longitudinal modality on the same machine platform. Ideally, these nonlongitudinal technologies would be compared with the longitudinal modality on the Stellaris with its synergistic technologies of the refined vacuum pump, Dual Linear Pedal Control, and Adaptive Fluidics; however, the lack of an industry standard for ultrasound energy/power would make such a study difficult to interpret.

Fluidics: Vacuum Pump

A distinguishing feature of Bausch & Lomb's phaco platform is a dedicated venturi vacuum pump compared with the much more common flow pump or dual pump platform on other machines. Starting several decades ago with the Daisy and Premiere platforms, Bausch & Lomb has continued to refine this modality for phaco fluidics. Vitreoretinal surgeons have predominantly chosen the vacuum pump for its linear responsiveness. However, many cataract surgeons have historically had concerns that vacuum pumps were potentially too fast or responsive to the point of being dangerous. However, these concerns are largely rooted in the performance of earlier venturi machines with larger bore 19-G needles and larger aspiration lines, which could result in precariously fast flow rates, particularly as phaco methods evolved to higher vacuum techniques such as chopping and divide-and-conquer.

Several improvements have mitigated this past downside of vacuum pumps. Both phaco needles and aspiration lines have decreased in diameter, and the consequent increased resistance to outflow (per Poiseuille's law) has served to limit outflow rates and enhance chamber stability. Furthermore, improved surgeon understanding of phacodynamics has improved technique with high vacuum applied only when needed and titrated to safer levels for chamber stability and reduction in postocclusion surge. As discussed below, Dual Linear Pedal Control further facilitates this intraoperative Control of phacodynamic parameters and is synergistic with the vacuum pump technology on the Stellaris platform.

Post occlusion Surge Prevention: Stellaris Vacuum Pump

- Improved chamber stability with higher resistance phaco needles and aspiration line tubing limiting outflow from the anterior chamber
- Pressurized infusion
- Dual Linear Pedal Control to facilitate independent control of vacuum and ultrasound to allow dynamic adjustment of vacuum for anticipated occlusion breaks

A unique advantage of vacuum pump technology is the simplicity of clinical parameter control of flow and vacuum. On peristaltic based machines, these parameters must be set independently and can sometimes be confusingly interactive. For example, the machine may override the surgeon's commanded flow setting because of a feedback loop caused by low vacuum limit settings that might be artifactually triggered by the aspiration of a viscous emulsate. In contrast a vacuum pump machine using a single pump allows direct control of increasing commanded vacuum. This allows the surgeon to command linear vacuum to attract fragments to the unoccluded aspiration port and then adjust the same vacuum parameter to grip the fragment for repositioning or chopping once it is occluding the aspiration port. Although

Fig. 20.10 Bausch and Lomb Stellaris Elite. (https://www.bauschsurgical.com/cataract/stellaris-elite/)

modern peristaltic flow pumps are much better at minimizing rise time (time for vacuum to build once the aspiration port is occluded), vacuum pumps offer a virtually instantaneous rise time for maximum efficiency. For surgeons who desire a slower vacuum buildup consistent with the fluidics of a flow pump, the Stellaris platform allows a more customized surgeon experience via software modulation. A final advantage of the refined vacuum pump is the option of full vitreoretinal technology (including Vitesse ultrasonic vit cutting) as a cost-effective solution for ASC's serving both anterior and posterior segment surgeons.

Adaptive Fluidics

Although a longstanding feature of dedicated vitreoretinal machines, active pressurization represents a more recent advance for anterior segment machines. These previously solely relied on an elevated irrigating bottle to supply a gravity-induced pressure head to mitigate chamber collapse in the face of aspiration outflow. However, the motorized IV pole that holds the irrigating bottle is limited by electromechanical delays in how responsive it can be with more rapidly changing commanded vacuum inputs. This explains the popularity of active pressurization on the vitreoretinal platforms. Rather than simply reacting to pressure changes that occur during surgery, the Stellaris machine has introduced a proactive approach called *Adaptive Fluidics*. A baseline safe IOP is first set by the irrigating bottle height. Then, as commanded vacuum is engaged and increased, the irrigation line/bottle pressure is proportionately increased to provide a safety buffer. Any inadvertent occlusion break occurs in a chamber that is already pressurized to a level appropriate to that commanded vacuum. This prevents the surge from reaching that threshold, which would shallow or collapse the anterior chamber. The surgeon can program panel preferences to further refine compensation curves according to the resistance of the diameter of the phaco or I/A port being used.

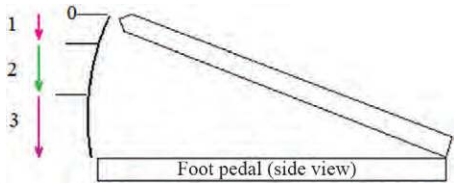

Fig. 20.11 Traditional footpedal control.

Dual Linear Foot Pedal Control

A unique innovation in phacoemulsification technology is the Dual Linear Foot Pedal Control. For decades the phaco foot pedal control remained largely unchanged. It had position 0 in its default top position, along with travel ranges 1, 2, and 3 (Fig. 20.11). Position 0 deactivated all machine activity (no ultrasound, vacuum, or flow). Range 1 pressurized the eye by equilibrating bottle height pressure with the intraocular irrigation ports. Range 2 introduced pump function and aspiration outflow through the aspiration port proportionate to the degree of pedal depression (linear control). Range 3 introduced ultrasound energy modulated in linear fashion (linear control began toward the end of the 20th century).

The standard pedal configuration has two fundamental limitations. First, having three ranges of travel in the total pedal pitch range (up and down) means that each range is relatively small, which translates to poor control sensitivity. In other words, if linear vacuum control in range 2 is from zero to 400 mm Hg, then moving the pedal only a fraction of an inch could change vacuum by 200 mm Hg (half of the very small angular travel). This excessive reactivity could preclude the surgeon from controlling fluidics with greater finesse to better adapt the parameter to a particular cataract. The second and perhaps even greater liability of the standard setup is the sequential arrangement of ranges 2 and 3, which preclude the independent control of fluidics and vacuum. This limitation is particularly relevant with high vacuum methods such as phaco chop in which the high levels of vacuum required for cataract stabilization during the actual chop become a clinical liability, predisposing toward postocclusion surge when transitioning to phacoaspiration of the chopped fragment.

Standard Foot Pedal Control

- All functions on one plane of travel; pitch (up and down)
- Limited control sensitivity because of short pedal travel for each range (1, 2, and 3)
- Inability to independently control ultrasound and fluidics

Dual Linear Pedal Control, introduced originally by companies outside of the United States but popularized by Bausch & Lomb, overcomes the standard pedal's limitations by allowing separation of ultrasound and fluidics into two planes of pedal movement, the original pitch motion plus additional yaw motion (side to side) (Fig. 20.12). With the original total pitch travel for ranges 2 and 3 now occupied by a single parameter (either fluidics or ultrasound), the range of control sensitivity doubles. The same slight pedal depression (with 0–400 mm Hg linear vacuum) that produced an abrupt increase to 200 mm Hg would produce a controlled increase to 100 mm Hg, allowing the

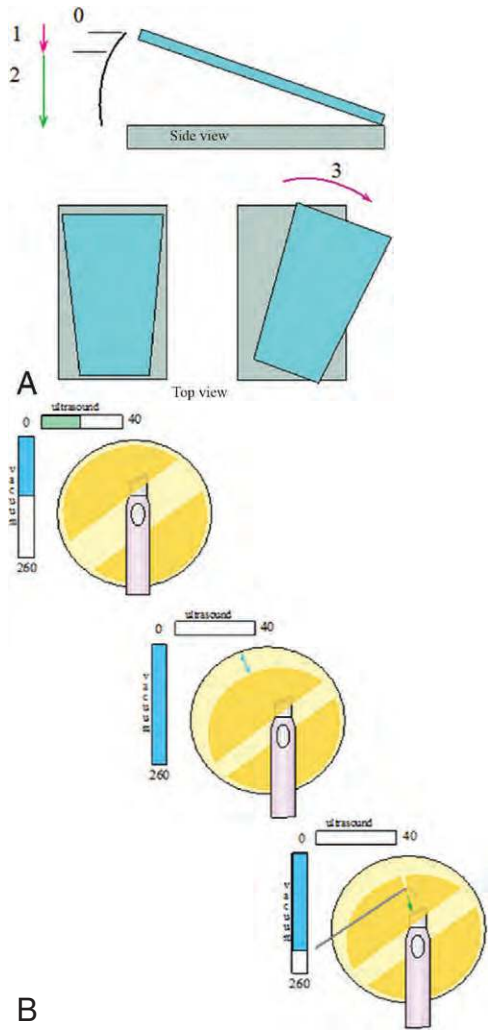

Fig. 20.12 Surgeons can control vacuum or ultrasound energy with angle flexion (B) or yaw (A).

surgeon more precise titration of vacuum. This is of particular importance during the transition from high vacuum chop to emulsification of fragments. Beyond improved control for a single parameter, the separation of vacuum and ultrasound control into different planes provides independent control of each function that is not possible with a standard pedal configuration.

To fully understand the benefits of independent control one can look more closely at phaco chop, where high vacuum is needed to immobilize and stabilize the engaged nucleus as the chopping instrument chops the fragment. As noted previously, maintaining this same high level of vacuum when subsequently transitioning to a carouselling phacoaspiration of the fragment would lead to higher risk of chamber instability and postocclusion surge. Using Dual Linear Pedal Control, the surgeon can simply reduce applied linear vacuum while the aspiration port is still occluded, and then apply appropriate levels of linear ultrasound to phacoaspirate the chopped fragment at an appropriately lower vacuum level (Fig. 20.13). A standard pedal forces the surgeon to maintain the highest level of linear vacuum from range 2 as the surgeon transitions in pitch to range 3 ultrasound. By using enhanced Dual Linear Pedal Control, the surgeon can titrate the potentially repelling force of ultrasound with the attractive fluidic forces of flow and vacuum. A standard pedal can only reduce ultrasound against the

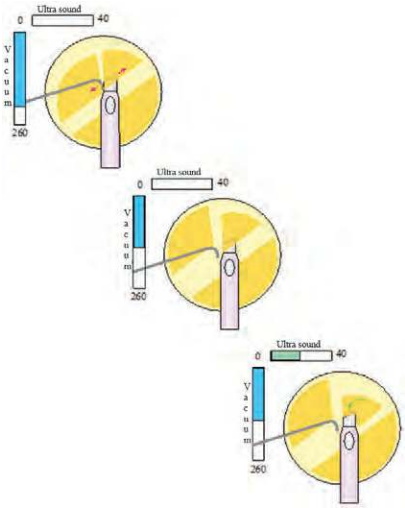

Fig. 20.13 This shows Dual Linear Pedal Control to enable appropriate parameters for maximum efficiency and safety at each step of a chopping procedure. When Dual Linear Pedal Control was first introduced by Bausch & Lomb, surgeons were encouraged to program ultrasound in pitch and vacuum in yaw.

highest level of linear vacuum/flow range, whereas a Dual Linear Pedal facilitates titration of both parameters. With Dual Linear Pedal Control the surgeon can either lower ultrasound power or raise vacuum in real time rather than taking time to adjust or switch between settings on the machine. A standard pedal setup is available for those who prefer this option as a software option on the Stellaris Elite.

Dual Linear Pedal Control

- Two independent planes of pedal travel; pitch (up and down) and yaw (side to side)
- Enhanced control sensitivity because of greater pedal travel for each range compared with standard pedal
- Ability to independently control ultrasound and fluidics

The Stellaris platform also includes a unique advance in Eyetelligence and CapsuleGuard. Eyetelligence facilitates real-time data accumulation and monitoring by Bausch & Lomb to help analyze individual surgeon efficiencies and provide immediate support when needed. Such data capture also facilitates studies of various aspects of cataract surgery, such as parameters used for a specific type of surgical method or nuclear density. CapsuleGuard is a soft silicone tip I/A handpiece to maximize safety when contacting the lens capsule, whether inadvertent or intentional, such as when polishing.

In summary, the Bauch & Lomb Stellaris Elite combines a refined vacuum pump with smaller bore, higher resistance phaco needles and tubing and Adaptive Fluidics anterior chamber pressurization. The Dual Linear Pedal further enhances safety and efficiency by providing surgeons with independent and more sensitive control of pump and ultrasound levels.

JOHNSON & JOHNSON VERITAS VISION SYSTEM

Jeff Pettey, MD, MBA

The Johnson & Johnson VERITAS Vision System brings meaningful improvements to two critical areas of phacoemulsification: fluidics management and ergonomics. New to VERITAS is the Hybrid Fluidics Technology with Advanced Tubing System (ATS), a swivel handpiece, and a new ergonomic foot pedal. VERITAS builds on the heritage of

WHITESTAR technology, ELLIPS transversal ultrasound, and dual-pump control with the choice of using either a peristaltic or venturi pump or both pumps during the same procedure.

Fluidics

The VERITAS system features unique Hybrid Fluidics Technology for chamber stability through the Dual Pump System and its proprietary ATS. It offers both venturi-based vacuum and peristaltic pump options with the same phaco pack allowing surgeons to choose either pump system for each case. Surgeons can even alternate between the two pumps on demand. Venturi systems can provide better efficiency with less chatter.[14] The ATS described below prevents the surge that can accompany more rapid fragment emulsification. Peristaltic pumps tout greater holding power, whereas venturi pumps exhibit improved followability and efficient fragment removal. This allows the surgeon to select a venturi or peristaltic pump for any stage of surgery and to balance the features of each for maximum efficiency and safety. A typical surgical setup might use the peristaltic pump for the steps of sculpting, initial quadrant engagement during phaco chop, and the intentionally slower epinuclear removal. When efficiency of emulsification is prioritized, the venturi pump can be engaged during quadrant or fragment removal when the phaco needle is safely positioned at or above the iris plane. The venturi pump is often used to increase the efficiency of cortical removal and for vitrectomy steps when necessary.

VERITAS' ATS is designed to minimize postocclusion surge. The unique design combines a high-durometer (stiff) inner tube with a softer outer layer to improve chamber stability. The inner tube reduces AFR for a given vacuum setting and stores less energy when occluded. The outer layer maintains flexibility and smoothness to contour to the surgeon's hand and arm and to avoid interfering with critical surgical maneuvers.

VERITAS offers two types of phaco packs: the VERITAS Advanced Infusion pack with or without gas-forced infusion. The unique gas-pressurized infusion option adds pressurization output from the console through a connection to the BSS bottle. This duplicates the effect of raising the irrigating bottle further beyond the limit of the bottle height stand (equivalent to 30 cm H_2O bottle height). This additional bottle pressure can be used to increase anterior chamber pressure and depth, to increase irrigation inflow for high aspiration vacuum/flow settings, and to achieve higher effective bottle heights in operating rooms (ORs) with low ceilings.

Additional fluidic features in the Intelligent Occlusion Sensing system work in conjunction for safety and convenience. The Chamber Stabilization Environment monitors aspiration and optimizes vacuum for both holdability and to minimize postocclusion surge. Likewise, Occlusion Mode regulates ultrasound power during occlusion and vacuum rise time after occlusion. Continuous Irrigation Auto-Off automatically detects removal of the handpiece from the eye and then stops irrigation flow. This eliminates the need to press foot pedal buttons that can be used for other functions.

Reflux and venting features allow the surgeon to decrease vacuum at the tip or even reverse fluid flow to push away inadvertently entrapped iris or capsule. Reflux can be manually activated with a foot pedal button. Automatic reflux venting is an option that can be enabled to automatically occur when the foot pedal is released from position 2 to position 1, eliminating a need for a button press. Foot pedal button mapping and venting strength can be customized according to surgeon preferences.

Ultrasound Motion: Transversal Ultrasound

Traditional ultrasound uses longitudinal "forward and back" motion of the phaco tip to emulsify the cataract fragments through direct mechanical impact force and cavitation. Inherent to longitudinal phaco is the tendency to repel lens fragments away from the tip. These repeated movements away from the tip bore create chatter as fragments bounce off the tip leading to decreased phacoemulsification efficiency.[15] The Johnson & Johnson VERITAS system offers traditional longitudinal phacoemulsification and advanced ELLIPS FX technology, which blends transverse "side to side" horizontal with longitudinal ultrasound so the phaco tip subtends an ellipse. In this way it has neither the isolated longitudinal motion of traditional phaco ultrasound or the isolated horizontal motion found in torsional ultrasound handpieces.[16] The result is a blend of efficiency benefits by combining longitudinal phaco's direct pulverization of fragments with the efficient sculpting of horizontal ultrasound. Additionally, ELLIPS FX does not require the use of a specific straight or bent phaco tip, offering the surgeon an elliptical cutting path compatible with straight, curved or bent phaco tips.

Beyond advances in ultrasound motion, Johnson and Johnson pioneered innovations in the timing of ultrasound delivery. Early phaco machines used continuous delivery of energy to the phaco tip which can lead to excessive chatter, heat generation, and unwanted collateral energy delivery to ocular tissues. As phaco technology progressed, pulse or burst power modulation preserved cutting efficiency while limiting the energy delivery to the corneal endothelium. The next advance was WHITESTAR Technology, which delivers energy in extremely brief modulated ultrasound bursts alternating with short "off" pauses to allow cooling of the tip.[17] The timing and delivery can be customized with the duration of *on* and *off* cycles individually modulated.

Handpieces

The VERITAS system introduces a unique swivel handpiece while also supporting ELLIPS FX and WHITESTAR handpieces. The industry-first VERITAS Swivel handpiece is the only phaco handpiece with up to 220-degree rotation of the distal end while the proximal end with tubing remains stationary to enhance surgical comfort and maneuverability, potentially reducing hand–arm fatigue.

The VERITAS Swivel handpiece offers the same ELLIPS FX needle technology for the efficiency of longitudinal and transverse tip motion. It also features a locking Luer connector on the irrigation port, to prevent the tubing from inadvertently becoming disconnected.

Foot Pedal

The VERITAS system works with several different foot pedals including a new ergonomic VERITAS foot pedal and the Dual Linear Advanced Control Pedal. The VERITAS foot pedal supports both wired and wireless operation, and button assignments and travel ranges can be customized in the user interface. It features optimized design for more control of system operations and improved comfort across different foot sizes and types of footwear. The programmable top and side switches are accessible and allow for easy actuation. The switches actuate along the full length of the switch paddle and require less force. A removable heel rest allows customized fit, both for position relative to buttons and for alignment of the surgeon's ankle with the treadle pivot. The pedal treadle has improved treadle tactile feedback between foot pedal zones, and travel has been reduced to 11 degrees of total travel. The pedal includes four control buttons to govern reflux, continuous irrigation control, and transitioning between various settings.

The Dual Linear Advanced Control Pedal allows the surgeon to independently control fluidics and ultrasound with dual linear functionality by separating treadle pitch and yaw.

Graphical User Interface

The VERITAS system uses a touchscreen interface, guiding the surgical team through an intuitive setup for the pending case. Setup and control are done through a 19-inch capacitive touchscreen, which is responsive without the need for calibration, and a handheld remote control. Setup is guided at each step, and, during surgery, the left side of the screen allows

toggling between phacoemulsification, I/A, diathermy, and vitrectomy settings. Visual and audible cues inform the surgeon of critical parameters like irrigation flow, vacuum level, and detection of occlusion. For any specific settings, the parameters are displayed in numerical and graphical form for easy viewing and modification by the surgical technician.

ZEISS QUATERA 700

Sumit (Sam) Garg, MD

QUATERA 700 from Carl Zeiss Meditec AG is a next-generation phacoemulsification system with three differentiating features that aim to transform phacoemulsification (Fig. 20.14A).

A

B

Fig. 20.14 Johnson and Johnson Veritas Vision System. (A) Swivel Handpiece for Vertias. (B) Photo of Johnson and Johson Veritas Vision System.

QUATTRO Pump

The QUATTRO Pump is a Synchronized Fluid Exchange System. This unique fluidic system synchronizes I/A by assessing how rapidly fluid is leaving the eye and then automatically regulating irrigation inflow to precisely match the outflow. Traditional phaco pump systems primarily regulate outflow from the eye. Currently, there are two predominant aspiration pump configurations in phacoemulsification systems: peristaltic or venturi. Although they work in different ways, they both control only the rate at which fluid moves out of the eye, or how much vacuum is generated at the occluded tip. The irrigation associated with these pump systems is either based on bottle height or positive pressure in the bottle (or bag). This is fundamentally passive irrigation flow to replace fluid that has left the eye. QUATTRO Pump changes this by actively regulating the irrigation (or infusion) in a real-time manner based on how fluid moves out of the eye. This Synchronized Fluid Exchange System infuses at the same rate that it aspirates with automatic compensation for leakage at the incision. Being neither peristaltic nor venturi, QUATTRO creates a new classification for phacoemulsification fluid dynamics.

A consistent challenge in cataract surgery has been to maintain perfect chamber stability during nuclear emulsification and evacuation. Transient negative pressure within the chamber results when outflow momentarily exceeds inflow, and this can cause forward vaulting of the exposed and thin posterior capsule. Greater degrees of postocclusion surge cause iris fluttering or visible shallowing of the anterior chamber. Although continuing improvements in fluidic systems have dramatically improved chamber stability, there are still many situations where chamber fluctuation persists. In these situations, surgeons may attempt to increase infusion, thereby increasing IOP, which can be uncomfortable for patients and produce negative side effects. Another tactic to reduce chamber instability is to introduce flow restrictors in the phaco tip, handpiece or aspiration tubing. These restrictions limit outflow from the eye, but this can lead to clogging of the aspiration line or reduced responsiveness. Both strategies require tradeoffs; either increasing the IOP or restricting the fluid outflow of fluids, which can reduce efficiency. In contrast to peristaltic and venturi systems, the QUATTRO 700 Pump's Synchronized Fluid Exchange System simultaneously regulates both inflow and outflow to minimize any transient negative chamber pressure. There is no increase in the IOP nor decrease in response time, so that the surgeon need not sacrifice safety for emulsification efficiency.

QUATERA 700 as the Data Hub in the Operating Room

Quatera 700 provides digital integration with the Zeiss surgical microscope and other Zeiss diagnostic devices. The machine's display screen can serve as a data hub of preoperative imaging and information for the surgeon and sterile scrub technician. The live video from the microscope, patient information (such as the name, selected IOL, etc.) and other procedural information can be displayed on the Quatera 700 screen so that the surgeon can conveniently and directly access it without otherwise looking at printouts (see Fig. 20.15B) The surgeon can use the footpedal to cycle through other functions, such as the CALLISTO digital marking to guide toric IOL alignment. These enhancements enable a more efficient workflow that reduces dependence on the circulating OR staff.

Power on Demand Ultrasound

The Power on Demand ultrasound component is an automatic regulation of the ultrasound delivery based on phaco tip occlusion. The system can detect when there is nuclear material at the tip, and it can scale the power available to the surgeon based on whether the tip is occluded or not. For example, if there is nothing at the phaco tip, it does not allow the surgeon to unnecessarily deliver ultrasound energy to the eye. Once the phaco tip becomes occluded, the system permits the surgeon to command more power, but it will only deliver the maximum power when the tip is fully

Fig. 20.15 (A) Photo of the Zeiss QUATERA 700. (B) Graphical user interface of QUATERA 700.

occluded. Power on Demand automatically improves the efficiency of ultrasound delivery by adjusting power level to the level of tip occlusion.

These unique features of the Quatera 700 provide a truly new system of fluidics and power modulation with the goal of improving safety and efficiency over conventional pump systems.

SUMMARY

Dr. Charles Kelman could have scarcely imagined the technological advances available today in modern phaco platforms. However, the fundamental ultrasound physics and phacodynamics remain unchanged. Each new generation of phacoemulsification platforms has advanced surgeon control, safety, and efficiency, and each of these three platforms covered in this chapter convey excellent patient outcomes.

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21

Extracapsular Cataract Extraction and Manual Small-Incision Cataract Surgery

David F. Chang and Rengaraj Venkatesh

CONTENTS

Although phacoemulsification (phaco) is technically a method of extracapsular cataract extraction (ECCE), the ECCE acronym usually refers to manual ECCE without the use of phaco. In the 1980s posterior chamber (PC) intraocular lenses (IOLs) and their requirement for capsular support spurred the global transition from intracapsular cataract extraction (ICCE) to manual large-incision ECCE. This remained the dominant cataract surgical method worldwide until foldable IOLs drove the subsequent transition to phaco by the early 1990s. For North America and Europe, this explains why older cataract surgeons are the most proficient and experienced with manual ECCE and why newer generations of surgeons have had limited training and exposure to this technique.[1]

As a more cost-effective method of cataract surgery, manual ECCE is more popular in low resource settings.[2–14] Phaco requires the capital and maintenance costs of the machine, higher consumable costs per case, more expensive foldable IOLs, and a longer surgical learning curve. The additional burden of more advanced cataracts in indigent patient populations increases the risk for serious complications with phaco compared with manual ECCE, depending on the surgeon's level of experience and training.[9–12]

Traditional manual ECCE requires a 10- to 11-mm limbal incision that is closed with multiple interrupted sutures. Smaller incision manual ECCE techniques have been developed by several international groups to enable self-sealing closure of the incision, or at least a reduction in the number of sutures required.[9] We will separately discuss both variations in this chapter, starting first with the larger incision manual ECCE.

LARGE INCISION MANUAL ECCE

Indications and Comorbidities

If adept at the technique, phaco surgeons may elect manual ECCE as a primary procedure for certain complex cases to reduce the risk for surgical complications (Table 21.1). The most common indication is an ultrabrunescent cataract, especially with coexisting surgical risk factors, such as a small pupil, absent red reflex, poor corneal visibility, zonulopathy, or a shallow anterior chamber (AC). In these eyes at greatest risk for posterior capsular rupture (PCR), retained lens material, and corneal decompensation with phaco, minimizing incision size assumes a much lower priority.

A second, separate indication would be converting intraoperatively from phaco to a larger incision, manual ECCE to extract a nucleus in danger of descending posteriorly because of capsular or zonular insufficiency (Table 21.2).[15, 16] Loss of the normal capsular or zonular barrier also increases the risk for aspirating vitreous with the phaco tip. Recognizing this danger and converting early enough to a manual ECCE technique can prevent retained nuclear fragments and ensnaring vitreous with the phaco tip with the attendant high risk for creating a giant retinal tear.

During nuclear emulsification, signs that raise earlier suspicion of zonular dialysis or PCR include a sudden widening of the pupil and deepening of the anterior chamber, excessive horizontal displacement or tilting of the nucleus, and partial descent of the nucleus or nuclear fragments.[17] Although it may be impossible to directly visualize the capsular or zonular defect, these indirect signs of capsular complications make it prudent to convert to a manual ECCE, especially if the nucleus is dense and a significant amount remains to be emulsified.

ANESTHESIA

A retrobulbar or peribulbar anesthetic block is administered for a planned, primary manual ECCE. A regional anesthetic injection should also be considered for complex cases in which the possibility of needing to convert from phaco to a manual ECCE is deemed to be higher. When converting to a manual ECCE for an eye under only topical anesthesia, supplemental anesthetic can be administered. A retrobulbar or peribulbar block may be more difficult when the eye has already been prepped and draped, and after an incision has been

TABLE 21.1 Potential Indications for Primary ECCE

- Ultrabrunescent mature nucleus, especially with surgical comorbidities, such as a small pupil, absent red reflex, suspected zonulopathy, zonular dialysis (e.g. traumatic)
- Very shallow anterior chamber
- Dense lens with suspected posterior capsular defect (e.g. capsular damage with vitrector or from an intravitreal injection)

TABLE 21.2 Indications for Converting From Phaco to ECCE

- Brunescent lens with anterior capsular complications (e.g., radial capsulorrhexis tear)
- Brunescent lens with significant or progressive zonulopathy noted during phaco
- Zonular dialysis with significant remaining nucleus
- Suspected or confirmed posterior capsular rupture or vitreous prolapse with significant remaining nucleus
- Problems with phaco technique (e.g. nucleus too dense, inability to disassemble nucleus, failure of equipment)

made. One method is to administer a posterior sub-Tenon's injection of 2 mL of 2% lidocaine through a small bulbar conjunctival cut-down in the inferior fornix.[18] One then passes a blunt, curved Simcoe cannula through this opening and advances it posteriorly along the contour of the globe into the posterior sub-Tenon's space before injecting the lidocaine. Alternatively, if the patient is relaxed and cooperative, one may only need to inject some subconjunctival lidocaine in the limbal region where the peritomy is to be made for the manual ECCE incision.

SURGICAL PROCEDURE (CONVERTING FROM PHACO TO MANUAL ECCE) [VIDEO 21.1]

- Inflate the AC with an ophthalmic viscosurgical device (OVD). Avoid the constraints of a small diameter capsulorrhexis by making multiple relaxing incisions in the edge or by converting it to a can-opener capsulotomy (Fig. 21.1a).
- Abandon the temporal, self-sealing, clear corneal incision. Reposition the surgeon and the microscope to operate superiorly. If self-sealing, the temporal clear corneal incision can be left unsutured.
- Perform an ~11-mm limbal peritomy and obtain hemostasis with cautery (see Fig. 21.1b).
- Depending on the anticipated nuclear diameter, perform ~10- to 11-mm limbal groove and enter the AC with a keratome (see Fig. 21.1c,d).
- Extend the incision for the length of the groove with corneal-scleral scissors or a keratome (see Fig. 21.1e).
- Employ bimanual expression or a lens loop to deliver the nucleus if the zonules and posterior capsule are intact. Bimanual expression is generated with the tip of a muscle hook pressing just within the inferior limbus, and point counterpressure on the scleral edge at the midpoint of the superior incision (see Fig. 21.1f–h). The former tilts the proximal pole of nucleus upward toward the incision.
- Use a lens loop if a zonular dialysis or posterior capsular rupture is suspected. Rather than compressing the nucleus against the cornea as resistance is encountered, use the heel of the lens loop to gradually depress the scleral side of the incision.
- Temporarily close the incision with at least 2 interrupted "safety" sutures, such as 8-0 Vicryl or 10-0 nylon (see Fig. 21.1i).
- Perform an anterior vitrectomy with split infusion if vitreous prolapse is encountered.
- Complete cortical cleanup with irrigation-aspiration (IA) instrumentation (see Fig. 21.1j).
- Remove 1 temporary suture after expanding the posterior capsular space with OVD.
- Implant AC or PC IOL, depending on the posterior and anterior capsular status and surgeon preference (see Fig. 21.1k).
- Perform a peripheral iridectomy if an AC IOL is implanted.
- Close the incision with interrupted 10-0 nylon sutures, bury knots, and cover with conjunctiva (see Fig. 21.1l).

When performing a primary manual ECCE for an advanced, mature cataract, a retrobulbar or peribulbar anesthetic is administered. After making the limbal groove, a can-opener capsulotomy is performed, employing trypan blue dye if the red reflex is poor or absent. The remaining steps are as listed above.

CONVERTING TO MANUAL ECCE: SURGICAL PEARLS

- Supplement topical anesthesia with posterior sub-Tenon's injection or local subconjunctival injection of 2% lidocaine. Consider placing suture in temporal clear corneal incision prior to administering supplemental anesthesia.
- Abandon temporal clear corneal incision; move superiorly to create ECCE incision.
- Make relaxing incisions in capsulorrhexis edge, or convert to can-opener capsulotomy.
- The incision must be adequately large. If too much resistance to nuclear extraction is encountered, stop and further enlarge the incision.
- If able, implant the posterior chamber IOL prior to cortical cleanup to reduce the risk of capsular aspiration.
- Instill intraocular miotic to confirm a round pupil and that neither iris nor anterior capsular flap is incarcerated in the incision.

POTENTIAL COMPLICATIONS

The larger limbal incision of the manual ECCE procedure increases the risk of surgical and postoperative wound complications. Poor wound construction may lead to intraoperative iris prolapse and chamber instability during cortical IA. Absence of a small, self-sealing phaco incision is potentially catastrophic in the rare event of a suprachoroidal hemorrhage or a patient that suddenly sits up. Postoperatively, there is a greater risk of wound leak, wound dehiscence, and excessive astigmatism caused by the sutures or progressive wound relaxation.

With a planned manual ECCE, one must have an adequately large capsulorrhexis diameter to minimize resistance to nuclear expression. A can-opener capsulotomy should have a continuous circumferential opening. Large tags and flaps that can be inadvertently aspirated with the IA tip should be avoided. Because manual ECCE is often selected for the most mature cataracts, trypan blue-dye staining should be considered to optimize capsular visualization.

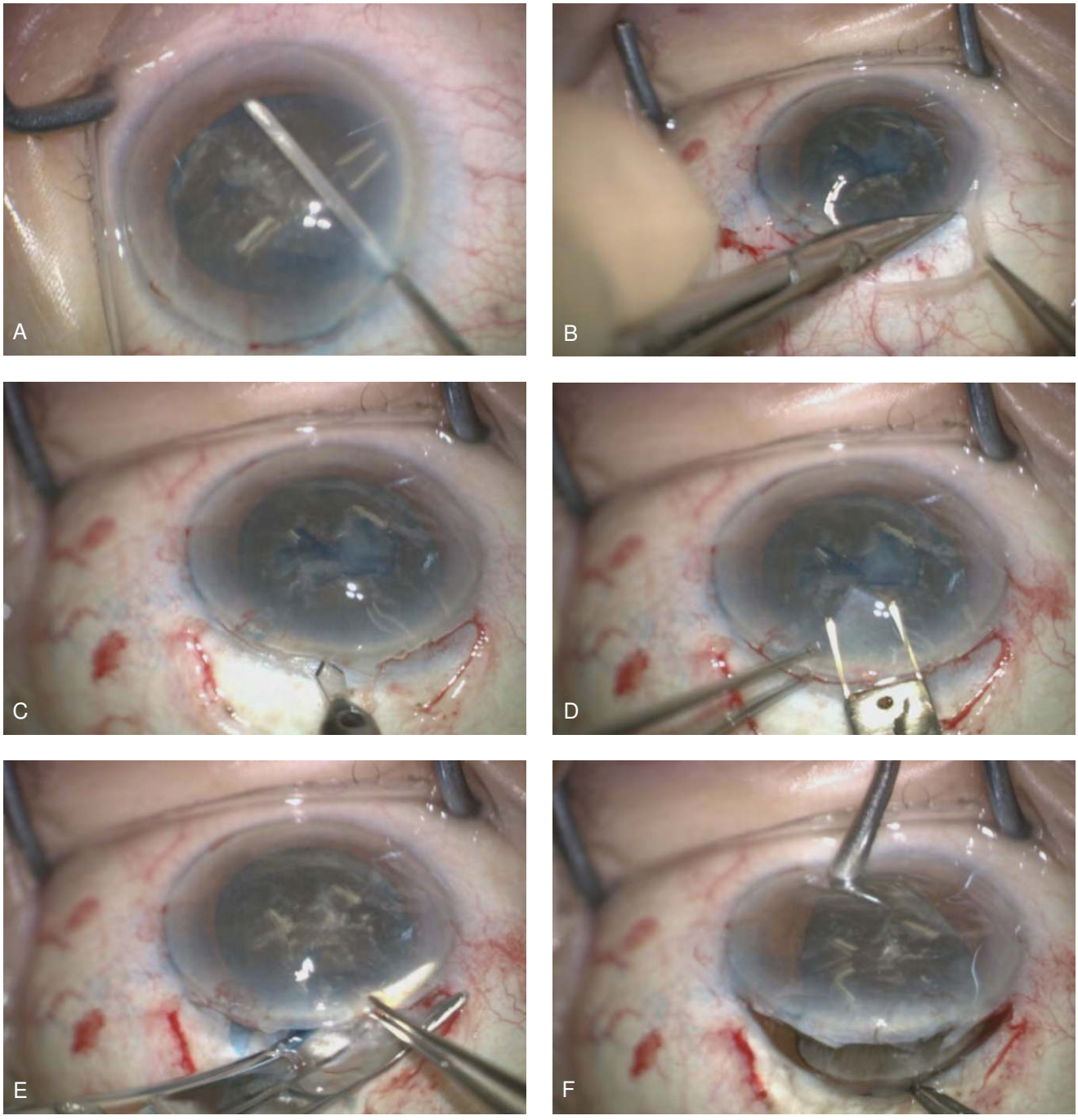

Fig. 21.1 Converting from phaco to manual ECCE. (A) Capsulorrhexis is converted to a can-opener with a #25 capsulotomy needle. (B) A superior limbal peritomy is performed. (C) A limbal groove is made. (D) The AC is entered with a diamond keratome. (E) The incision is extended with corneoscleral scissors. (F–H) Bimanual nuclear expression is performed with a muscle hook pressing inferiorly just within the nucleus, and point pressure with forceps on the scleral side of the incision. (I) The incision is temporarily closed with 8-0 interrupted Vicryl sutures. (J) Cortical aspiration is performed with the automated IA tip. (K) A 3-piece IOL is implanted into the posterior chamber. (L) The superior ECCE incision is closed with multiple 10-0 nylon sutures.

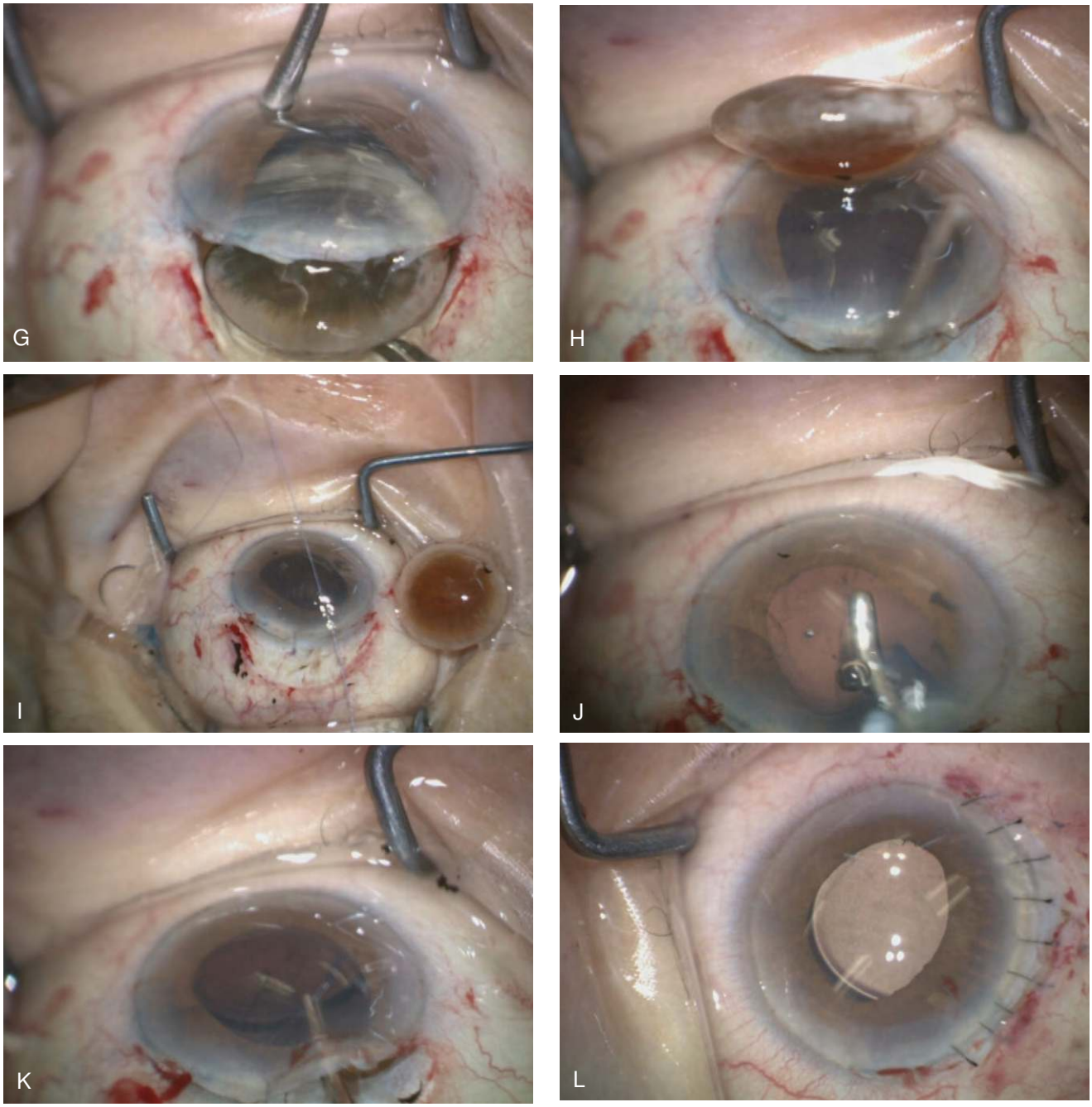

Fig. 21.1 cont'd

A common problem to avoid is insufficient incision size. This increases the trauma of lens loop extraction if the surgeon tends to compress the nucleus against the corneal endothelium to generate more force. Bimanual expression can result in iatrogenic zonular dehiscence if the nucleus cannot exit the incision with increasing globe compression. Finally, a small pupil can restrain the nucleus from exiting the incision as well. Mechanically stretching the pupil after partial thickness iris sphincterotomies may be necessary, in combination with prolapsing the superior pole of the nucleus anterior to the proximal iris with OVD.[18]

Surgical and postoperative hyphema are rarely severe but are more common than with phaco because of the larger incision.[10] Hyphema may also complicate AC IOL placement and positioning. Temporarily elevating the intraocular pressure (IOP) is usually sufficient to tamponade such bleeding. Pupillary distortion may result from overly aggressive iris sphincterotomies, partial iris incarceration in the incision, wound incarceration of a long anterior capsular flap, or from iris tuck caused by AC IOL haptics. Intraocular miotic instillation at the conclusion of surgery will facilitate diagnosing these problems. A peripheral iridectomy should accompany AC IOL placement to prevent pupillary block.

! CONVERTING TO MANUAL ECCE: POTENTIAL PITFALLS

- Converting shelved temporal clear corneal incision to a large limbal ECCE incision
- Attempting to manually prolapse the nucleus through a small diameter capsulorrhexis or pupil
- Inadequate incision size relative to the nucleus diameter
- Attempting bimanual nuclear expression in the presence of PCR or a zonular dialysis
- Compressing nucleus against the corneal endothelium with lens loop
- Improper suture placement (e.g. too long, nonradial) resulting in excessive astigmatism or poor wound apposition
- Premature suture removal (e.g. prior to 6 weeks) may result in excessive ATR astigmatism

POSTOPERATIVE MANAGEMENT

Postoperatively, manual ECCE patients are typically cautioned to avoid bending over and Valsalva maneuvers that could increase periorbital pressure against the globe. A nighttime shield should be considered for the first month to reduce the risk for wound dehiscence or suture breakage caused by eye rubbing. Early postoperative hypotony should trigger Seidel testing of the incision. Minor wound leaks often resolve by combining patching and aqueous suppression with topical beta blockers and/or carbonic anhydrase inhibitors. The presence of sutures and the larger incision can be associated with initial discomfort requiring more frequent and prolonged artificial tears and anti-inflammatory drops. Superiorly placed sutures causing irritation or inducing excessive with-the-rule astigmatism can be cut at the slit lamp and removed if necessary. However, premature suture lysis can exaggerate the eventual drift toward increasing against-the-rule astigmatism over time. This is attributed to relaxation of the wound in a similar manner to the effect of a limbal relaxing incision.

If conversion from phaco to manual ECCE was necessitated by PCR and vitreous prolapse, postoperative management must include careful monitoring and treatment of IOP elevation, cystoid macular edema, iridocyclitis, prolonged corneal edema, and possible retinal tear or detachment. Patients with retained, dropped nuclear fragments should be promptly referred to a vitreoretinal surgeon for surgical extraction.

SUMMARY (MANUAL ECCE)

Manual ECCE provides a reasonable alternative to phaco for advanced mature cataracts, particularly if associated with additional surgical risk factors. Removing the brunescent nucleus without ultrasound and without creating multiple fragments can reduce the risk for corneal decompensation, PCR, and retained lens material in the highest risk eyes. Which procedure to employ will depend on the surgeon's personal level of experience and confidence with each technique. Patient factors, such as desire for a refractive IOL, may also influence this decision. A major benefit to learning large-incision ECCE is as a rescue technique if PCR, progressive zonulopathy, or a zonular dialysis complicates phaco.[15, 16]

MANUAL SMALL-INCISION CATARACT SURGERY

Manual small-incision cataract surgery (MSICS) refers to manual ECCE performed through a smaller self-sealing incision. The shelved incision has a larger internal opening and smaller external dimension, which can be left sutureless or closed with a single radial or mattress suture. MSICS is potentially safer and can achieve a better uncorrected visual outcome in comparison to large-incision ECCE; it is significantly faster and less likely to induce wound-related astigmatism.[7–11] Because it is much less expensive and technology-dependent than phaco, MSICS may be a more appropriate technique in eyes with mature cataracts in the developing world.[3–14]

TABLE 21.3 Advantages of MSICS Over Phaco in Resource-Limited Settings

- Reduced reliance on technology requiring capital investment, specialized repair and maintenance, and reliable electricity
- Reduced costs-per-case
- Easier learning curve with fewer complications
- Lower complication rate with mature and brunescent cataracts
- Faster than phaco with advanced cataracts

INDICATIONS AND COMORBIDITIES

In developing nations and other resource-limited settings, large-incision ECCE or MSICS are generally more cost-effective and affordable compared with the higher per-case and capital equipment costs of phaco (Table 21.3). Phaco machines require a reliable electrical power supply and access to parts and trained technicians for maintenance and repair. Compared with ECCE, phaco entails a longer learning curve with a much higher rate of surgical complications such as endothelial decompensation, vitreous incarceration, and retained lens fragments. This is particularly true because of the high prevalence of mature and brunescent cataracts in these populations. Many health care settings may also lack the cornea or vitreoretinal subspecialists required to successfully manage these complications.

The indications for MSICS are generally the same as for manual large-incision ECCE listed earlier. However, the Aravind Eye Care System has pioneered an assembly line system of high-volume, sutureless, MSICS for its indigent patients.[14] Using a square-edged PMMA IOL, a single surgeon can perform between 10 to 16 MSICS cases per hour with a supply cost of $20 USD per case. This lower cost, low-tech procedure provides excellent outcomes.

ANESTHESIA

Because of the scleral pocket incision, MSICS is usually performed using a peribulbar, retrobulbar or sub-Tenon's anesthesia. At Aravind,

MSICS: SURGICAL PEARLS

- Superior rectus bridle suture stabilizes and immobilizes the globe during incision dissection and nuclear extraction.
- Temporal placement of a frown- or chevron- shaped scleral pocket incision reduces wound-induced astigmatism.
- Use a can-opener capsulotomy if unable to make a large diameter capsulorrhexis, particularly with an ultrabrunescent nucleus.
- Use hydro- or viscoexpression for softer nuclei.
- Use an irrigating vectis with or without a second instrument for larger and denser nuclei.
- Stop and widen the incision if too much force seems necessary to extract the nucleus.

sub-Tenon's anesthesia is preferred because it eliminates the risk for retrobulbar hemorrhage and globe perforation with a needle injection.[18] Topical anesthesia is not sufficient for the scleral pocket dissection and bridle suture placement.

SURGICAL PROCEDURE (MSICS) [VIDEOS 21.2-21.5]

Incision

Constructing a self-sealing, tri-planar incision is the key to sutureless MSICS. The superior location is commonly used because of the protection afforded by the upper lid. However, a temporal or superotemperal location may be chosen when there is significant against-the-rule astigmatism. This is also recommended for glaucoma patients who have had, or may later need, a trabeculectomy or a glaucoma drainage device. The amount of surgically induced astigmatism (SIA) is directly proportional to the cube of the length of the incision and inversely proportional to the distance of the incision from the limbus: SIA $\propto$ Length^3/Distance from the limbus.[5] The longer the radial track of the sclerocorneal pocket, however, the more the incision can constrain surgical maneuvers and nucleus extraction.

- A 4-0 silk superior rectus bridle suture fixates the globe and can elevate a deeply set globe. Downward rotation of the globe improves surgical access for a superior scleral tunnel incision. A lateral rectus bridle suture is used for a temporal incision.
- An 8- mm fornix-based conjunctival flap is created, and the underlying scleral bed is lightly cauterized.
- The initial groove for the incision is made with a #15 Bard-Parker blade. Novices should start with a straight groove before advancing to a frown or chevron shape (Fig. 21.2a). The farther this posterior edge of the incision is from the limbus, the less astigmatism will be induced, but the more constrained certain surgical maneuvers will be.
- Sclerocorneal tunnel construction is performed using a bevel-up crescent blade to undermine the groove anteriorly at approximately 1/3 to 1/2 scleral thickness (see Fig. 21.2b). This plane is advanced into clear cornea using wriggling motions of the crescent blade until its tip reaches the blue-white limbal junction. The heel of the crescent blade is then lowered to redirect the tip more anteriorly as it is advanced into clear cornea. This pocket incision should extend at least 1 mm into clear cornea to create a self-sealing wound. The sclerocorneal tunnel is widened with lateral movements of the crescent blade within the same tissue plane.
- To facilitate nucleus delivery, the incision should have lateral extensions, called "side pockets" that extend diagonally forward (see Fig. 21.2b). This produces a trapezoidal shape to the corneoscleral pocket incision in which the internal opening through Descemet's membrane is wider than the posterior scleral opening.
- A "frown" or chevron shape to the scleral groove is more astigmatically neutral.[19] The goal is for the radial distance to the limbus to be only 1.5 to 2 mm centrally but longer on the two sides of the pocket incision. This decreases any sliding of the tunnel roof over time, which would induce more astigmatism.
- A paracentesis is made at 8 to 9 o'clock, through which intracameral diluted adrenaline and/or trypan blue can be injected. OVD is then injected into the AC to pressurize the eye.
- A sharp bevel down 3.2 mm keratome enters the anterior chamber and extends this entry laterally for the full excursion of the sclerocorneal groove.

Capsulotomy

A continuous curvilinear capsulotomy (CCC) of at least 5.5 mm in diameter is preferred (see Fig. 21.2c), but a can-opener capsulotomy may be safer for prolapse of an ultrabrunescent nucleus out of the capsular bag. Trypan blue dye is used if the red reflex is poor or absent. If a radial tear or extension occurs while performing the CCC, it should be converted to a can-opener capsulotomy. Hydrodissection with or without hydrodelineation is performed to free the nucleus from its cortico-capsular attachments. The nucleus is then rotated within the bag to confirm its separation from the bag and cortex.

Nuclear Prolapse and Delivery

Multiple methods can be used to deliver the undivided nucleus, and the choice may depend on the type and size of anterior capsulotomy.[2,3,5–9,20–23] The initial step is to prolapse the nucleus partially or entirely out of the capsular bag. With a can-opener capsulotomy, a Sinskey hook engages the equator of the nucleus, displaces the nucleus to one side, and lifts and **manually prolapses** that pole out of the bag. Rotating the nucleus either clockwise or counterclockwise prolapses the rest of it out of the bag.

With a CCC, a soft and smaller nucleus can be **hydroprolapsed** out of the bag. During hydrodissection, continuing to inject fluid after the posterior fluid wave has crossed to the opposite equator will tend to levitate the opposite nuclear pole out of the capsular bag (see Fig. 21.2d). A Sinskey hook is then used to dial the remainder of the nucleus out of the bag (see Fig. 21.2e). Bimanual instrumentation is needed for larger, dense nuclei. As the nucleus is displaced to one side of the bag with a Sinskey hook, a spatula is slid under the exposed pole through either the side port or main incision. The spatula tip then elevates the pole out of the bag. To prevent the nucleus from falling back into the bag, the spatula remains in place to serve as a ramp while the rest of the nucleus is dialed into the AC with the Sinskey hook.

Once the proximal pole of the nucleus has been prolapsed, **viscoexpression** works well for soft to moderately hard nuclei if the incision is adequately large. The endothelial surface is coated with OVD. As the posterior lip of the main incision is depressed and gaped with the OVD cannula shaft, the cannula tip is directed posteriorly underneath the prolapsed nuclear pole. Continuing to inject more OVD will eventually expel the nucleus through the incision until it can be dialed completely out with an instrument tip.

We prefer to deliver moderate to hard nuclei using an **irrigating vectis** measuring 4 x 8 mm (Fig. 21.3). OVD is first liberally injected above and below the prolapsed nucleus. While holding the superior rectus bridle suture loosely with the nondominant hand, the vectis (without irrigation) is slid beneath the nucleus with the concave side up until is lies beneath the majority of the nucleus. The vectis and its placement can be visualized through even dense nuclei. Holding the bridle suture taut provides counterfixation as the vectis is slowly withdrawn without irrigation, until the superior pole of the nucleus plugs the internal opening of the tunneled incision. Irrigation is then activated, which increases the intraocular pressure

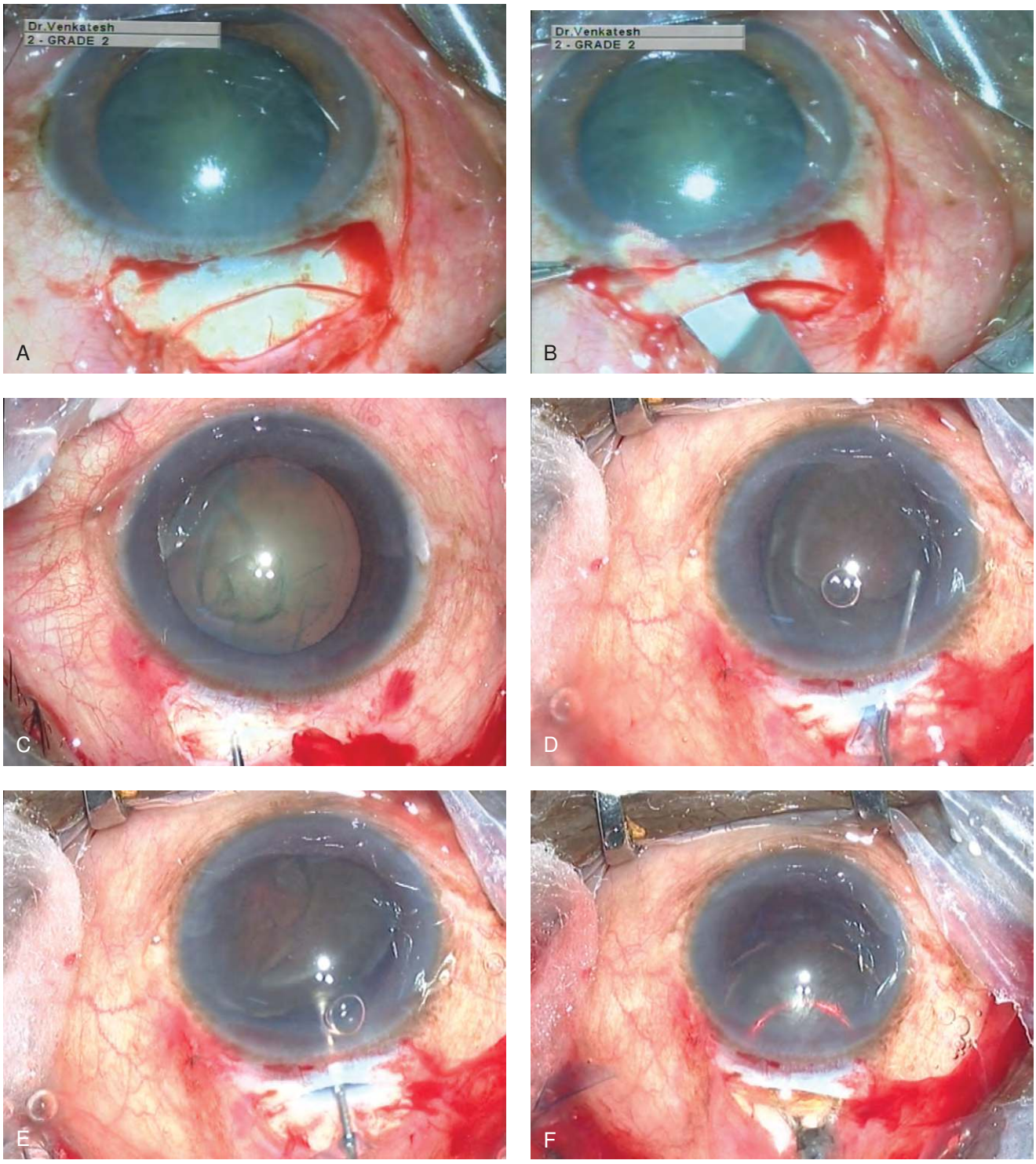

Fig. 21.2 (A) Superior frown-shaped scleral pocket incision with central radial length of 2 mm. (B) Sclerocorneal tunnel construction with side pockets. (C) Large diameter capsulorrhexis. (D) Partial hydroprolapse of one nuclear pole out of the capsular bag. (E) Remaining nucleus is prolapsed by rotating it out of the bag. (F) Nucleus delivery using irrigating vectis. (G) Single piece square edge PMMA IOL implanted in the bag.

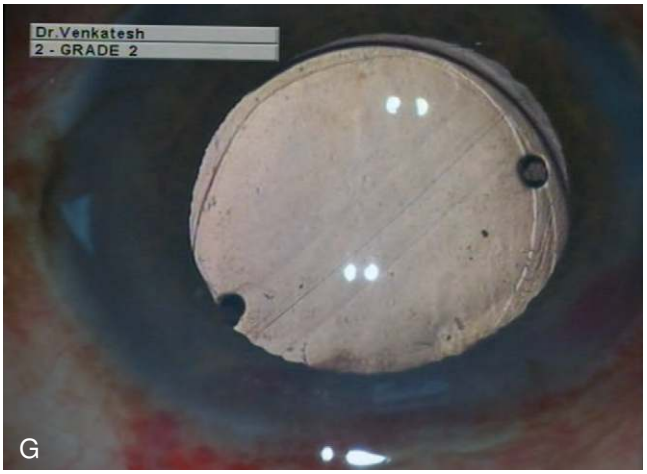

Fig. 21.2 cont'd

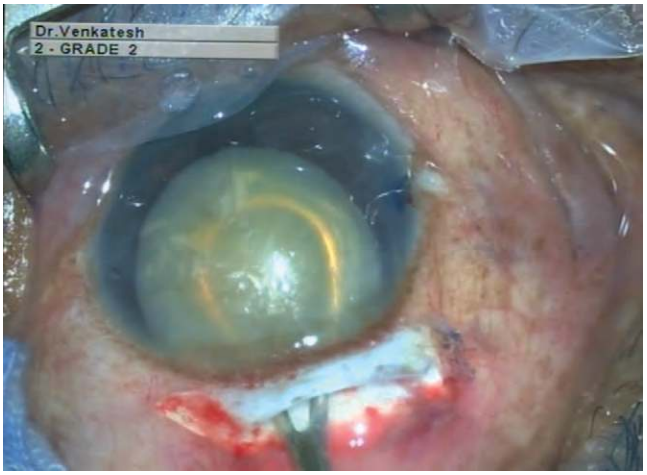

Fig. 21.3 Irrigating vectis placed beneath the nucleus after prolapse into the anterior chamber. (Image courtesy Rengaraj Venkatesh.)

and propels the nucleus out as the vectis is slowly withdrawn. The vectis shaft and tip exert steady downward pressure on the posterior scleral lip to gape the incision during this maneuver. Care should be taken to reduce the force of irrigation once the widest diameter of the nucleus has just crossed the inner lip of the tunnel. Reducing the irrigation pressure will prevent overly abrupt nuclear expression and AC collapse.

An alternative to using irrigation is the "phaco sandwich" technique, using a Sinskey hook and the vectis like two forceps arms to extract the nucleus while an assistant pulls on the superior rectus bridle suture to immobilize the globe. Because of the second anterior instrument, this method requires a generous amount of OVD to protect the corneal endothelium.

Cortical Removal and IOL Implantation

- Absent the phaco machine or automated IA, a Simcoe IA cannula is used for manual cortical extraction.
- Placing the IA cannula through a side port incision facilitates aspiration of subincisional cortex.
- A single or 3-piece rigid PMMA IOL with a 6-mm diameter optic is implanted in the capsular bag (see Fig. 21.2g). With a can-opener capsulotomy, a 3-piece PMMA IOL is implanted in the ciliary sulcus. For PMMA IOLs placed in the capsular bag, a square optic edge is preferable to reduce the incidence of posterior capsular opacification.[24]
- The OVD is aspirated with the Simcoe IA tip.
- The AC is inflated and pressurized with BSS through the side port paracentesis.
- The self-sealing incision is tested and left sutureless if water tight. Interrupted 10-0 or 9-0 nylon sutures are used if the incision is not self-sealing.

POTENTIAL COMPLICATIONS

Construction of the larger triplanar incision is challenging for novices, and wound complications are more common during the learning curve. Angling the crescent blade tip too posteriorly during dissection of the scleral flap may cause premature entry. This may result in a cyclodialysis or iris prolapse that then complicates most of the subsequent surgical steps. Angling the crescent blade tip too anteriorly may cause a button hole or tear in the scleral tunnel roof, with subsequent difficulty maintaining the AC because of an incision leak. Particularly if the wound construction is faulty, external globe pressure can result in postoperative wound leak or iris prolapse.

Descemet's membrane detachment (DMD) occurs more commonly with MSICS than with phacoemulsification.[10] Older age, brunescent nuclei, pseudoexfoliation, and a shallow AC are other factors that predispose an eye to DMD. Descemet's can be detached by a blunt keratome, fluid or OVD injection, or instrument tips that catch its edge during insertion.[25]

Prolapse and extraction of an undivided nucleus with MSICS requires an adequately large CCC. If the diameter is too small relative to the size of the nucleus, it may be difficult or impossible to prolapse the nucleus without causing a CCC tear or a zonular dialysis. Too small of an incision can also prevent nuclear expression and excessive extraction force can cause iris prolapse, zonular dialysis, PCR, or traumatic endothelial cell loss. If the vectis tip is angled too posteriorly during insertion, it can catch the proximal iris causing a superior iridodialysis. An inferior iridodialysis can result if the iris is caught between the prolapsed nucleus and vectis during nuclear extraction.

Compared with phaco, the AC shallows more frequently during manual IA with a Simcoe cannula. One must avoid aspirating or puncturing a bulging posterior capsule, or causing a zonular dialysis by inadvertently aspirating a capsular flap following a can-opener capsulotomy. Both haptics of a 3-piece IOL should be placed in the ciliary sulcus following a can-opener capsulotomy. With the latter, intentional intracapsular IOL placement usually results in postoperative subluxation of one haptic into the sulcus as the capsular bag contracts. This predisposes to IOL decentration and tilt. As with phaco, PCR can occur for a variety of reasons, including wraparound radial anterior capsular tears. However, the risk of post-occlusion surge is avoided with manual ECCE and retained nucleus is much less likely following PCR than when multiple nuclear fragments have been created during phaco.

Expulsive suprachoroidal hemorrhage is rare but more likely to occur with manual ECCE than with phaco. Risk factors include elevated IOP, advanced age, systemic hypertension and arteriosclerosis, anticoagulation, nanophthalmos, and prior vitrectomy. The smaller, self-sealing MSICS incision may reduce the risk of expulsive hemorrhage relative to the larger manual ECCE incision.

POSTOPERATIVE MANAGEMENT

The MSICS wound is more stable than the larger manual ECCE incision.[7, 11] Patients should avoid strenuous physical activities or lifting heavy weights at first. A nighttime shield can be considered for the initial 7 to 10 days after surgery. Wound gape or leak causing AC shallowing and hypotony should be immediately addressed with suturing. Anti-inflammatory steroid eye drops should be continued for 6 weeks. Postoperative IOP spikes with MSICS are most commonly caused by retained OVD. Using topical antiglaucoma medications for several days are enough to manage this.

After PCR and vitreous loss, the patient should be monitored for IOP elevation, postoperative iridocyclitis, cystoid macular edema, possible retinal tear or detachment, and endophthalmitis. Patients with retained, dropped nuclear fragments should be promptly referred to a vitreoretinal surgeon for surgical extraction.

! MSICS: POTENTIAL PITFALLS

- During scleral pocket dissection, improper angling of the crescent blade tip can lead to premature posterior entry, or a button hole in the scleral tunnel roof.
- A corneoscleral tunnel that is too short or posterior predisposes to iris prolapse, postoperative wound leak, and incision-induced astigmatism.
- Instrument pressure against the posterior edge of the large, scleral pocket incision can cause AC leak and shallowing.
- A small diameter CCC can prevent prolapse of the nuclear pole.
- Insufficient incision size can impede or prevent nuclear extraction and cause greater risk of trauma to the iris, zonules, and corneal endothelium.
- If the incision is not self-sealing, postoperative wound complications are more likely with a sutureless incision.

SUMMARY (MSICS)

As a primary surgical technique, MSICS is more cost-effective than phaco. This and the reduced risk for PCR and endothelial decompensation with advanced brunescent cataracts compared with phaco make MSICS a more suitable primary technique in many low- resource developing countries. Sutureless MSICS is more astigmatically neutral than large-incision manual ECCE, particularly if performed temporally.[7, 11] For advanced cataracts, it is a faster procedure than phaco, results in less early postoperative corneal edema, and is more amenable to very high volume surgical delivery when using protocols such as Aravind's.[5, 6] For less experienced surgeons in developing countries, it is easier and safer to learn than phaco.[10] For those adept at phaco, MSICS may still reduce complication rates with advanced and mature cataracts, particularly if complicated by zonulopathy or zonular dialysis. When the need to convert from phaco to manual ECCE arises, MSICS provides the advantage of a smaller self-sealing incision but should be employed only by those already experienced with the technique in noncomplicated eyes.

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Video 21.1: Converting from phaco to manual ECCE.

Video 21.2: MSICS in immature cataract.

Video 21.3: MSICS in brown cataract with small pupil.

Video 21.4: MSICS in intumescent mature cataract.

Video 21.5: MSICS in hyper-mature cataract.

22

Principles of Nuclear Disassembly

Thomas A. Oetting

CONTENTS

KEY POINTS

- Mastery of nuclear disassembly is a key skill for cataract surgeons.
- Residents find nuclear disassembly difficult to master.
- Surgeons should have several disassembly techniques at their disposal.
- Softer or harder nuclear cataracts are approached differently.
- Patient issues like corneal guttata, zonular integrity, and capsule integrity affect disassembly technique.

INTRODUCTION

Nuclear disassembly is a critical part of the cataract surgery procedure. Cataract surgery trainees consider this portion of the procedure one of the most difficult to master.[1] Nuclear disassembly is a risky phase of the cataract procedure for capsular and/or zonular injury, which can lead to vitreous prolapse and other complications. Surgeons have developed many useful techniques to disassemble the nucleus, including the divide-and-conquer technique, chopping techniques, and mechanical fragmentation. Surgeons should have several disassembly techniques in their skill set to safely fragment lenses of various density. Surgeons may also vary their disassembly strategy depending on other patient factors such as a small pupil, weak zonules, or preexisting injury to the lens capsule.

BASIC PRINCIPLES OF NUCLEAR DISASSEMBLY

Nuclear disassembly (or nucleofractis) is a critical step of small incision cataract surgery. All the techniques for nuclear disassembly share the common principles of exposing the nucleus, freeing the nucleus, and then using phacoemulsification to remove the nucleus in some fashion.

Exposure of the Nucleus

The anterior capsule is removed centrally in the crystalline lens to allow access to the lens material including the nucleus. Typically, an initial tear in the central capsule is carried into a round continuous tear using forceps or a needle.[2] A discontinuous tear or other capsular injury can make nuclear disassembly more difficult and prone to vitreous prolapse or loss of nuclear pieces into the vitreous space (see Chapter 17).

Freeing the Nucleus

After the central capsule is removed, the surgeon has access to the lens material including the nucleus. Fluid dissection between the lens capsule and the lens is called *hydrodissection* and can free the lens from the capsule. Fine described cortical cleaving hydrodissection in which even the cortex was freed from the capsule.[3] Fluid dissection between the epinucleus and the nucleus is possible in softer lenses and is called *hydrodelineation*. After proper hydrodissection, the lens can rotate within the capsular bag to facilitate nuclear disassembly techniques usually with phacoemulsification.

Fluid pressure during hydrodissection can tear the capsule or cause anterior prolapse of the lens (intended or not). When the anterior capsule is not continuous, hydrodissection should be delicate or avoided because the capsule may tear posteriorly, causing the vitreous to prolapse or the lens to fall posteriorly. Hydrodissection is usually avoided if a defective posterior capsule is suspected. Risk factors for the latter include posterior polar cataract, posttraumatic cataract, and eyes that have undergone vitrectomy or intravitreal injections [4–8] (see Chapter 18).

Phacoemulsification

Most nuclear disassembly techniques use ultrasound and vacuum from phacoemulsification machines to remove nuclear material. The phaco needle tip holds the nucleus during mechanical disassembly (chopping) of the nucleus into smaller pieces. The fluid dynamics of phacoemulsification machines are covered elsewhere in this textbook, but there are generally three distinct phases for phacoemulsification machines during disassembly (see Chapter 19).

One phacoemulsification phase, often called *sculpt*, uses a low vacuum and flow rate of fluid to allow controlled sculpting of grooves in the lens. The second phase is often called *chop* and has a high vacuum and ultrasound characteristics designed to hold onto the nucleus while chopping the lens into smaller pieces. The third phase is often called *quadrant removal* with a high vacuum and ultrasound power designed to attract the disassembled nuclear pieces into the emulsifier.

Disassembly Location

Usually the disassembly of the nucleus occurs within the capsular bag. After hydrodissection the nucleus can freely rotate and is broken into smaller pieces for eventual emulsification. However, some techniques disassemble the nucleus in the supracapsular space or in the anterior

chamber (AC). These out-of-the-bag techniques are particularly useful when the bag is less robust or when the lens is soft (see Chapter 24).

CLASSIC NUCLEAR DISASSEMBLY TECHNIQUES

There is no single best technique for nuclear disassembly. The technique used depends on a variety of factors including surgeon preference, density of the nucleus, capsule issues, zonular issues, pupil size, and stability of the corneal endothelium. Table 22.1 lists several of the most common techniques for nuclear disassembly. Three classic disassembly techniques are often compared with each other and to any newer strategies: divide-and-conquer, phaco-chop, and stop-and-chop techniques.

Divide-and-Conquer Technique

Gimbel described the classic and continuously useful divide-and-conquer technique in 1991.[10]

- The lens is divided in to four pieces within the capsule bag.
- Initially two perpendicular grooves are made with the phaco needle that form a cross and intersect in the middle of the lens. These grooves are wider in dense lenses (1.5 mm) and thinner in soft lenses (1 -mm). The depth of the groove is about 70% to 80% of the depth of the nucleus. Typically, the red reflex and the 1 -mm needle diameter help the surgeon gauge the depth and width of the groove. The surgeon stays mindful of the posterior shape of the lens, which is thicker in the center than the periphery.
- After sculpting, the surgeon uses the grooves to divide or crack the nucleus into four equal quarters.
- The division of the nucleus along each groove can be done with one hand with a nucleus cracking forceps (Fig. 22.1A) or with bimanual instruments applying force on each side of the groove (see Fig. 22.1B).
- The advantage of this technique is that it is relatively easy to learn and can be performed with just one hand.[11]
- The disadvantage of this technique compared with chopping techniques is that it requires more ultrasound energy to sculpt grooves.[12]

Phaco-Chop Technique

Nagahara first described the phaco-chop technique in 1993.[13]

- Phaco chop eliminates the need for nuclear sculpting, which can lead to excessive ultrasound damage to the corneal endothelium.[12,14]

TABLE 22.1 Techniques for Disassembly

	Strategy	Advantages	Disadvantages
Bowl then prolapse	Sculpt out large bowl, prolapse nucleus anterior to capsule, remaining nucleus removed in anterior chamber with phaco.	One-handed, does not require rotation, nice for softer lenses.	Increased exposure to ultrasound energy, difficult with even moderate density lenses.
Pop and chop[9]	Prolapse nucleus out of bag, nucleus is half in bag -half in anterior chamber, nucleus is removed either directly with phaco or mechanically chopped.	Can be one handed, easy to learn, does not require rotation.	Requires large rhexis, phaco energy close to cornea.
Divide and conquer	Sculpt two long grooves 90 degrees apart that cross in the middle, use grooves to crack lens into 4 pieces, remove pieces high vacuum phaco.	Can be one handed, works for most all nuclei, easy to learn.	Requires rotation of nucleus, increased exposure to ultrasound energy.
V groove	Sculpt two long grooves that join in subincisional area forming V shape, use grooves to crack lens into 3 pieces, remove pieces high vacuum phaco.	Does not require rotation, does not require hydrodissection.	Increased exposure to ultrasound energy, V-shaped grooves can be hard to produce.
Stop and chop	Sculpt one groove, divide nucleus in half, chop halves into smaller segments, remove pieces high vacuum phaco.	Less exposure to ultrasound energy.	Two handed, nondominant hand is critical to success, requires rotation of nucleus.
Crater and chop	Sculpt a crater near incision, chop nucleus in half across from incision with crater assisting nuclear division, chop halves into smaller segments, remove pieces high vacuum phaco.	Less exposure to ultrasound energy.	Two handed, nondominant hand is critical to success, requires rotation of nucleus.
Horizontal Phaco chop	Chop nucleus without initial sculpting, horizontal motion, remove pieces high vacuum phaco.	Least exposure to ultrasound energy, in soft lenses can use no vacuum to eliminate risk of capsule injury.	Two handed, nondominant hand is critical to success, requires rotation of nucleus.
Vertical Phaco chop	Chop nucleus without initial sculpting, vertical motion, remove pieces high vacuum phaco.	Least exposure to ultrasound energy, great for hard lenses.	Two handed, nondominant hand is critical to success, requires rotation of nucleus.
Mechanical	Examples are prechop and miLoop, lens is mechanically divided into 2–6 pieces, remove pieces high vacuum phaco.	Least exposure to ultrasound energy.	May require rotation of nucleus.

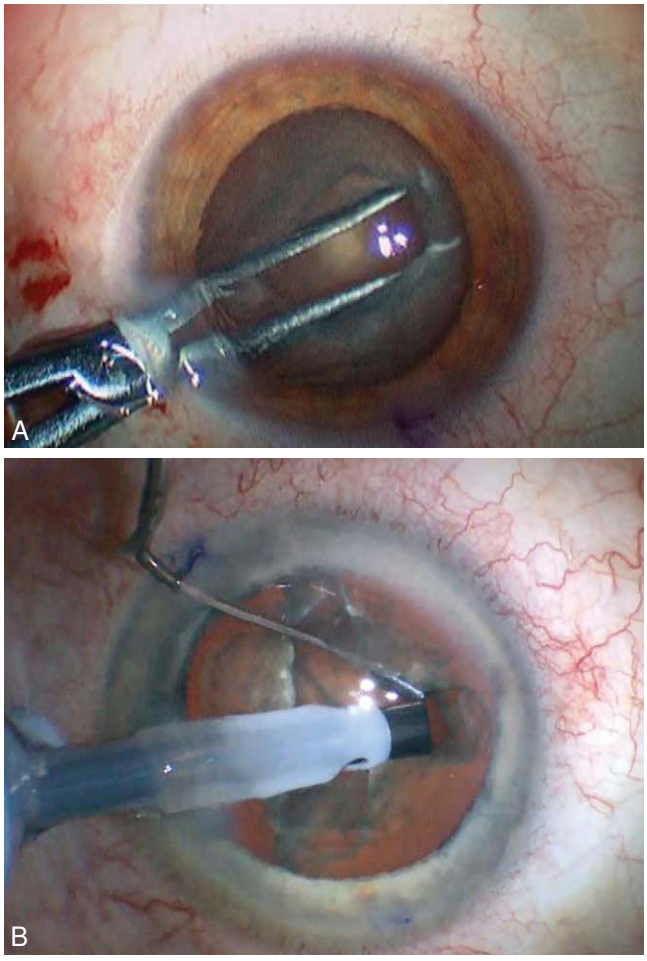

Fig. 22.1 (A) A one handed nucleus cracker is used to divide the lens in the bag. (B) two hands are used with the phaco needle and a hook to divide the lens into two pieces.

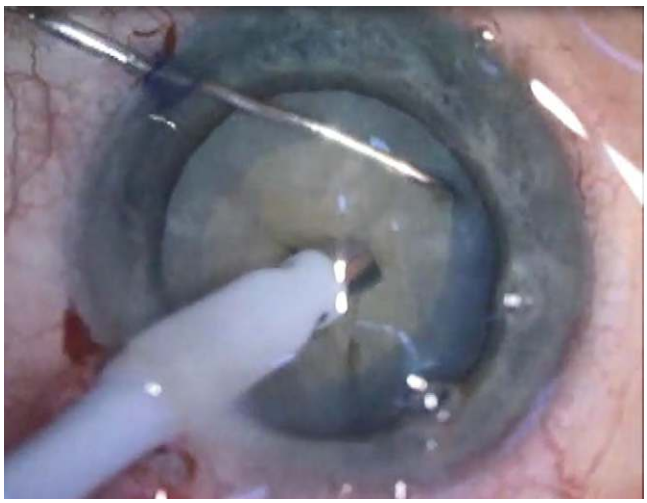

Fig. 22.2 Phaco chop procedure is used without an initial groove to divide the lens within the capsule bag.

- With the phaco-chop procedure, the phaco needle holds the lens while a hook-like chopper mechanically splits the lens material (Fig. 22.2).
- The phaco-chop procedure is particularly indicated when grooving is difficult such as when zonules are weak or in soft lenses when groove depth is difficult to estimate. This procedure is more difficult to learn than the divide-and-conquer technique because the non-dominant hand is so critical for the chop maneuver.
- Phaco-chop techniques are often divided into horizontal and vertical chop. This distinction refers to the relative motion of the phaco needle and the chopping instrument. Horizontal chop is better when the lens is soft, and vertical chop is better when the lens is hard. Further details of the phaco-chop technique are included in other chapters in this text (see Chapter 23).

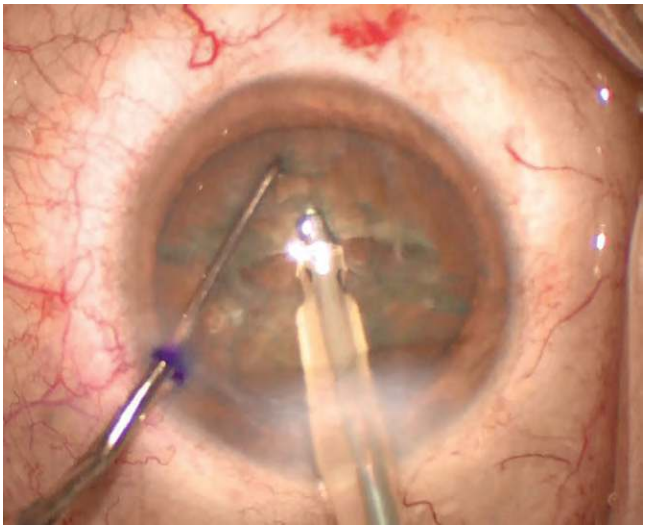

Fig. 22.3 In Stop n Chop an initial grove is made and then the lens is divided in two. The two halves are chopped into smaller pieces.

Stop-and-Chop Technique

Koch described the stop-and-chop technique in 1994, and it has served both as a primary disassembly technique and as a transition to the phaco-chop technique.[15]

- The technique starts off like the divide-and-conquer technique with a central groove used to divide the lens in half.
- Then that technique is stopped and the two halves are chopped, hence the name *stop and chop* (Fig. 22.3).
- The advantage of this technique is that less ultrasound is used than in the divide-and-conquer technique.[12,15] The initial groove in this technique allows for more space for pieces to free from each other during segment removal. For many surgeons, the stop-and-chop technique is their primary technique; but for others, it served as a bridge to get to the phaco-chop technique, which may offer some advantages (see Table 22.1).

NUCLEAR DENSITY

The optimal nuclear disassembly technique depends on several factors, with the density of the lens being the most notable (Fig. 22.4). The most difficult lenses to disassemble are either very soft or very hard. With medium density lenses, the classic nuclear disassembly techniques described previously work very well for most cases; however, soft and hard lenses present problems for the classic techniques and require special strategies. Fig. 22.4 shows how different techniques are used depending on the density of the lens.

Soft Lenses

Soft lenses are difficult because the vacuum from the phaco needle can aspirate the soft material so quickly that the phaco tip injures the capsule. For soft lenses, an effective strategy is to simply prolapse the lens into the AC during hydrodissection. This allows for a very safe removal of the material away from the capsular bag often with minimal

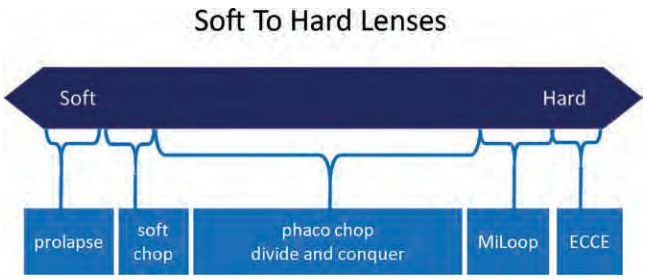

Fig. 22.4 The nucleus disassembly strategy depends on the hardness of the lens.

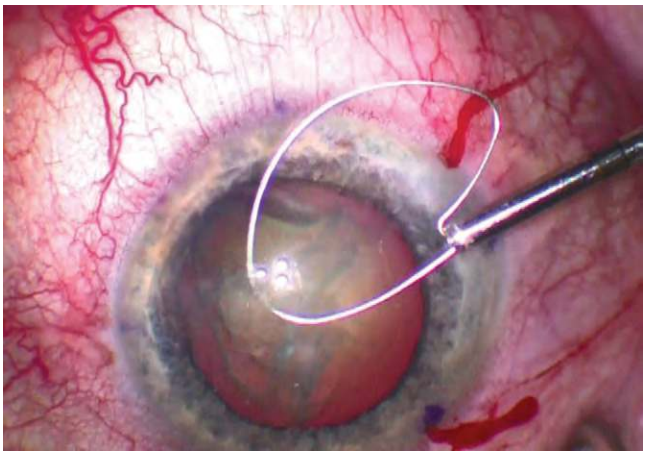

Fig. 22.5 A wire snare can be used to mechanically divide hard lenses before phacoemulsification.

ultrasound energy. Another strategy, so called *soft chop*, is to use horizontal chopping techniques but with minimal vacuum (Video 22.1).

Hard Lenses

Sometimes the best strategy with extremely hard lenses is to manually extract the lens in one piece with no disassembly. Ruit showed in a beautiful randomized study that skillful extracapsular surgery was comparable to phaco in a cohort with dense lenses.[16] Another interesting option is to use mechanical fragmentation of the lens within the bag with a loop that is compressed to split the nucleus (Fig. 22.5).[17] After the lens is split into 2 to 6 pieces with the loop, the pieces can be removed with the phacoemulsification machine or manually. The prechop technique is better than sculpting techniques like the divide-and-conquer technique for hard lenses.[12,14]

DISASSEMBLY IN SPECIAL SITUATIONS

Corneal Endothelial Issues

Disassembly techniques that lessen sculpting and anterior ultrasound cause less damage to the corneal endothelium. Disassembly within the capsular bag rather than in the AC decreases corneal endothelial cell loss but increases the risk to the posterior capsule. Chopping techniques and mechanical disassembly techniques typically use less ultrasound than the divide-and-conquer technique.[12] The use of the antioxidant glutathione may decrease cornea endothelial cell injury.

Capsular Tears

Tears in the anterior or posterior capsule makes nuclear disassembly difficult. The primary concern is that any pressure against the capsule will extend the tear, allowing nuclear material to fall posteriorly.

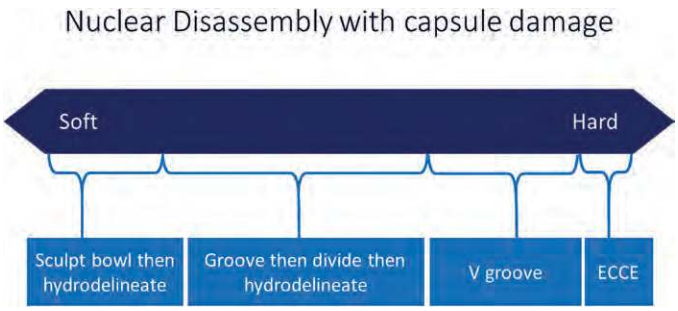

Fig. 22.6 The strategy for nuclear disassembly with capsule damage depends on the hardness of the lens.

Hydrodissection can create pressure between the nucleus and the capsule and extend an existing capsule tear or open an area of weakened capsule. Nuclear disassembly techniques that do not require hydrodissection or those that allow for a more controlled dissection between the capsule and nucleus are preferred when the capsule is potentially deficient.

Capsule tears can start posterior or anterior to the lens equator. Anterior capsular radial tears most commonly are iatrogenic and come from an errant capsulorrhexis but can also be caused by penetrating trauma or laser peripheral iridotomy. Posterior polar cataracts can have an area of central weakened posterior capsule in the area of the polar opacity. A rapidly developing cataract after pars plana vitrectomy may be caused by capsular injury from the surgery. More recently, capsular injury after repeated intravitreal injections has become more apparent.[5–7] A rapid onset of cataract after laser vitreolysis can indicate an iatrogenic posterior capsular tear.[8] The strategy for nuclear disassembly in the setting of capsular depends on the density of the lens (Fig. 22.6).

Soft Lens

If the lens is soft with a capsular tear present, the surgeon can simply sculpt out a central bowl with the phaco machine. The remaining material can then be removed after gentle hydrodelineation or dispersive viscoelastic dissection. This allows the lens material to prolapse on itself with less outward pressure against the capsule, which can extend an existing tear.

Medium Lens

If the lens is of medium density, the surgeon can sculpt a central groove and then crack the lens without rotation or hydrodissection. Hydrodelineation is then directed into the side of the groove to free the lens material. Because the lens is already cracked centrally, fluid can vent into this vacant space to reduce pressure on the capsule. The groove also allows the lens material to fold in, which also creates less outward pressure on the capsule.

Hard Lens

Dr. Charles Kelman described the V-groove technique in 1994.[4,18] With this technique, two grooves are made that intersect in the subincisional space to form a V shape (Fig. 22.7A). The V groove is then used to break the lens into three pieces without rotation and without dissection (see Fig. 22.7B). This technique is ideal in the face of zonulopathy or a capsular tear because the nucleus can be disassembled without rotation or hydrodissection (Video 22.2).

Zonular Deficiency

Surgeons should use the technique they are most comfortable with when zonules are loose. Many surgeons feel that chopping techniques place less stress on the zonules, assuming that they are proficiencient with this technique. Other chapters will outline techniques using capsular tension rings and other devices to stabilize the capsular bag during nuclear disassembly (see Chapter 34).

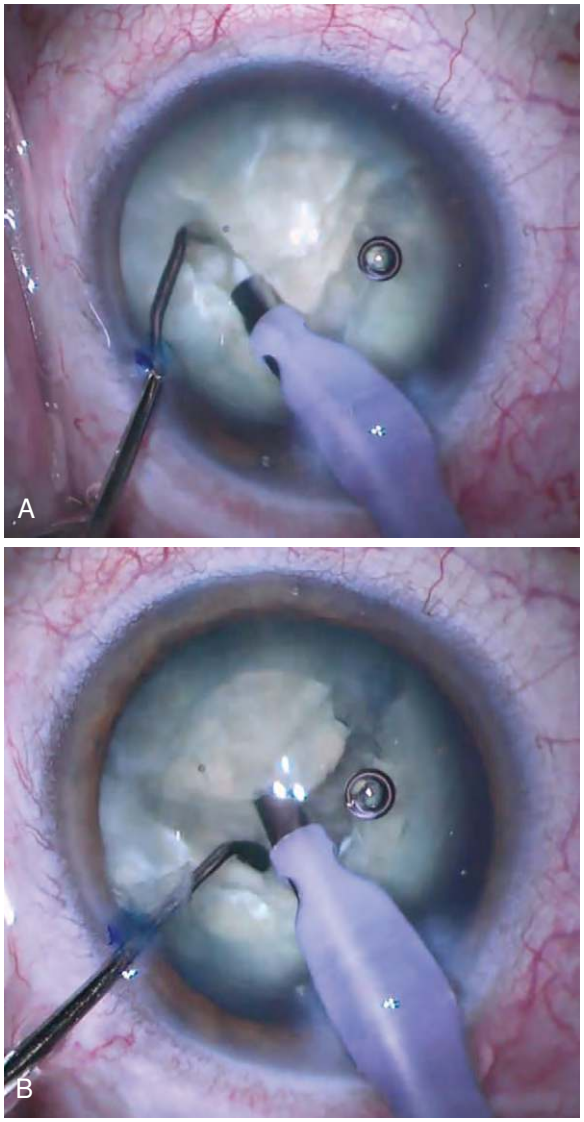

Fig. 22.7 (A) In the V groove technique 2 grooves are made that join in the subincisional space forming a "V" shape. (B) Using the V shaped grooves the lens is divided into 3 pieces.

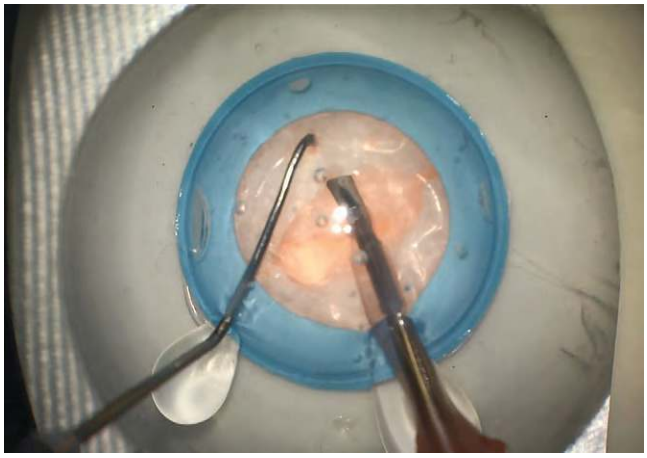

Fig. 22.8 A Phillips Studio Simulated Eye (#PS-12) is used to simulate nuclear disassembly.

Fig. 22.9 Dr David Phillips is shown using a Kitaro simulated eye to practice nuclear disassembly in a real OR.

LEARNING NUCLEAR DISASSEMBLY

Senior residents find nuclear disassembly to be the most difficult part of cataract surgery to master.[1] Resident surgeons can transition in a stepwise fashion to learn disassembly techniques. Simulation, such as practicing surgery on model or animal eyes, is an important way for residents learn these techniques prior to operating on patients.

Transition to Phaco Chop

Bimanual maneuvers are difficult at first for resident surgeons. Techniques that can be done with one hand, such as the divide-and-conquer technique, are preferred to develop basic lens disassembly skills.[19–21] The faculty attending can guide the second instrument at first, even if it requires an extra incision. The stop-and-chop procedure serves as an excellent technique for transitioning to the phaco-chop procedure. The additional space in the endocapsular bag makes placement of the chopper easier. Also the space from the groove makes it easier to remove the chopped pieces, which can get interlocked together because the chops between pieces are not always sharp breaks.

Simulation

Simulation can shift the learning curve to make resident cases safer.[22] The use of simulated eyes has dramatically improved the realism of nuclear disassembly (Fig. 22.8). Practicing on model eyes in the operating room creates a higher fidelity simulation by using the same microscope and phaco machine used for patients (Fig. 22.9). Completely virtual simulation devices such as the EyeSi have also improved our ability to simulate nuclear disassembly.

SUMMARY

Mastery of nuclear disassembly is a key skill for cataract surgeons. The classic techniques of divide and conquer, stop and chop, and phaco chop have remained popular for many years. Surgeons should have several disassembly techniques at their disposal because different situations favor certain techniques. Softer or harder nuclear cataracts are approached differently and can be the most difficult for nuclear disassembly. Ocular issues such as corneal guttata, zonular integrity, and capsule integrity affect the choice and method of disassembly technique. Residents find nuclear disassembly difficult to master, but simulated eyes and other simulation techniques have made mastery of them safer for patients.

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Video 22.1: Soft chop (Courtesy of EyeRounds.org University of Iowa).
Video 22.2: V groove (Courtesy of EyeRounds.org University of Iowa).

23

Phaco Chop Techniques

David F. Chang

CONTENTS

KEY POINTS

- Phaco chop reduces ultrasound energy and zonular stress.
- Chopping requires bimanual instrumentation, dexterity, and maneuvers.
- Horizontal chop uses compressive force to fracture the nucleus.
- Vertical chop uses shearing force to fracture the nucleus.
- A central pit or partial trench in the nucleus facilitates vertical chopping of brunescent nuclei.

INTRODUCTION

Modern phaco methods employ lens disassembly to divide the firm nucleus into smaller maneuverable pieces. This strategy permits removal of the 10 mm–wide nucleus through a 5 mm diameter capsulorrhexis. In addition, most of the nuclear material is emulsified near the center of the pupil and at a safe distance from the iris, posterior capsule, and corneal endothelium.

- A continuous curvilinear capsulotomy (CCC) is a prerequisite to preserving the bag-like anatomy of the lens capsule. In addition to securely fixating and centering the intracapsular intraocular lens (IOL), the continuous edge renders the entire capsular bag much more resistant to tearing during nuclear disassembly and emulsification (see Chapter 17).
- The "hydro" steps are equally important.
  - Hydrodissection separates the epinucleus from the capsule so that it can spin within the capsular bag. It also loosens the capsular-cortical attachments, which facilitates subsequent cortical cleanup.
  - The hydrodelineation wave cleaves a thin epinuclear shell apart from the firm endonucleus. Because the epinucleus is soft, it is not divided by nuclear chopping or cracking maneuvers. Aspirating endonuclear fragments is much easier if they separate easily from the attached and surrounding epinucleus. The mass of the epinuclear shell restrains the posterior capsule from trampolining toward the phaco tip as the final endonuclear fragments are emulsified (see Chapter 18).
- Nucleofractis methods include divide-and-conquer and the many variations of nuclear chopping, including prechopping.

ADVANTAGES OF CHOPPING (BOX 23.1)

Reduction in Ultrasound

Pure chopping techniques eliminate lens sculpting as a means to divide the nucleus into smaller pieces.[1] Ultrasound energy is instead reserved for the phaco-assisted aspiration of the nuclear fragments. A number of studies have documented a significant reduction in ultrasound power, time, and energy with chopping compared with divide-and-conquer.[2–6] This is especially important for brunescent nuclei where the risk of endothelial cell loss and wound burn is much higher.

Reduction in Zonular Stress

During sculpting, the capsular bag provides counterfixation and immobilizes the nucleus as the phaco tip cuts the groove. Sculpting a bulky brunescent lens exerts greater stress on the zonules for this reason. Unlike a soft nucleus that absorbs pressure like a pillow, a large firm nucleus directly transmits instrument forces, such as those used for sculpting, rotation, and cracking directly to the capsular bag

BOX 23.1 Five Advantages of Chopping

1. Reduction in ultrasound energy and time
2. Reduction in stress on the zonules and capsular bag
3. Confining most ultrasound and vacuum-assisted aspiration to the supracapsular plane
4. Decreased reliance on the red reflex because of kinesthetic maneuvers
5. Greater reliance on maneuvering the second instrument instead of the phaco tip

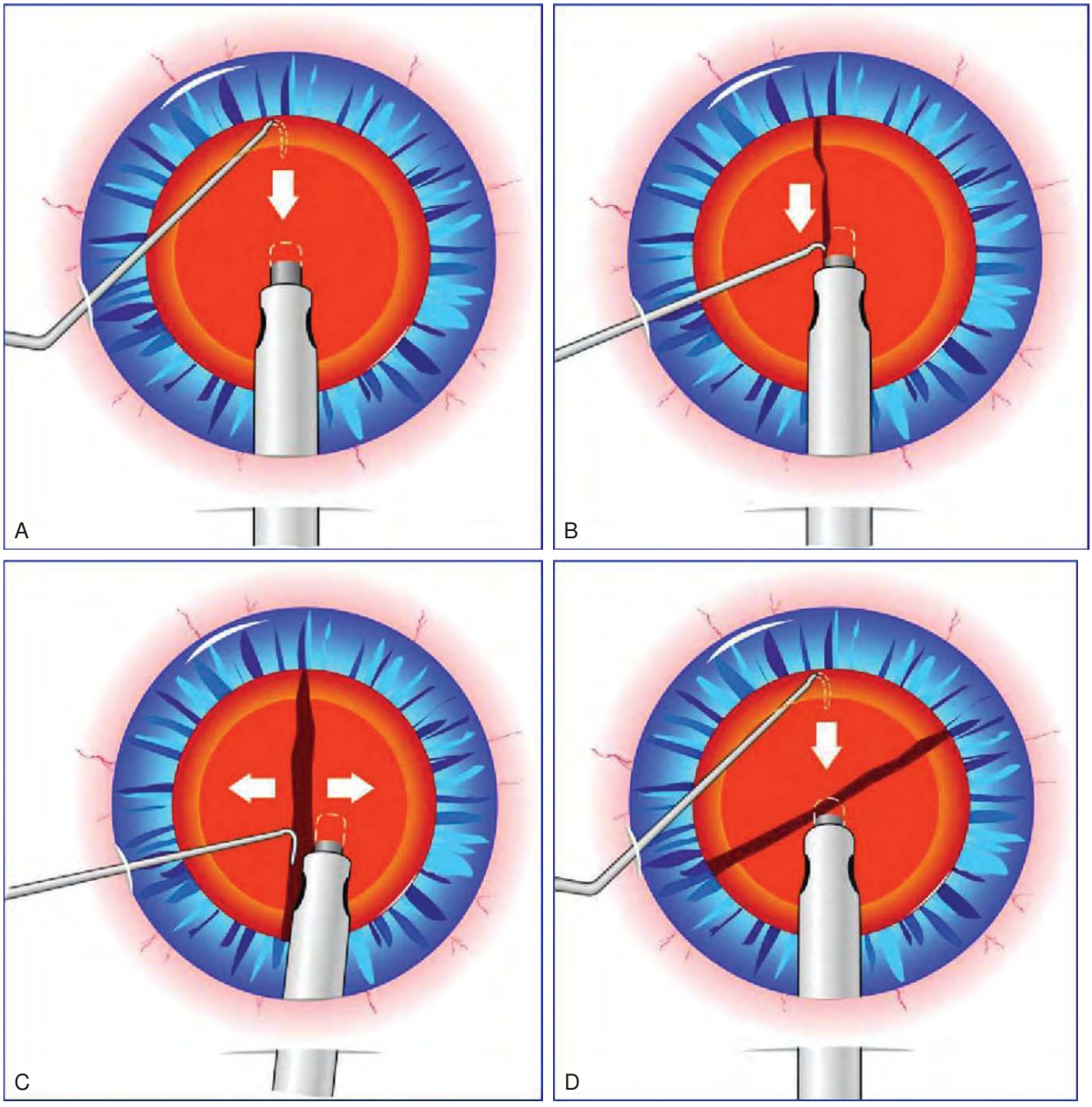


Fig. 23.1 Horizontal chop. (A) Chopper passes beneath the continuous curvilineal capsulotomy rim to hook the nuclear equator. The initial chop is in the horizontal plane. (B) The chopper moves directly toward the impaled phaco tip causing compression of nuclear material until a fracture occurs. (C) A sideways, manual separating motion by the two instrument tips propagates the fracture through the remaining proximal nucleus. (D) After rotating the nucleus clockwise with the chopper, the second chop is initiated by repeating these same maneuvers.

and zonules. Lateral displacement of a brunescent nucleus should be minimized during sculpting to reduce stress on the zonules. Excessive nuclear movement can occur if there is inadequate ultrasound power or a sculpting stroke that is too fast or too deep.

In contrast, with chopping, the phaco tip braces and immobilizes the nucleus against the incoming mechanical force of the chopper[2] (Figs. 23.1 and 23.2). The manual forces, generated by one instrument pushing against the other, replace the need for ultrasound energy to subdivide the nucleus. In addition, these manual forces are directed centripetally inward and away from the zonules, rather than outward toward the capsule. This significant difference in zonular stress is readily appreciated when both chopping and sculpting are compared from the Miyake-Apple viewpoint in cadaver eyes.

Supracapsular Emulsification

Chopping shares many of the same advantages of supracapsular phaco techniques. Virtually all of the emulsification is reserved for phaco-assisted aspiration of smaller fragments that have been elevated out of

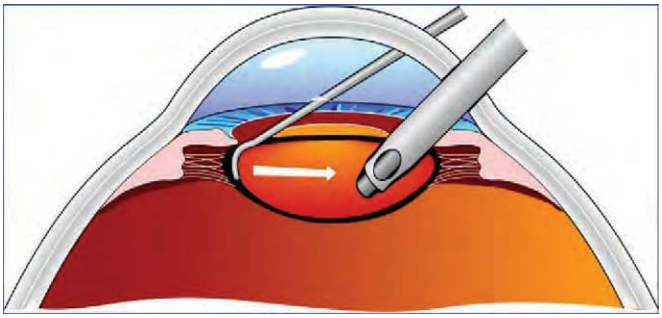


Fig. 23.2 Horizontal chop. As much nucleus as possible is in the path of the horizontal chopper. The chopper tip must be kept deep during the chop, and the phaco tip must be impaled deeply enough.

the capsular bag. Most of the emulsification is performed centrally in the pupillary plane at a safe distance from the posterior capsule and endothelium. The phaco tip does not need to travel outside the central 2 to 3 mm zone of the pupil, which decreases the chance of cutting the iris or capsulorrhexis edge in small pupil cases. In contrast to other supracapsular techniques, there is no need to prolapse and flip the entire nucleus. The latter maneuver is riskier with a shallow anterior chamber, zonulopathy, a small diameter CCC, or large brunescent nucleus.

Decreased Reliance on the Red Reflex

During sculpting, we judge the depth of the phaco tip by monitoring the increasingly brighter red reflex at the base of the trough. With phaco chop the maneuvers performed with the chopper are more kinesthetic and tactile, and there is no need to visualize the exact depth of the phaco tip. This is why chopping is advantageous with a poor or absent red reflex, such as with small pupils and advanced mature cataracts.

Greater Reliance on the Chopper than the Phaco Tip

Compared with the phaco tip, the chopper is much more maneuverable and executes the most important movements with chopping. Using a slender and maneuverable chopper, instead of the phaco tip, to manipulate the nucleus lessens the need to use ultrasound and vacuum near the posterior capsule or close to the edge of the pupil and capsulorrhexis. This is particularly advantageous if the nucleus fails to rotate for any reason. Sequential chops can be made without rotating the nucleus by simply repositioning the chopper in different equatorial locations and chopping toward the centrally impaled phaco tip. If aspirating an intracapsular nuclear fragment with the phaco tip is ineffective, a horizontal chopper can be used to hook the equator and tumble the fragment out of the capsular fornix.

These five universal features make chopping an excellent technique for complicated cases that entail greater risk of posterior capsule rupture or corneal decompensation: brunescent nuclei, white cataracts, weak zonules, posterior polar cataracts, crowded anterior chambers, capsulorrhexis tears, and small pupils. Chopping is also an excellent routine phaco technique for many of the same reasons.

PHACO CHOP VARIATIONS

Since Kunihiro Nagahara first introduced the concept of phaco chop at the 1993 ASCRS meeting, many different chopping variations have been introduced.[7–11] Hideharu Fukasaku introduced his technique of "phaco snap and split" at the 1995 ASCRS meeting. Vladimir Pfeifer's "Phaco Crack" method of chopping was introduced at the 1996 ASCRS meeting and is a similar technique. Abhay Vasavada published his "stop, chop, chop, and stuff" technique in 1996,[9] and Steve Arshinoff published his "phaco slice and separate" method in 1999.[10] For simplification, this author first proposed that all bimanual chopping methods be conceptually divided into two general categories: horizontal and vertical chop.[1] Both share the universal benefits of being able to fragment the nucleus manually but accomplish this objective in different ways. The classic Nagahara technique is an example of **horizontal** chopping because, after the chopper hooks the endonucleus within the capsular bag, it initially chops centrally toward the fixating phaco tip in the horizontal plane (see Fig. 23.2). In **vertical** chopping, the phaco tip deeply impales the central nucleus and the sharp chopper tip presses downward in the vertical plane during the initial chop (Fig. 23.4).

STOP AND CHOP

Paul Koch's stop-and-chop method is a hybrid of divide-and-conquer and horizontal chopping.[7,12,13]

- His technique begins with sculpting a traditional deep, central groove in order to crack the nucleus in half.
- One then *stops* the divide-and-conquer method, and *chops* the hemi-nuclei.[1]
- Advantages:
  - Nucleus is first bisected with sculpting and cracking, rather than with a single chop. In addition to avoiding the difficult first chop, one chops only across the radius, rather than the full diameter of the nucleus.
  - Unlike with pure "nonstop" chop, the phaco tip can be positioned within the trough up against the side of the hemi-nucleus that is to be cleaved.
  - The presence of the central trench facilitates removal of the first fragment because it is not tightly wedged inside the capsular bag. Although chopping the hemi-nuclei does partially reduce ultrasound energy, the majority of the sculpting required by divide-and-conquer is used to create the first groove. Thus, although stop and chop uses some chopping, it cannot deliver the full benefits that pure horizontal and vertical chopping techniques can.[14]

PRECHOP TECHNIQUES

Among the many chopping variations, Takayuki Akahoshi and Jochen Kammann ("Minimal energy chopping has advantages," *Ophthalmology Times*, 1997) devised techniques for prechopping the nucleus before insertion and use of the phaco tip. Prechopping requires additional steps and instrumentation that incorporate the principles of horizontal chopping. In the case of a denser lens, one manual instrument must generally hook the equator so that the penetrating and chopping forces are not transmitted directly to the capsular bag and zonules.

One potential challenge with prechop techniques is that a certain amount of debris is liberated after the initial chop. Without the phaco tip to aspirate it, this may impair visibility for the subsequent steps. Another challenge is that most prechop techniques and instrumentation are designed to create four nuclear quadrants. Although adequate for soft and medium nuclei, it is more difficult to create multiple, smaller pieces with prechopping, as would be desirable for larger and denser nuclei. Another challenge with using the Akahoshi prechopper is the ability to judge how deeply it has penetrated into a thicker, firm nucleus. Adequate depth is necessary before separation is commenced, but overpenetration can be risky for the capsular bag.

The miLOOP (Carl Zeiss) is a retractable nitinol microfilament that functions as an intracapsular nuclear snare[15] (Fig. 23.5) (Video 23.1).

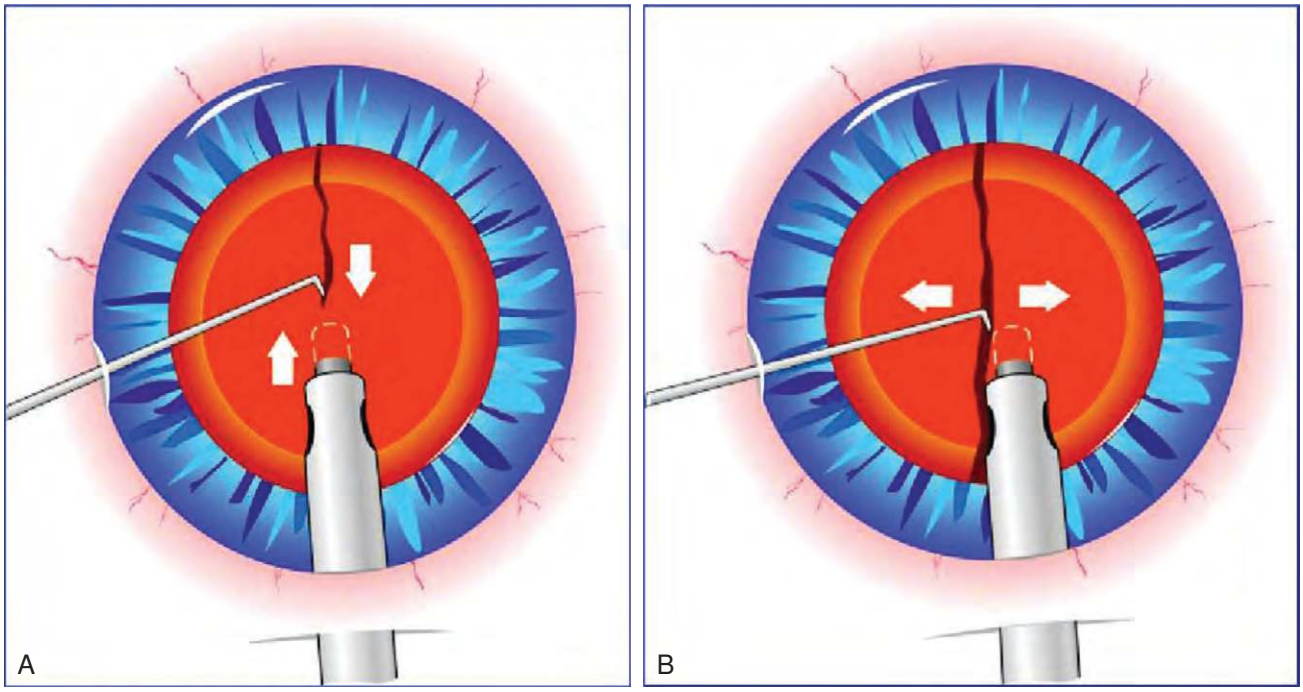


Fig. 23.3 Vertical chop. (A) After impaling the center of the nucleus with the phaco tip, the vertical chopper incises downward into the nucleus just anterior to the phaco tip. (B) A sideways, manual separating motion by the two instrument tips propagates the fracture through the remaining nucleus.

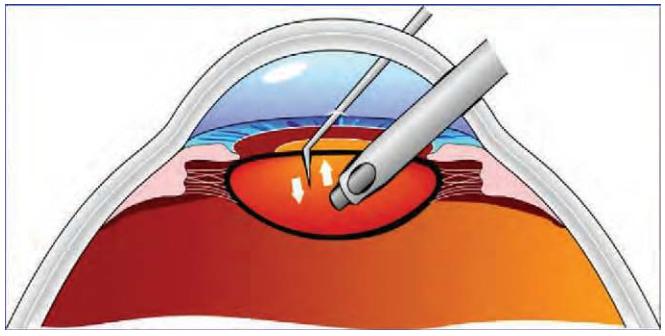


Fig. 23.4 Vertical chop. The phaco tip lollipops into the central nucleus and lifts slightly as the vertical chopper tip impales downward. This shearing action fractures the nucleus.

- It is gradually opened beneath the capsulorrhexis rim in the coronal plane (see Fig. 23.5A).
- Once fully opened, the nitinol loop is rotated around the nuclear equator until it encircles the nucleus along the sagittal plane (see Fig. 23.5B).
- Retracting the microfilament into the barrel of the injector shaft bisects the nucleus in half. For denser nuclei, a second instrument presses against the nasal nuclear pole during loop retraction to prevent it from rotating anteriorly out of the capsular bag (see Fig. 23.5C).
- Rotating the nucleus 90 degrees and repeating this set of maneuvers creates four quadrants that are then emulsified with the phaco tip. Like other methods of manually fragmenting the nucleus, ultrasound power and time are reduced compared with divide-and-conquer.[16]

By precutting and softening the nucleus the femtosecond laser can also reduce the amount of ultrasound or manual instrument energy needed to remove the nucleus. The denser the nucleus the greater the potential reduction in ultrasound energy and time afforded by femtosecond laser nucleotomy will be.[17] Chapter 26 describes this technology and method in greater detail.

HORIZONTAL CHOP TECHNIQUE

Horizontal chopping uses compressive force to bisect the nucleus along the natural fracture plane created by the lamellar orientation of the lens fibers (see Fig. 23.1) (Video 23.2). The key initial step is to use the chopper tip to hook the nuclear equator within the epinuclear space of the peripheral capsular bag before initiating the horizontally directed chop (see Fig. 23.2). Whether to first position the chopper or the phaco tip is a matter of personal preference. Because chopper placement is the most difficult and intimidating step, many transitioning surgeons find it easier to first position the chopper before impaling the nucleus with the phaco tip (Fig. 23.6).

INITIAL CHOP

- Hydrodelineation is particularly important for horizontal chopping because it decreases the diameter of the endonucleus that must be peripherally hooked and divided by the chopper.[2] In addition, the separated soft epinucleus provides anatomic working space within which the horizontal chopper can be placed and maneuvered peripheral to the endonuclear equator without overly distending or perforating the peripheral capsular bag. After the endonucleus has been evacuated, the epinuclear shell can be flipped and aspirated as the final step.[11]
- First aspirate the central anterior cortex and epinucleus with the phaco tip in order to better visualize and estimate the size of the endonucleus and the amount of separation between the endonucleus and the surrounding capsular bag.

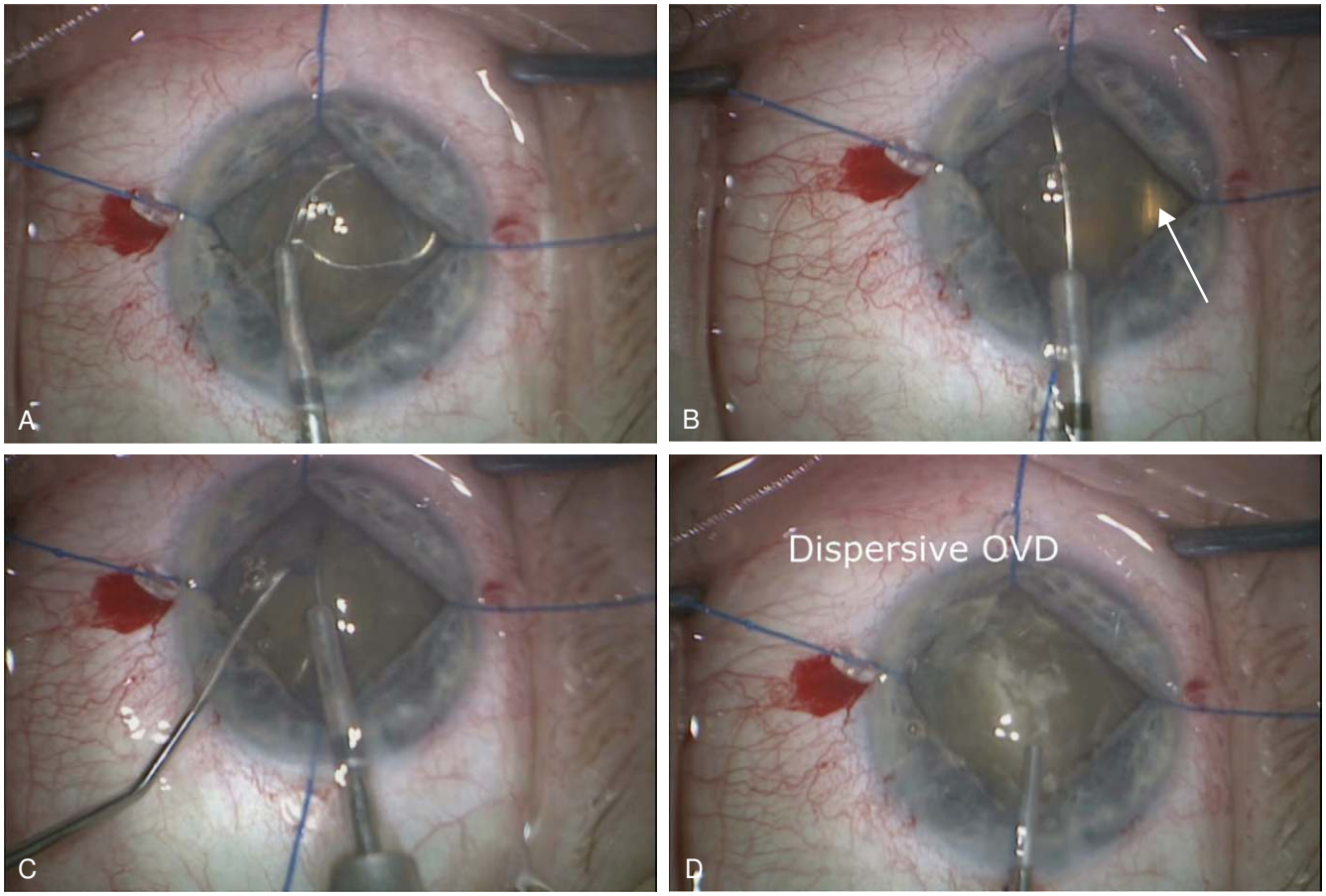


Fig. 23.5 Prechop with miLOOP. (A) Nitinol loop is opened in the coronal plane and beneath the anterior capsule. (B) The opened loop is swept along the posterior capsule to encircle the nucleus in the sagittal plane. The posterior-most portion of the loop can be visualized at the right *(arrow)*. (C) A second instrument provides counter pressure against the nasal nuclear pole as the nitinol loop is retracted back into the tubular instrument shaft. (D) The linear fracture through the bisected dense nucleus can be visualized after injected dispersive optical variable device.

- The chopper tip touches the central endonucleus, and maintains contact as it passes peripherally beneath the opposing capsulorrhexis edge (see Fig. 23.6B–C). This ensures that the tip stays inside the bag as it descends and hooks the endonucleus peripherally. Although some surgeons tilt the chopper tip sideways to reduce its profile as it passes underneath the capsulorrhexis edge, this is generally not necessary unless the CCC diameter is small or the endonucleus is very large. During this series of maneuvers, the elongated horizontal chopper tip can be kept in an upright and vertical orientation because the capsulorrhexis will stretch like an elastic waistband without tearing (see Fig. 23.6B).
- Once it reaches the epi/endonuclear junction, the chopper tip must be vertically oriented as it descends into the epinuclear space alongside the edge of the endonucleus (see Fig. 23.6C). If it has not traveled peripherally enough, lowering the chopper will depress, rather than hook the nucleus equator. The smaller the endonucleus, the larger the epinucleus, and the easier this step will be. Once in position, slightly nudging the nucleus with the chopper confirms that it is alongside the equator and that it is within, rather than outside the capsular bag. Injecting dispersive OVD beneath the distal CCC edge will improve visualization and expand the space through which the chopper must pass (see Fig. 23.6A).
- Next, the phaco tip deeply impales the nucleus just within the temporal CCC edge (see Fig. 23.6C). The phaco tip should be directed vertically downward and positioned as proximally as possible to maximize the amount of nucleus located in the path of the chopper[2] (see Fig. 23.2). If the depth of the phaco tip is too shallow, sufficient compression of the central nucleus cannot occur. Once impaled, the phaco tip holds and stabilizes the nucleus with vacuum in foot pedal position 2. Although not quite as essential for horizontal chopping as with vertical chop, high vacuum improves the holding power, which keeps the nucleus from wobbling or spinning during the chop.
- The chopper tip is pulled directly toward the phaco tip; upon contact, the two tips move directly apart from each other (see Fig. 23.6D). This sideways separating motion occurs perpendicular to the path of the initial chop, and propagates the fracture through the remaining nucleus located behind the phaco tip (see Fig. 23.1C). The denser and bulkier the endonucleus, the further the hemi-sections must be separated in order to cleave the posterior-most nuclear attachments. Thanks to the elasticity of the CCC, even a momentary wide separation of large hemi-nuclei will not tear the capsular bag.

The ergonomics and tactile feel of the horizontal chop will vary significantly as one advances along the nuclear density scale. A soft nucleus has the consistency of soft ice cream. Simply depressing the phaco tip into the nucleus, without either vacuum or ultrasound, can embed it deeply enough. In addition, no resistance is felt as the chopper is moved. With a medium density nucleus, the chopper

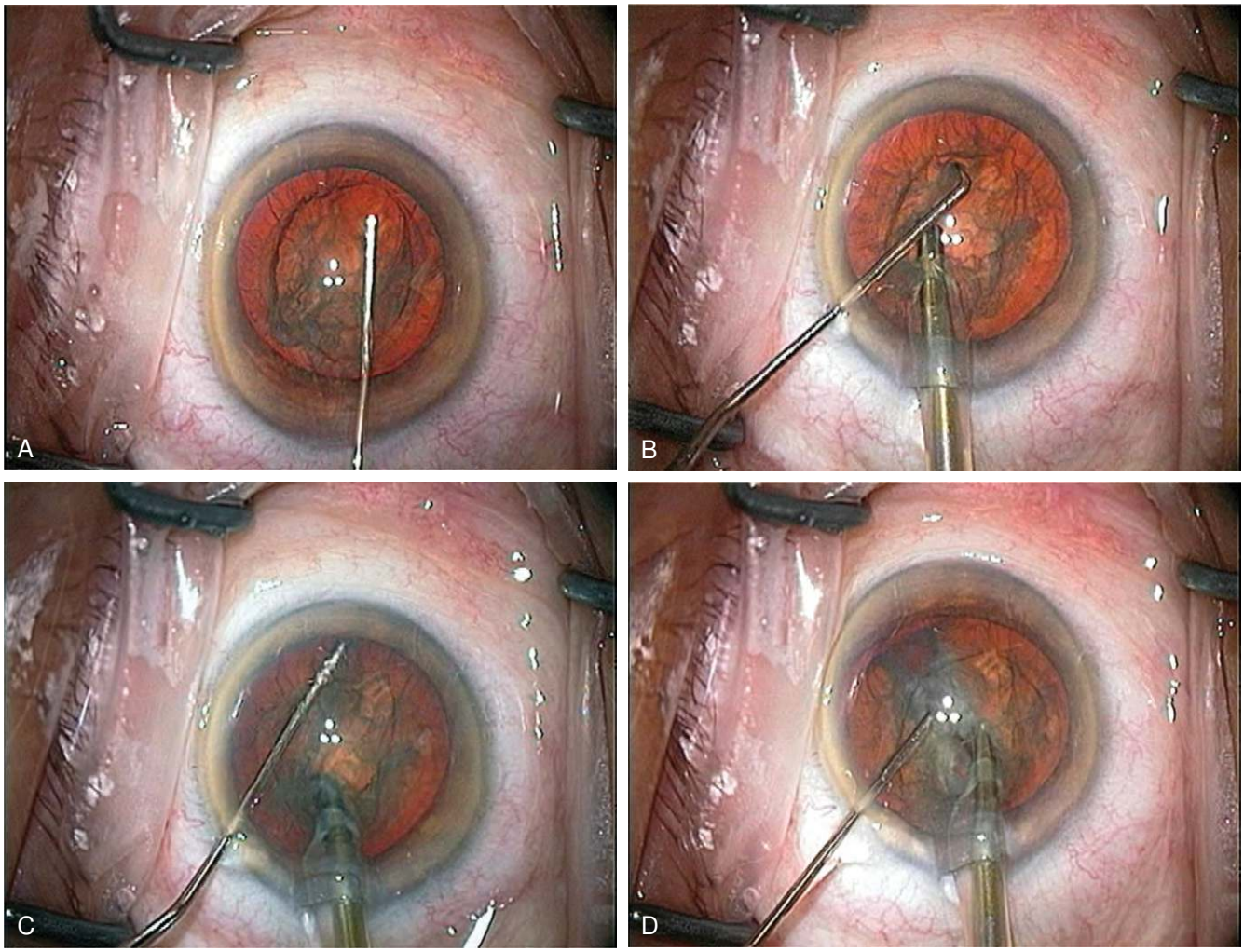


Fig. 23.6 Horizontal chop. (A) Dispersive OVD (Viscoat) is injected beneath the nasal anterior capsular rim and into the equator of the capsular bag. (B)The horizontal chopper tip maintains contact with the anterior endonuclear surface as it passes beneath the anterior capsular rim. (C) After the chopper tip descends within the epinuclear shell to hook the nasal equator of the endonucleus, the phaco tip impales the proximal nucleus just within the temporal continuous curvilinear capsulotomy edge. (D) The chopper moves in the horizontal plane toward the phaco tip; sideways separation of the two instrument tips propagates the fracture until the nucleus has been bisected.

encounters slight resistance as the chopping motion is initiated, which indicates that the desired compression is taking place. This resistance becomes much greater when chopping denser brunescent nuclei. As the chopper drives toward the phaco tip, it feels as though the nucleus is being squeezed in between the two instrument tips (see Fig. 23.2). This is followed by an abrupt snap as the full-thickness split occurs. Correspondingly more ultrasound power must be used in order for the phaco tip to be able to impale denser nuclei. Deeper penetration can be achieved by retracting the irrigation sleeve further to expose more of the metal tip, and using single burst or pulse mode rather than continuous phaco.[11]

REMOVING THE CHOPPED FRAGMENTS

- Upon completion of the initial chop, the nucleus should be completely bisected. If not, it can be rotated so that that a second attempt can be made in a new area. The chopper tip rotates the bisected nucleus 30 to 45 degrees in a clockwise direction, and the opposite heminucleus is impaled with the phaco tip in a central location. If there is difficulty in occluding the phaco tip, the bevel may need to be aligned parallel to and facing the surface it is about to impale. Repeating the same steps of hooking the equator and chopping toward the phaco tip will now create a small, pie-shaped fragment.
- The strong holding force afforded by high vacuum facilitates levitation of this first piece out of the bag. Insufficient holding force may be the result of inadequate vacuum settings or failure to completely occlude the phaco tip.
- Each subsequent chop is a repetition of these same steps. Because of the need to hook the equator during every horizontal chop, it is advisable to remove each wedge-shaped piece as soon as it is created. Once half of the capsular bag is vacated, the phaco tip can impale and pull the remaining hemi-nucleus toward the center of the pupil. This allows the horizontal chopper tip to be positioned alongside the outer endonuclear edge under direct visualization, and without having to pass it beneath the anterior capsule.

- Larger nuclear pieces can be further chopped into smaller fragments. The size of the pieces should be kept proportional to the size of the phaco tip opening. For example, just as one cuts a steak into smaller portions for a child's mouth, the nucleus should be chopped into smaller pieces for a smaller diameter 20-G phaco tip. Poor followability and excessive chatter of firm fragments engaged by the phaco tip may indicate that they are too large.

Pearls for the Initial Horizontal Chop

- Remove the anterior epinucleus centrally before initiating chopping.
- Impale deeply with the phaco tip just within the temporal CCC edge.
- Keep the chopper tip deep as it moves toward the phaco tip.
- Pull the chopper tip directly toward the phaco tip to maximize compressive force.

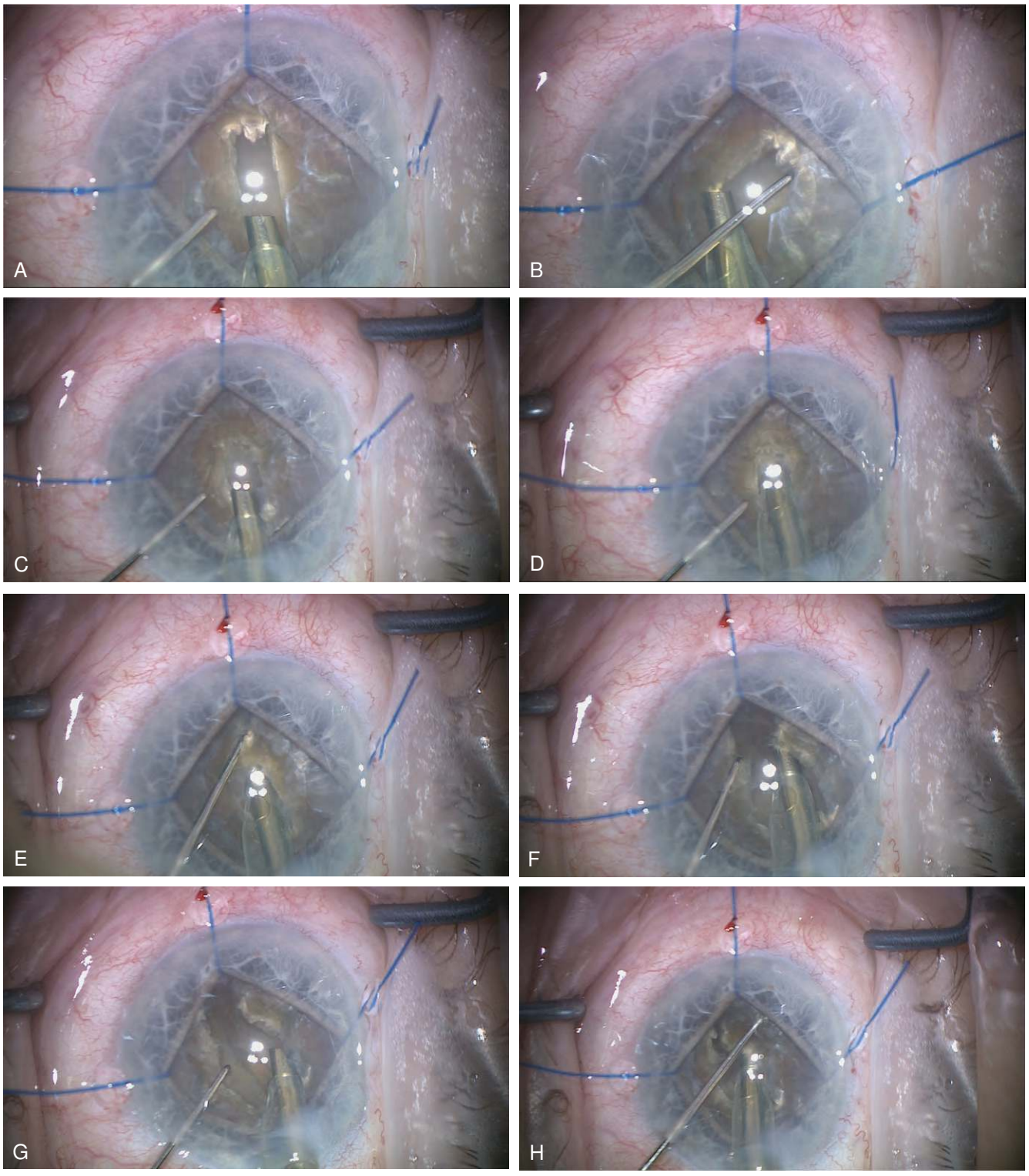
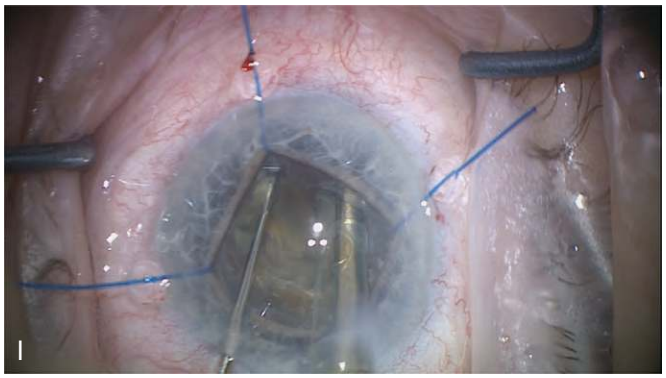


Fig. 23.7 (*Continued*)



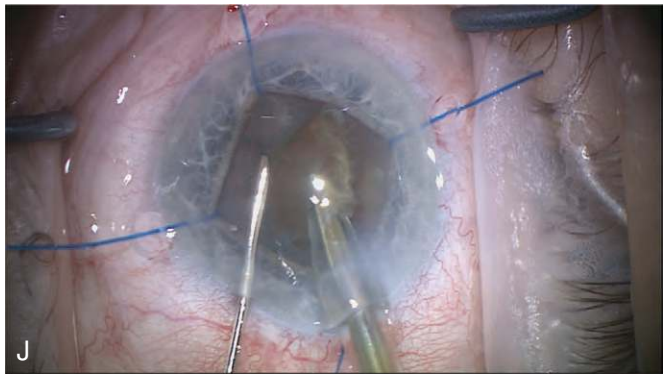


Fig. 23.7 Vertical/diagonal chop of a brunescent nucleus. (A) Sculpting nasally creates a half-trench. (B, C) The nucleus is rotated 180 degrees until the trench beneath the phaco tip. (D) The phaco tip impales the nasal unsculpted nucleus at the base of the half-trench. (E) The vertical chopper tip is positioned beneath the trypan blue–stained anterior capsular rim and initiates a diagonal/vertical chop toward the impaled phaco tip. (F) Sideways separation of the two instrument tips propagates the fracture through the leathery posterior plate peripherally. (G) After the two instrument tips are repositioned more centrally, repeating the sideways separating motions extends the fracture through the central posterior plate until the nucleus has been bisected. (H) After rotating the nucleus slightly counterclockwise, the phaco tip impales one heminucleus; the second diagonal/vertical chop is initiated. (I) Progressive sideways separation of the two instrument tips propagates the fracture through the leathery posterior plate starting peripherally until it intersects centrally with the prior fracture. (J) The horizontal chopper abuts the equator of the large mobile fragment to "subchop" it in half.

Potential Pitfalls During the Initial Horizontal Chop

- If the phaco tip is too central and shallow, insufficient compressive force will be generated.
- Elevating the chopper tip during the initial chop will only score the nuclear surface.
- Veering the chopper to the side to avoid contacting the phaco tip reduces compressive force and causes the nucleus to swivel.
- Make sure the chopper tip remains underneath the edge of the CCC.
- Try to keep the nuclear complex centered during the initial chop to avoid transmission of forces to the zonules.
- If a nucleus is too dense, consider converting to an alternate technique such as stop and chop.

Vertical Chop Technique

- Whereas the horizontal chopper moves inward from the periphery toward the phaco tip, the vertical chopper is used like a spike or blade from above to incise downward into the nucleus just anterior to the centrally impaled phaco tip (see Fig. 23.3A). The sharp vertical chopper tip generally stays central to the capsulorrhexis margin. Thus, in contrast to horizontal chopping, it is always visualized and usually does not pass underneath the anterior capsule or behind the iris.
- The most important step in vertical chop is to bury the phaco tip as deeply into the center of the endonucleus as possible (Fig. 23.7). Depressing the sharp vertical chopper tip downward, while simultaneously lifting the nucleus slightly upward imparts a shearing force that fractures the nucleus (see Fig. 23.4). This is in contrast to the compressive force produced by horizontal chopping.
- After initiating a partial thickness split, the embedded instrument tips are used to pry the two hemi-sections apart. Just as with horizontal chopping, this sideways separation of the instrument tips extends the fracture deeper and deeper until the remainder of the nucleus is cleaved in half (see Fig. 23.3B).
- The phaco tip secures its purchase by penetrating deeply into the core of the brunescent mass and using high vacuum for holding power so that the nucleus doesn't become dislodged. In a brunescent lens, using single bursts of phaco avoids the coring away of material around the tip that occurs with continuous ultrasound. The result is improved purchase and a much better seal around the tip, which is a prerequisite for attaining and maintaining high vacuum.
- In horizontal chop, sequentially removing each newly created fragment provides the chopper and phaco tip with greater working space within the capsular bag. In contrast, vertically chopped pieces need not be removed until the entire nucleus is fragmented (see Fig. 23.7). This is because the presence of the adjacent interlocking pieces better stabilizes and immobilizes the section being chopped. In addition, because the vertical chopper is never placed peripheral to the nucleus equator, vacating space within the capsular bag early on provides no real advantage. Much like a chisel would be used with a block of ice or granite, the vertical chopper tip can be used to cleave the nucleus into multiple pieces of variable size.

COMPARING HORIZONTAL AND VERTICAL CHOP: WHICH TECHNIQUE?

It is worth learning and using both variations because the different fracturing mechanisms offer complimentary advantages and disadvantages. Vertical chopping requires a nucleus that is brittle enough to be snapped in half. A lack of firmness explains the difficulty of performing vertical chop or divide-and-conquer techniques in soft nuclei. The ability of the horizontal chopper tip to easily slice through a soft nucleus instead of fracturing it makes horizontal chopping an excellent method for these cases.

Horizontal chop is this author's preference for weak zonule cases, such as with pseudoexfoliation or traumatic zonular dialysis. Because of the inwardly directed, compressive instrument forces, horizontal chop minimizes nuclear movement or tilt. This is invaluable when any nuclear tipping or displacement could shear and dehisce weakened

zonules. Finally, horizontal chop is more effective for subdividing smaller, mobile nuclear fragments, particularly if they are brunescent. Small mobile pieces are hard to fixate adequately for vertical chopping because there is insufficient mass for the phaco tip to impale. Attempting to vertically shear such fragments with a chopper will often dislodge the small piece instead. Trapping and then crushing the fragment between the horizontal chopper and the phaco tip will immobilize and divide it most effectively.

The limitation of horizontal chopping is in its relative inability to transect thicker, brunescent nuclei. First, horizontal chopping should never be used in the absence of an epinuclear shell because there will be insufficient space in the peripheral bag to accommodate the chopper. In this situation, forcing the chopper tip into a tightly packed capsular bag risks tearing the CCC. Second, the horizontally directed path of the chopper may not be deep enough to sever the leathery posterior plate of a rock hard nucleus.

Because vertical chop is more consistently able to fracture the leathery posterior plate, it is generally preferable for denser nuclei[2] (see Fig. 23.7). After an axe blade is swung into an upright log, it can only penetrate part way. Prying the two hemi-sections apart is necessary in order to extend the split through the remainder of the log. The same is true for a brunescent nucleus after an initial horizontal or vertical phaco chop. Once the partial split is made by the chopper, it is the sideways separation of the instrument tips that extends the fracture along the natural lamellar cleavage plane through the remainder of the nucleus (see Fig. 23.7E–G). In horizontal chop, this propagating fracture continues horizontally toward the surgeon, but it will not tend to advance further and further posteriorly. In contrast, with vertical chop, as the two halves are pried apart, the advancing fracture propagates downward in the vertical plane until it eventually transects the posterior-most layer (see Fig. 23.3B).

DIAGONAL/VERTICAL CHOP FOR BRUNESCENT NUCLEI

- With an ultrabrunescent lens, slightly alter the angle of the vertical chop. Instead of incising straight down like a karate chop striking a board, the vertical chopper should approach the embedded phaco tip more diagonally (see Fig. 23.7E). This provides more of a horizontal vector that pushes the nucleus against the phaco tip, while the vertical vector initiates the downward fracture. This diagonal chop therefore combines the mechanical advantages of both strategies.
- Start by sculpting a central deep pit or half of a traditional groove before rotating the nucleus 180 degrees[18] (see Fig. 23.7A–C). By starting at the bottom of the pit or groove, the phaco tip can be impaled more deeply than would have been possible without this preliminary debulking step (see Fig. 23.7D). Retracting the irrigation sleeve and using single burst mode further maximizes penetration of the phaco tip.
- Because of the steep angle of the phaco tip, maximal penetration advances the tip into the peripheral nucleus. Initiating the vertical chop in this thinner region better enables it to transect the posterior-most layer of an ultrabrunescent lens. However, this means that the vertical chopper tip must pass peripherally beneath the capsulorrhexis rim before incising diagonally toward the phaco tip (see Fig. 23.7E). Because of the poor red reflex, capsular dye aids anterior capsule visualization for this purpose.
- After initiating the diagonal chop, the hemi-sections are manually pried apart until the propagating fracture breaks through the leathery posterior plate in the periphery (see Fig. 23.7F). Each time the separating motion is repeated, the chopper tip is repositioned more and more centrally. The posterior fissure will steadily unzip toward and across the central pole of the posterior plate (see Fig. 23.7G).
- Rotate the nucleus before repeating the same peripherally initiated diagonal chop (see Fig. 23.7H and I). The nucleus will be completely fragmented once the sequential fractures intersect in the center.
- Partially segmented fragments often remain apically connected by a central leathery posterior plate. Try to inject a dispersive OVD through one of the incomplete cracks in the posterior plate to distance it from the posterior capsule. Because a dispersive OVD resists aspiration, the surgeon can attempt to carefully phaco through the remaining connecting bridges that have been viscoelevated away from the posterior capsule.
- After being elevated out of the capsular bag the brunescent fragments are often still quite sizable. Switch to a horizontal chopper to subdivide mobile brunescent fragments into smaller pieces (see Fig. 23.7J).

Pearls for the Initial Vertical Chop

- Lollipop deeply into the central nucleus with the phaco tip.
- High vacuum provides the stronger grip needed for brunescent nuclei.
- Avoid phaco needle motion that will create a cavity (i.e., torsional or ellipse).
- Lift the nucleus slightly as the vertical chopper incises into it directly in front of the phaco tip.
- Sculpt a half-trench or central pit to allow the phaco tip to impale more deeply with a rock hard lens.

Potential Pitfalls During the Initial Vertical Chop

- A phaco tip that is too superficial generates insufficient leverage and shearing force.
- Creating a cavity surrounding the phaco needle precludes full tip occlusion, adequate vacuum generation, and "hold."
- The sharp chopper tip must be underneath or just within the CCC edge before incising vertically downward into the nucleus.
- Failure to intersect sequential chops through the posterior plate results in partially separated fragments that remain connected at their apex, like the petals of a flower.

COMPARISON OF HORIZONTAL AND VERTICAL CHOPPERS

The wide range of different chopper designs often confuses the transitioning surgeon. The many variations can be categorized as either horizontal or vertical choppers. Because each works in dissimilar ways, their design principles are quite different.

Horizontal choppers usually feature an elongated, but blunt-ended tip (see Fig. 23.2). A tip length of 1.5 to 2.0 mm is necessary to transect thicker nuclei, and the inner cutting surface of the tip may sometimes be sharpened for this purpose of incising denser lens material. The very end of the tip is always dull to diminish the risk of posterior capsule perforation. Many horizontal choppers have a simple right-angle tip design. However, this shape does not conform as well to the natural, curved contour of the lens equator and peripheral capsular bag. The author prefers the curved shape of an elongated microfinger or claw because it can wrap snuggly around the lens equator without distending or stretching the peripheral fornices of the capsular bag.[2] The microfinger design also allows one to cup the nucleus equator so that it cannot slip away as the compression begins.

Vertical choppers feature a shorter tip that has a sharpened point or edge in order to penetrate denser nuclei (see Fig. 23.4). If the tip is

too dull, it will tend to displace the nucleus off of the phaco tip rather than incising into it. In contrast to horizontal choppers, the length of the vertical chopper tip is shorter because it never encompasses the nuclear periphery.

The 3-dimensional manipulations required of the chopper are much simpler with vertical chop. Compared with horizontal chop, the vertical chopper tip is not positioned as peripherally and simply incises downward into the nuclear mass. The tip is kept vertically oriented and is always visible until it descends into the nucleus. In contrast, the horizontal chopper tip is much longer, must execute a far more difficult set of motions, must pass underneath the CCC edge, and must be blindly positioned behind the iris before initiating the chop (see Fig. 23.6C).

The side-port incision should always serve as the motionless fulcrum for the chopper shaft. To avoid displacing or distorting the side-port incision, somewhat counterintuitive movements must be made with the horizontal chopper in particular. Assuming a right-handed surgeon, the chopper should be introduced through a paracentesis located 45 degrees to the left of the phaco tip (see Fig. 23.6B).

COMPLICATIONS

Improper technique can lead to complications with either chopping method. If a firm nucleus is not well supported by the phaco tip, downward force from a vertical chopper can push the nucleus against the posterior capsule. This can displace the bag enough to rupture the zonules. If one loses track of the CCC location, one could perforate the peripheral anterior capsular rim with the vertical chopper. Finally, excessive surge during removal of the final nuclear fragment or epinucleus could cause forward trampolining of the posterior capsule into the sharp vertical chopper tip.

Likewise, because the horizontal chopper tip is not visualized once it passes behind the iris, erroneous placement outside of the bag could occur. If the chop is initiated with the horizontal chopper placed outside the capsular bag, a large zonular dialysis will result. Finally, the absence of an epinucleus with an ultrabrunescent nucleus is a contraindication to placing a horizontal chopper tip in the peripheral capsular space.

Too small of a CCC diameter increases the risk of tearing the continuous edge with the chopper tip or shaft. One should momentarily take a mental snapshot of the CCC shape and diameter after it is completed. This is because, after hydrodissection and nuclear rotation, the capsulorrhexis contour will no longer be visible, and the surgeon must remember its location.

SUMMARY

All chopping techniques use manual instrument forces to segment the nucleus, thereby replacing the ultrasound power otherwise needed to sculpt grooves. Such energy efficiency is possible because the lamellar orientation of the lens fibers creates natural fracture planes within the hardened nucleus that the chopping maneuver takes advantage of. In addition to being more efficient compared with divide-and-conquer, phaco chop is particularly advantageous for complex cases, such as eyes with smaller pupils, zonulopathy, or advanced mature cataracts. For soft nuclei, horizontal chopping is easier and more effective. For brunescent nuclei, vertical chop is more effective at initial nuclear fragmentation and fracturing the leathery posterior plate. However, the complimentary advantage of horizontal chop to subchop larger nuclear fragments can be combined in the same case.

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Video 23.1: Pre-chop using the miLOOP.

This video demonstrates the use of the miLOOP (Carl Zeiss) to pre-chop the nucleus.

Video 23.2: Phaco Chop Techniques.

This video demonstrates and compares the horizontal, vertical, and diagonal variations of phaco chop.

24

Tilt and Tumble Supracapsular Phacoemulsification

Elizabeth A. Davis and Richard L. Lindstrom

CONTENTS

The technique of tilt and tumble supracapsular phacoemulsification was developed by Dr. Richard Lindstrom and subsequently refined and modified by Dr. Elizabeth Davis to the method described in this chapter. For all but the most dense cataracts, when performed properly, this technique is one of the most efficient and safe methods of phacoemulsification. This technique significantly reduces the risk for capsular tear, rupture, and zonular dehiscence because the nucleus is prolapsed into the iris plane where low to no energy phacoemulsification is performed. This moves the phaco tip away from the posterior capsule and reduces the shear/rotational forces on the zonules. On average, the authors are able to perform phacoemulsification in the typical cataract seen today in 4 to 6 minutes and with zero or very little phaco energy. To use this technique, specific phacodynamics, machine settings, phaco needle size, and maneuvers are required. In the following paragraphs we will describe and illustrate this technique in enough detail to allow an ophthalmologist to evaluate it and employ it for his or her own patients.

INDICATIONS

The indications for the tilt and tumble phacoemulsification technique are quite broad. It can be used in most cases except for very dense cataracts (where extensive phacoemulsification energy is required) or when the endothelium is composed. In these situations, an endocapsular approach is preferable. With the availability of pupil expanders, it can also be used even with a small pupil. The technique does require at least a modestly sized continuous tear anterior capsulectomy of at least 5.0 mm diameter. If too small an anterior capsulectomy is created, the hydrodissection step to tilt the nucleus can be dangerous because it is possible to rupture the posterior capsule. If too small of an anterior capsulectomy is inadvertently created, it is probably safest to convert to an endocapsular phacoemulsification technique or else to enlarge the capsulorrhexis. If it is not possible to tilt the nucleus with either fluid or viscoelastic hydrodissection or a manual technique, one can embed the phaco tip into the midperipheral nucleus with either high vacuum or small pulses of phaco energy and then pull that pole of the nucleus upward until it rests in front of the anterior capsular edge. Occasionally the entire nucleus will subluxate into the anterior chamber (AC). In this event, phacoemulsification can be completed in the AC while maintaining as much nuclear clearance from the corneal endothelium if the nucleus is soft, the cornea is healthy if and the AC is sufficiently deep. Alternatively, one pole of the nucleus can also be pushed back inferiorly into the capsular bag to allow the iris plane tilt and tumble technique to be completed.

In patients with severely compromised endothelium, such as those with Fuchs' dystrophy or previous keratoplasty with a low endothelial cell count, endocapsular phacoemulsification is preferable to minimize endothelial trauma.

In most eyes, corneal clarity on the first day postoperatively is excellent. The technique is not only excellent for experienced surgeons, but it is also a very good technique for beginning surgeons because of the excellent safety aspect.

PREOPERATIVE PREPARATION

Patients with increased risk for excessive postoperative intraocular inflammation begin both steroid and nonsteroidal antiinflammatory drops 1 week preoperatively. All others begin their drop regimen the day before or the day of surgery.

After the patient enters the anesthesia induction or preoperative area and confirms and marks the operative eye, a drop of Tetracaine is administered for comfort. Dilation is then initiated with 1% tropicamide. Five minutes later, a broad-spectrum antibiotic drop is also applied. All patients receive topical and intracameral anesthesia intraoperatively. Additionally, all patients at our ASC have an IV placed in case of the need for additional sedation, antihypertensive agents, or other systemic therapies. Sublingual or oral sedation is also possible. Except for complex surgeries where a scleral tunnel or scleral suturing may be required, a periocular block is usually not necessary. Topical and intracameral anesthesia with mild sedation is more than adequate for the vast majority of cases.

The patient is visited preoperatively by the anesthetist, circulating nurse, and surgeon. The surgeon again confirms and marks the operative eye. Any questions are answered. The patient is then brought into the surgical suite.

Upon entering the surgical suite, the patient table is centered on preplaced marks so that it is appropriately positioned for operating microscope, surgeon, scrub technician, and anesthetist. We favor a wrist rest, and the patient's head is adjusted such that a ruler placed on the forehead and cheek will be parallel to the floor. The patient's head is stabilized with tape to the head board to reduce unexpected movements, particularly if the patient falls asleep during the procedure and suddenly awakens. A second drop of Tetracaine is placed. A periocular

preparation with 5% povidone-iodine solution is completed. One drop of povidone-iodine is also administered to the ocular surface.

A time-out is then performed. An aperture drape is applied followed by Tegaderm adhesive to cover the upper and lower lashes. We like to sit superiorly at the patient's head, making a superotemporal incision in right eyes and a superonasal incision in left eyes. We use an aspirating speculum (Lindstrom/Chu aspirating speculum, Rhein Medical) to avoid the pooling of irrigating fluid that can impair visualization, particularly with left eyes.

Goniosol or a viscoelastic agent is then applied by the circulating nurse in sterile fashion to the cornea such that corneal clarity is maintained during the surgery without the need for continuous irrigation by the scrub tech.

OPERATIVE PROCEDURE

We will first describe the general technique and then detail the necessary phaco machine equipment, settings, and instruments required.

Technique

(See videos of the tilt and tumble technique. Three separate videos (Videos 24.1 to 24.3) demonstrate the safety and efficiency of the technique with all procedures being less than 4 minutes.)

- The patient is asked to look down. The globe is supported with a dry merocel sponge, and a counter puncture is performed superiorly at the 10 to 11 o'clock position with a 1.1-mm metal blade (Fig. 24.1). Approximately 0.25 mL of 1% nonpreserved lidocaine with epinephrine in a 3:1 mixture is injected into the eye (Fig. 24.2). We advise the patient that he or she will feel a tingling or burning for a few seconds. We tell the patient that although he or she will feel some touch, pressure, and fluid on the eye, the patient will not feel anything sharp, and if he or she does, we can supplement with anesthesia. This injection also firms up the eye for the clear corneal incision. We do not find it necessary to inject viscoelastic prior to constructing the corneal wound.
- A superotemporal or superonasal limbal corneal incision is made while holding the paracentesis with toothed forceps. The AC is then entered parallel to the iris at a depth of approximately 300 μ. Care is taken not to incise the conjunctiva because this can result in ballooning during phacoemulsification and irrigation aspiration (Fig. 24.1, 24.3 to 24.15). A 2.65-mm blade is used. This creates an incision that maintains chamber stability without excess leakage around the phaco and irrigating needle and does not require enlargement for IOL insertion. After stromal hydration at the end of surgery, this incision is self-sealing.

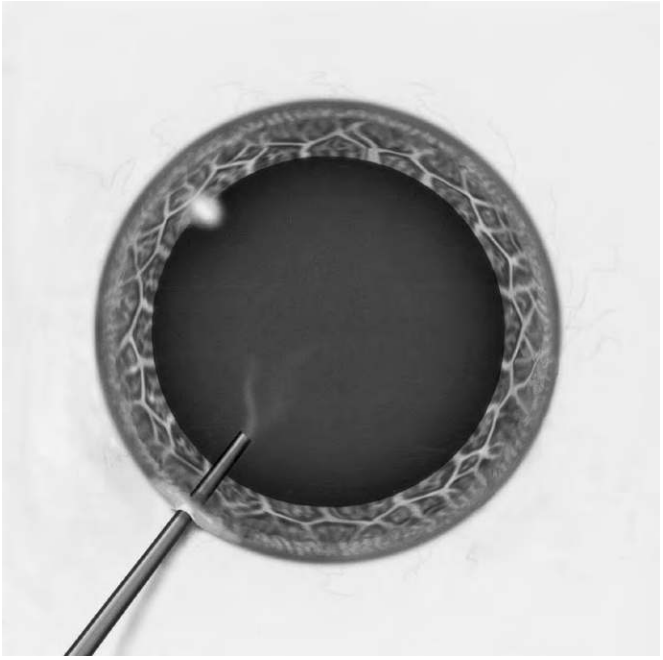

Fig. 24.2 Preservative-free xylocaine is injected intracamerally.

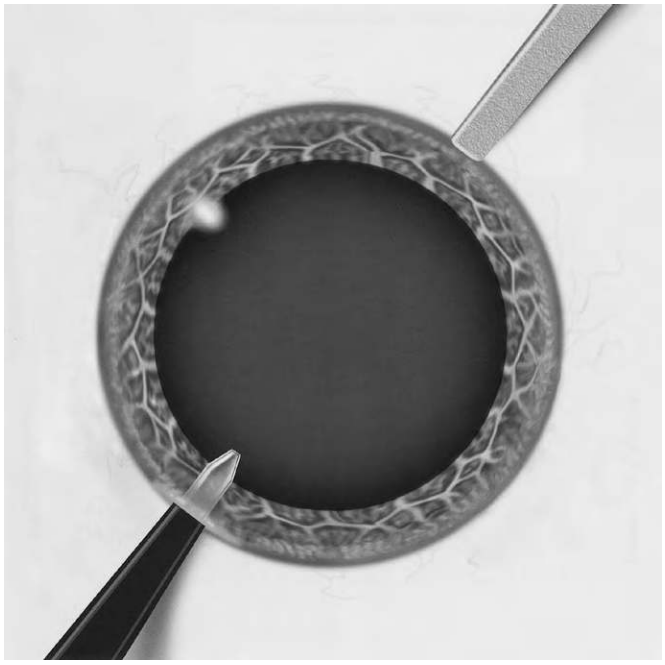

Fig. 24.1 Counterpuncture site of 1 mm is made with a diamond stab knife.

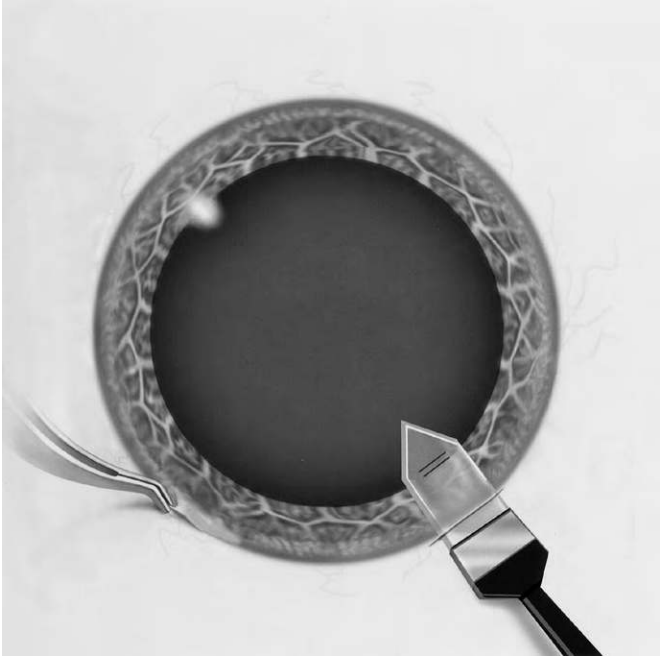

Fig. 24.3 A clear corneal incision is made temporally in right eyes and nasally in left eyes.

- The AC is constituted with a viscoelastic. For our technique, we prefer Amvisc Plus (Bausch and Lomb) because of its combination of both cohesive and dispersive qualities. There are certainly other viscoelastic agents that work equally well. However, the viscoelastic used should have some dispersive qualities to avoid its premature evacuation by the high vacuum employed.
- A relatively large diameter continuous tear anterior capsulectomy is fashioned (Figs. 24.4 and 24.5) This can be made with a cystotome or forceps. The optimal size is 5.0 to 6.0 mm in diameter and inside the insertion of the zonules (usually at 7 mm). With some IOLs, the capsule will seal down to the posterior capsule around the haptics rather than over the anterior surface of the intraocular lens (IOL). With this technique, there has not been any change in the incidence of IOL decentration or enhanced capsular opacification. Furthermore, refractive predictability has been excellent.
- Hydrodissection is then performed using a flat hydrodissection cannula on a 3-cc syringe filled with balanced salt solution (BSS). Slow continuous hydrodissection is performed gently lifting the anterior capsular rim until a fluid wave is seen. At this point, irrigation is continued until the nucleus tilts on one side, up and out of the capsular bag (Fig. 24.6). If one retracts the capsule at approximately the 7:30 o'clock position with the hydrodissection cannula, usually the nucleus will tilt superiorly. If it tilts in another position, it can either be approached in that direction or simply rotated until it is facing the incision (Fig. 24.7). If necessary, additional viscoelastic can be placed over the nuclear edge to protect the endothelium and to push the iris back, which is especially helpful in floppy iris cases.
- The nucleus is emulsified outside-in while supporting the nucleus in the iris plane with a second instrument, such as a Rhein Medical or Storz Lindstrom Star or Lindstrom Trident nucleus rotator (Fig. 24.8). Once half the nucleus is removed, the remaining one-half is tumbled upside-down and attacked from the opposite pole (Fig. 24.9). Again it is supported in the iris plane until the emulsification is completed (Fig. 24.10). Alternatively, the nucleus can be rotated and emulsified from the outside edge in with a carousel or cartwheel type of technique. Finally, in some cases, the nucleus can be continuously emulsified in the iris plane if there is good followability until the entire nucleus is gone. Most often during emulsification, we will manually chop or fragment the nucleus (manual disassembly) into small segments that are easily aspirated by the phaco needle with high vacuum and little to no phaco energy. We even sometimes stuff the fragments into the phaco tip, further fragmenting it.
- The cortex is removed with the irrigation aspiration hand piece. A curvilinear tip is used for most cortex removal. Subincisional cortex can be aspirated with a right angle tip (Fig. 24.11). If there is significant debris or plaque on the posterior capsule, one can attempt

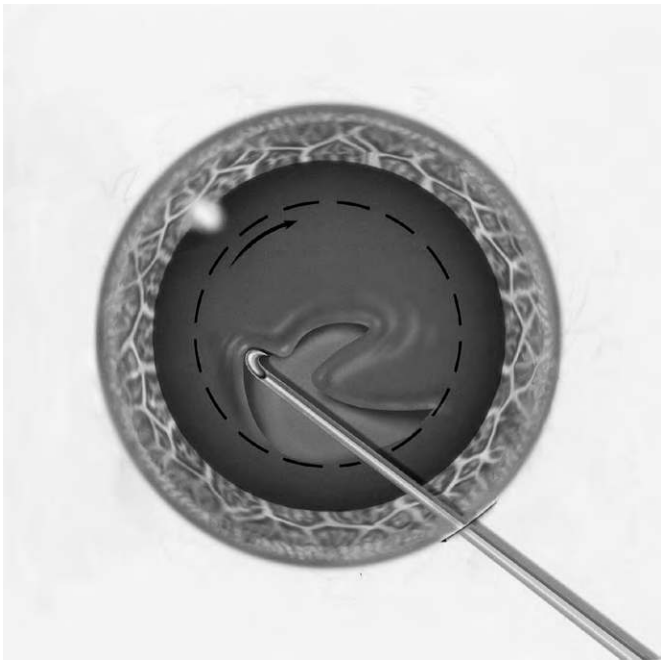

Fig. 24.4 A continuous curvilinear capsulotomy is made with a cystotome.

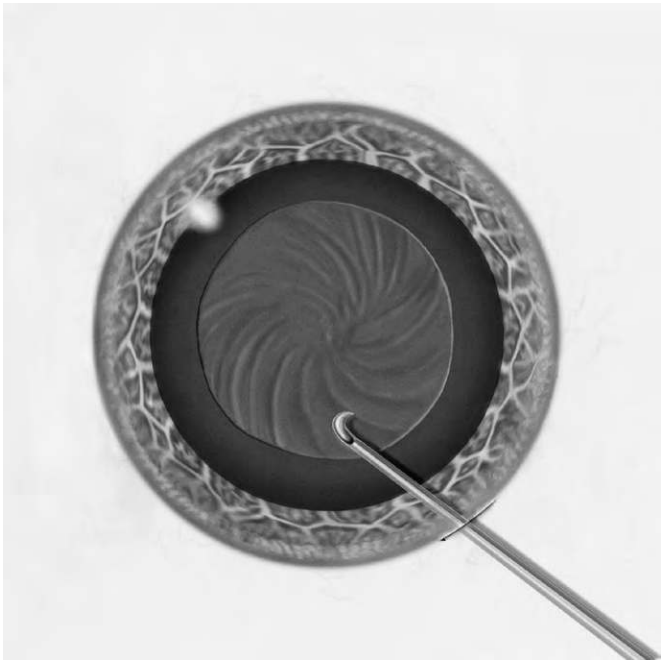

Fig. 24.5 The capsulotomy is optimally 5 to 6 mm in diameter.

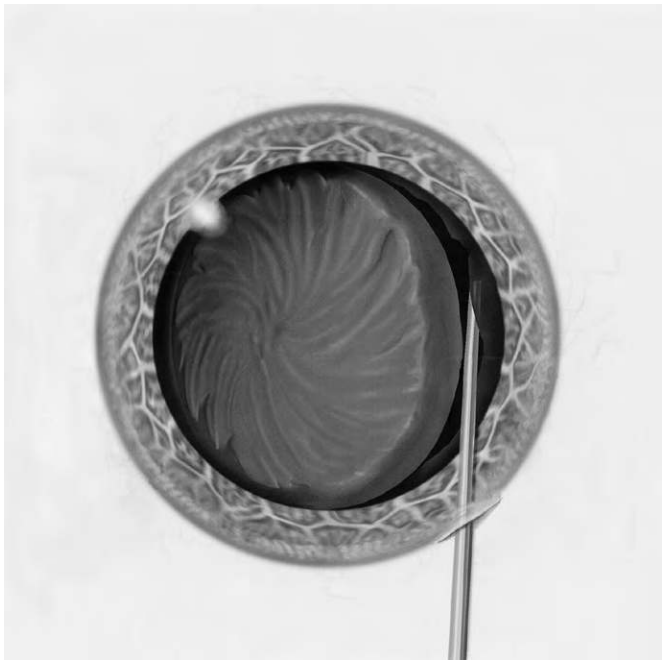

Fig. 24.6 Continuous slow hydrodissection leads to tilting of the nucleus out of the bag.

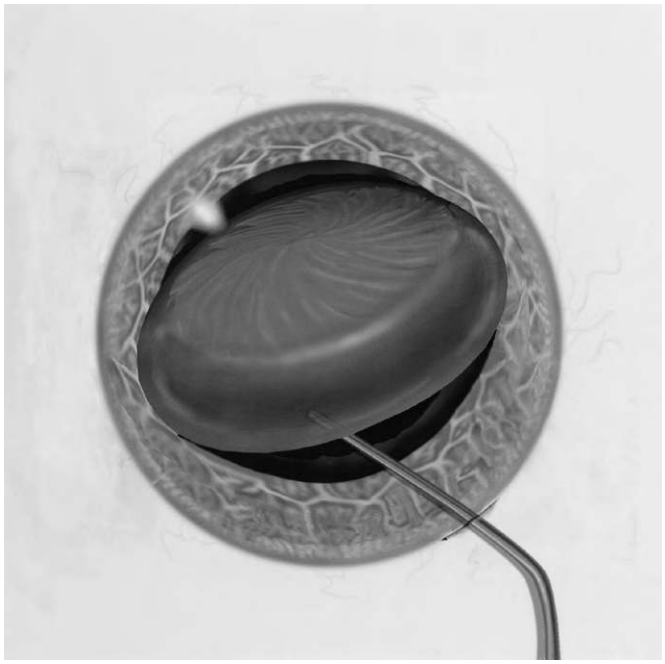

Fig. 24.7 The nucleus is rotated to face the incision.

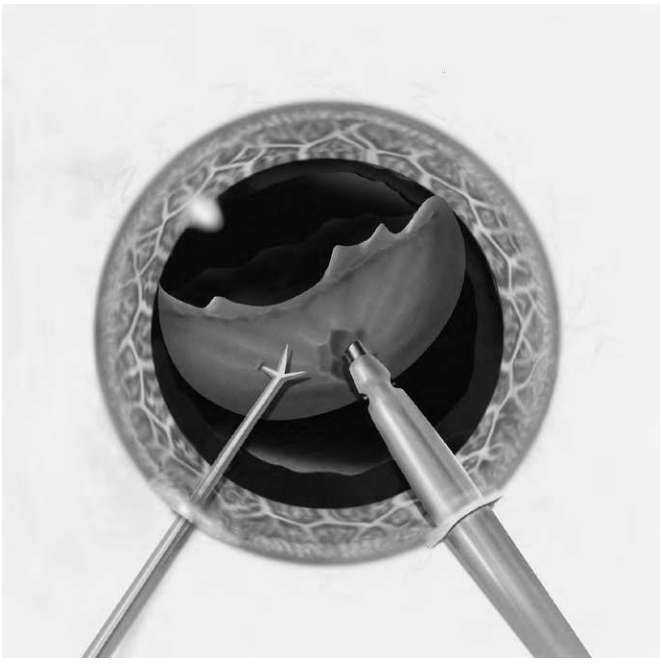

Fig. 24.9 The second of the nucleus is tumbled upside down.

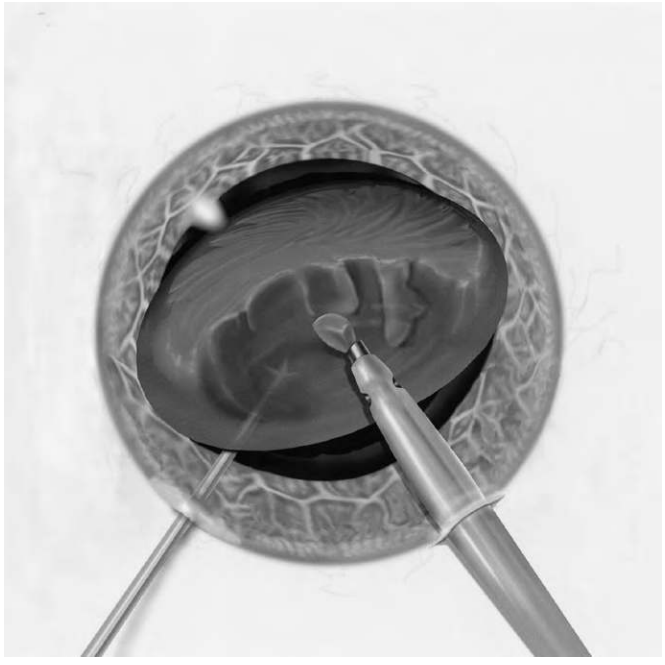

Fig. 24.8 The nucleus is supported during phacoemulsification with a second instrument.

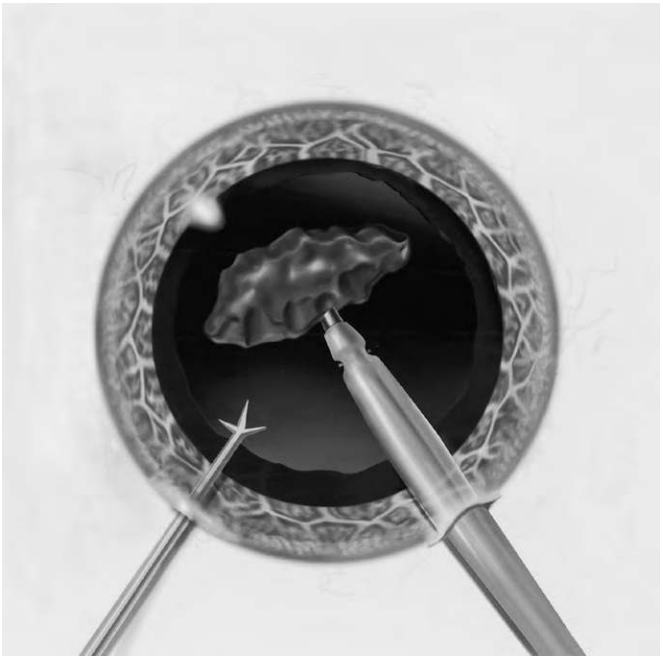

Fig. 24.10 Emulsification is completed in the iris plane.

some polishing and vacuum cleaning but not so aggressively as to risk capsular tears.

- The AC and capsular bag is filled with the same viscoelastic, and the IOL is inserted using an injector system (Figs. 24.12 and 24.13). Viscoelastic is then removed with irrigation aspiration. Pushing back on the IOLs and slowly turning the irrigation aspiration to the right and left two or three times allows a fairly complete removal of viscoelastic under the IOL.
- The AC is then refilled with BSS through the counterpuncture. Intracameral moxifloxacin or combination dexamethasone/moxifloxacin/ketorolac (Imprimis) is then injected (except in cases of allergy) as the published literature indicates its use significantly reduces the incidence of endophthalmitis. The main incision is then inspected. If the chamber remains well constituted and there is no spontaneous leak from the incision, wound hydration is not necessary. If there is some shallowing of the AC and a spontaneous leak, wound hydration is performed by injecting BSS into the incision periphery and roof, thereby hydrating it to bring the edges together. We confirm closure with a dry Weck cell.
- The lid speculum and drapes are then removed. A drop each of steroid and nonsteroidal antiinflammatory drug are then applied to the eye. The patient is then brought to the recovery room.

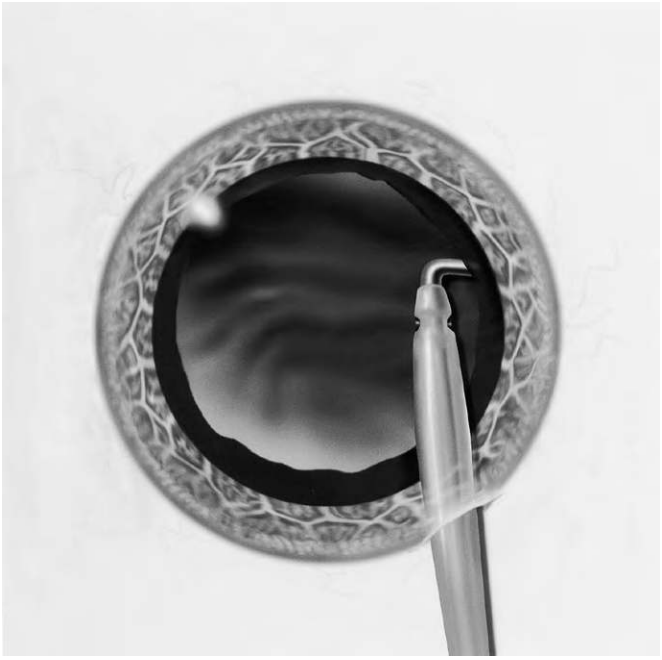

Fig. 24.11 Subincisional cortex is removed with a right angled tip.

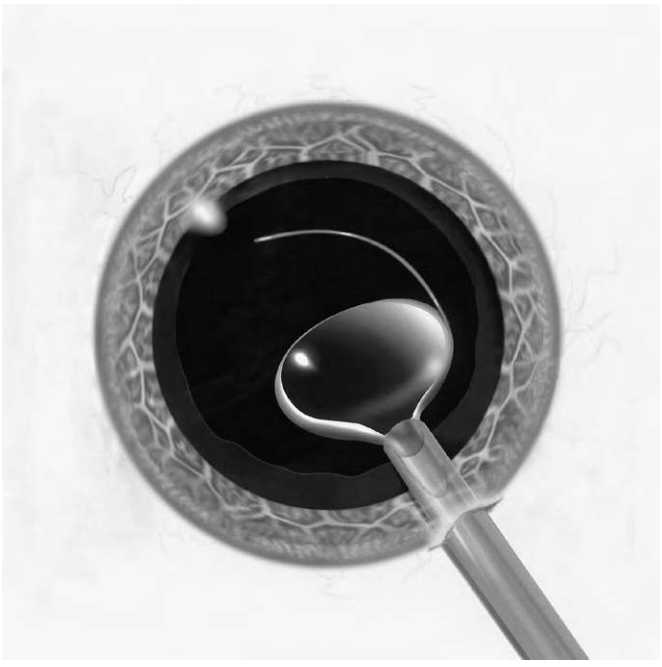

Fig. 24.12 The IOL is inserted with an injector system.

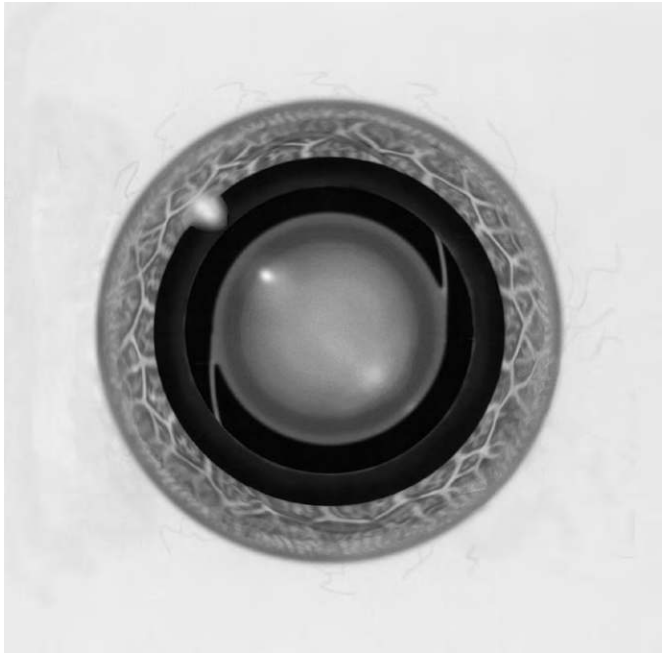

Fig. 24.13 The lens is centered in the capsular bag.

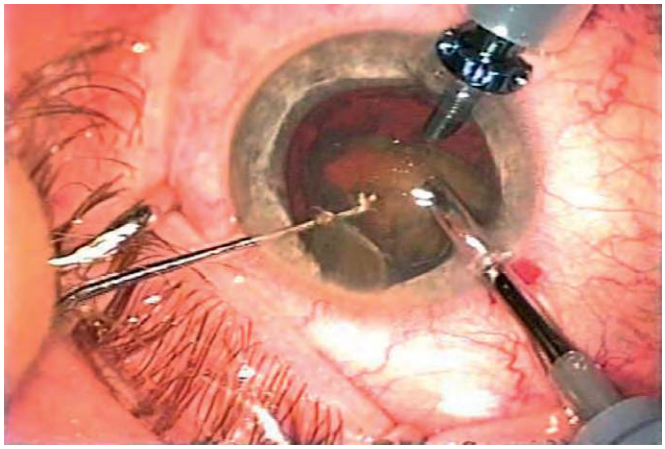

Fig. 24.14 Subincisional cortex is removed with the aspiration handpiece. Irrigation is provided by the AC maintainer.

Phaco Machine Equipment, Settings, and Instruments

Crucial to this technique is using appropriate phacodynamic settings and instrumentation. Because we are working in the iris plane rather than within the capsular bag, our goal is to markedly reduce the need for phaco energy. We are able to do so by employing very high vacuum levels, mechanical disassembly of the nucleus, and a large-bore phaco needle.

The authors have used Johnson & Johnson, Alcon, and Bausch and Lomb phacoemulsification machines with this technique. However, in our practice we most often use the Bausch and Lomb Stellaris. Hence, we will describe the parameters we employ with this particular machine with the understanding that other manufacturers' machines can also be set up to achieve the same phacodynamics.

- We work with very high vacuum levels to evacuate the nuclear particles using fluidics rather than phaco energy. To operate under high vacuum levels, it is imperative that a stable intraocular pressure be maintained to avoid chamber collapse. The Advanced Fluidics Module (AFM) continuously tracks vacuum flow rate and automatically adjusts infusion pressure to maintain AC stability. This is done via the Digiflow tubing that connect to the BSS bottle by automatic pressurization. We also keep our BSS bottle at maximum height of 120 cm for additional gravity assistance in pressurization.
- We use a large-bore, 19-g, 30-degree bevel coaxial phaco needle to aspirate large nuclear volume. To prevent postocclusion surge in addition to the forced infusion pressurization of AFM, we use Stable Chamber tubing for the phaco handpiece. This is small-diameter tubing that creates resistance to outflow. Additionally, a filter is integrated

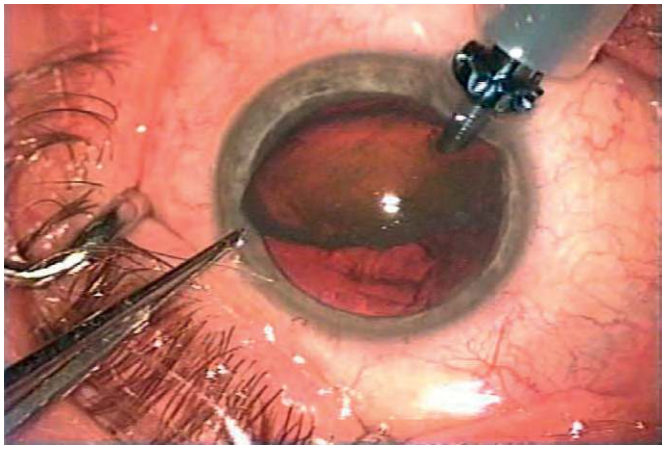

Fig. 24.15 Three-port microemulsification. The nucleus is supported during phacoemulsification with a second instrument.

Key Points in the Technique of Tilt and Tumble Phacoemulsification

1. The technique is broadly applicable, being useful in all but very dense nuclei or a compromised endothelium.
2. A medium to large capsulorrhexis is necessary.
3. Gentle continuous hydrodissection will prolapse one pole of the nucleus out of the bag.
4. The nucleus is phacoemulsified in the iris plane while being supported from beneath with a second instrument.
5. Phacoemulsification is performed away from the capsule, significantly decreasing the risk for capsular rupture.
6. With the use of high vacuum, mechanical disassembly, and a large-bore phaco needle, very little to no phaco energy is required.
7. Postocclusion surge is avoided by employing pressurized infusion, a high bottle height, and high resistance restrictive outflow tubing.
8. With experience, this technique is not only extremely safe but highly efficient.

Tilt and Tumble: Step by Step

1. Paracentesis and main incision are constructed.
2. A viscoelastic with dispersive properties is preferred.
3. The capsulorrhexis should be 5 mm or greater in diameter.
4. Gentle hydrodissection is done to prolapse one pole of the nucleus above the anterior capsulorrhexis.
5. Phacoemulsification of nuclear material is performed in the iris plane facilitated by manual disassembly.
6. Routine irrigation/aspiration is performed.
7. IOL is inserted.
8. Wound hydration is completed.

into the aspiration tubing that captures particles larger than 0.5 mm yet still allows the free flow of fluid by preventing clogging.

- With the combination of a large-bore needle, forced infusion, and high resistance outflow tubing, we can work at vacuum levels of 250 to 400 mm Hg. Nuclear material is evacuated quickly, safely, and efficiently in a responsive controlled surgical environment.

Tilt and Tumble: Phaco Machine Settings

- High vacuum levels
- Adaptive fluidics to maintain a pressurized chamber
- Maximum bottle height
- Large-bore phaco needle
- High-resistance outflow tubing

Our technique is very efficient and very safe. Surgery times range between 4 and 6 minutes with this approach rather than between 10 and 15 minutes for endocapsular phacoemulsification. The need for phaco energy with this high vacuum technique is most often zero or minimal. In addition, our capsular tear rate is below 1%. Therefore we find this technique to be easier, faster, and safer than others.

POSTOPERATIVE CARE

No patch is routinely used for the topical and intracameral approach. Patients are advised that they will have some erythropsia, meaning they will see a pink afterimage for the rest of the day, but usually this will resolve by the next morning. They begin their postoperative drops beginning 4 hours after surgery is completed. They are told not to engage in any heavy exertion or to lift more 20 pounds for 1 week. They are also asked not to swim or go into saunas for 2 weeks as infection precautions.

The typical postoperative visits are at 1 day and 2 weeks, at which point the second eye can then undergo surgery. Refractive stability is usually obtained at 2 weeks; hence spectacles can be prescribed at this point if needed. Our incision and technique induce less than 0.50 D of astigmatism.

Topical antibiotic, steroid and nonsteroidal, are used four times a day, tapering over 2 to 3 weeks.

Any yttrium aluminum garnet lasers are typically deferred for 90 days to allow the blood aqueous barrier to become intact and the capsular fixation to be firm.

SUMMARY

- Tilt and tumble phacoemulsification is a safe and efficient method of nucleus removal.
- Key elements in success are optimizing the phaco needle and fluidic settings, with the authors preferring a vacuum-based device with high vacuum settings to minimize phaco energy.
- As with any technique, every surgeon will find that slight variations in technique are required to achieve optimum results for their own individual patients in their own individual environment. Continuous efforts at incremental improvement result in meaningful advances in our ability to help the cataract patient obtain rapid, safe visual recovery after surgery.

Video 24.1: Tilt and Tumble technique for cataract extraction, Dr. Elizabeth Davis.

Video 24.2: Tilt and Tumble technique for cataract extraction, Dr. Elizabeth Davis.

Video 24.3: Tilt and Tumble technique for cataract extraction, Dr. Elizabeth Davis.

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Biaxial Microincision Phacoemulsification

Janet M. Lim, Richard S. Hoffman, Annette Chang Sims, and I. Howard Fine

CONTENTS

KEY POINTS

- Biaxial phacoemulsification's ability to separate irrigation from aspiration/phacoemulsification allows the following:
  - A more stable anterior chamber
  - Improved followability
  - The handpieces to be switched to remove the lens, which can allow a safer approach to cataract surgery in challenging cases
  - The irrigation to be used as an additional tool
  - The irrigation to be kept above the iris plane while aspirating below the iris plane, preventing billowing of the iris
  - Chopping as the preferred lens removal technique in biaxial phacoemulsification
  - Improved access to subincisional cortex
  - Transition to biaxial phacoemulsification as a short and safe learning curve with a small investment in new surgical instrumentation

INTRODUCTION

The idea of removing the cataractous lens through two microincisions is not a new concept and has been attempted with varying degrees of success and failure since the 1970s.[1–3] As phacoemulsification technology and power modulations developed,[4] emulsification and fragmentation of lens material without the generation of significant thermal energy became possible. Thus the removal of the cooling irrigation sleeve and separation of infusion and aspiration/emulsification through two separate incisions became a viable alternative to traditional coaxial phacoemulsification.

Much has been made of incision size as the main advantage for a microincision technique; however, the greatest advantages of biaxial phacoemulsification stem not from incision size but from the biaxial approach to lens removal. Although microincisions may offer the advantages of less induced astigmatism[5,6] and perhaps greater safety after traumatic injuries to the globe, the ability to approach difficult and challenging cases from two different incision locations, in addition to the peculiar fluidics of biaxial irrigation and aspiration, are the strongest assets for this surgical technique.

Although learning any new surgical technique has its intimidating moments, the transition to biaxial microincision phacoemulsification is a relatively straightforward process with a short safe learning curve and requires only a small investment in new surgical instrumentation.

SURGICAL TECHNIQUE

A single 1.1-mm incision is created 30 to 45 degrees to the left of the temporal limbus using a 1.1-mm diamond or steel keratome (Fig. 25.1). Diamond knives are more cost effective in the long run, but for surgeons who may not be sure that they will convert to biaxial phacoemulsification, metal blades are a good starting option. A trapezoidal diamond keratome will create an incision configuration with an internal opening of 1.0 mm and an external opening of 1.1 mm. This is followed by the instillation of 0.5 cc nonpreserved Lidocaine 1% and a dispersive ophthalmic viscoelastic device (OVD). A second microincision is then created 90 to 120 degrees from the left-sided incision (Fig. 25.2). Placing an OVD into the anterior chamber prior to creating the second microincision will repressurize the eye and ensure a more accurate incision length. The precision of these incisions is critical because an incision that is too long can constrain movement of the instruments.

The capsulorrhexis can be started with a specially designed forceps constructed to function through a 1.1-mm incision. Most instrument companies are currently manufacturing microincision capsulorrhexis forceps; however, we have had a preference for the MST Fine/Hoffman microincision forceps (# DFH-0002, MicroSurgical Technology, Redmond, WA, USA) (Fig. 25.3AB). The capsulorrhexis is initiated by puncturing the central lens capsule with the tips of the microincision capsulorrhexis forceps. This is easily accomplished using a single blade of the forceps tip in the open configuration and then grasping the edge of the open capsule with the forceps in the closed configuration (Fig. 25.4). After completion of the capsulorrhexis, cortical cleaving hydrodissection and hydrodelineation are performed with a 26-G cannula. Performing rotation of the crystalline lens after hydrodissection but before hydrodelineation will ensure that both the endonucleus and epinucleus are freely mobile. Once the lens is rotated, hydrodelineation can then be performed to separate the epinucleus from the endonucleus and phacoemulsification can commence.

Chopping is the preferred lens disassembly technique because it will reduce ultrasound energy and will lower any risk of incision burns. A 21-G irrigating chopper is inserted through the left-handed incision followed by placement of the bare phacoemulsification needle (without an irrigation sleeve) through the right-handed incision. We

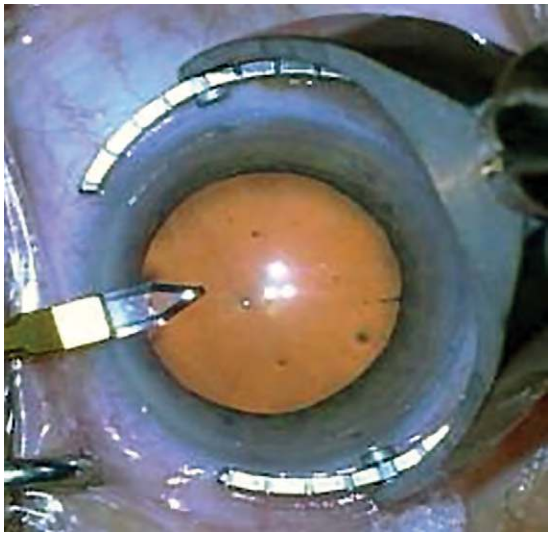

Fig. 25.1 A diamond keratome is used to create the first microincision to the left.

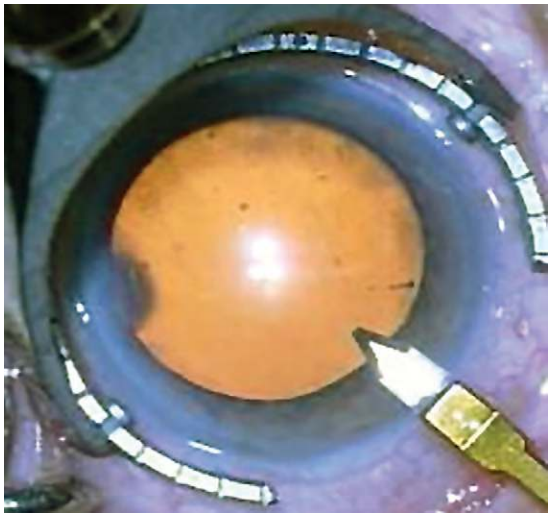

Fig. 25.2 The second microincision is created with the diamond keratome to the right.

currently prefer Microsurgical Technology's MST Duet System, which offers the option of both vertical and horizontal choppers (Fig. 25.5A–C). Insertion of the irrigating chopper involves a short learning curve. It is best accomplished by inserting the vertical chopping element at the tip, parallel with the incision until the distal aspect of the chopping segment clears the internal opening of the clear corneal incision (Fig. 25.6). Once the tip clears the internal opening, the handpiece can then be rotated while the remainder of the chopper is advanced into the eye.

After trimming the anterior epinucleus with aspiration from the bare phaco needle, a horizontal chopper is placed at the distal golden ring and the phaco needle is buried proximally into the endonucleus to 50% to 60% depth. Horizontal chopping is then performed by bringing both instruments together and then pulling 90 degrees away to create the first chop. The lens is then rotated 90 degrees with either the chopper or the bare phaco needle, and the second chop and segment removal is performed (Video 25.1). Removal of the endonucleus is followed by trimming and flipping of the epinucleus as previously described.[7] Rotating the chopping element (located at the tip of the irrigating chopper) into a horizontal position during removal of the last endonuclear segment and removal of the epinucleus will decrease the chances of accidentally tearing the posterior capsule if it were to move anteriorly at this point in the procedure. Residual cortical material is then removed with the bimanual irrigation and aspiration handpieces (Fig. 25.7AB). Switching handpieces between the two incisions can be helpful to remove subincisional cortical material (Fig. 25.8).

After removal of all lens material, the capsular bag and anterior chamber are filled with a cohesive OVD, and a temporal clear corneal incision is made for insertion of the intraocular lens (IOL). The size of the incision is dictated by the IOL model and injector characteristics. Once the IOL is inserted into the capsular bag, the OVD is removed using the biaxial irrigation and aspiration handpieces. Stromal hydration of all three incisions is then performed. On occasion there may be leakage from any of the incisions. This can be treated with additional stromal hydration in addition to pressing on the roof of the incision with a dry Merocel sponge to help oppose the roof of the incision to the floor. If leakage cannot be stopped, a 10-0 nylon can be placed in the incision and removed postoperatively.

SURGICAL PEARLS

- The forward irrigating chopper is preferred over the side irrigating chopper because a forward irrigation port does not get blocked off by the walls of the incision when retracted. In addition, the flow of fluid will not be directed toward the corneal endothelium when the chopper is rotated away from the posterior capsule.
- If it is difficult to insert the phaco needle, briefly turning off the irrigation to lower the anterior chamber pressure can facilitate its insertion.
- If a needle is needed to initiate the capsulorrhexis, a straight 25 or 27 as opposed to a traditional bent tip should be used to prevent inadvertent laceration of the corneal microincision when exiting the eye.
- If there is a concern for weakened zonules or a weakened posterior capsule, place external pressure on the posterior lip of the incision with the cannula when hydrodissecting to allow the egress of fluid and prevent an excessively high intraocular pressure.
- Rotating the lens after both hydrodissection and hydrodelineation ensures complete lysis of the cortical capsular connections and prevents an adherent epinucleus after the endonucleus is removed.
- Horizontal choppers are preferred for 1-2+ nuclear sclerosis, while vertical choppers are preferred for denser 3-4+ nuclear sclerosis.
- If nuclear fragments are not held onto the tip of the phaco needle while in aspiration mode, evaluate the orientation of the forward irrigating chopper. Many times followability can be improved by angling the irrigator away from the phaco needle.
- If limbal relaxing incisions (LRIs) are large and it is not possible to place the microincisions on either side away from the LRIs, the microincisions can be created at a 50% depth within the LRIs.
- Options for IOL insertion include enlarging one of the biaxial incisions or creating a new temporal clear corneal incision between the biaxial microincisions. Our current preference is to create a new temporal incision for IOL insertion because of the potential stretching and lack of self-sealability of an enlarged microincision. However, either method is acceptable and can be used for IOL insertion.

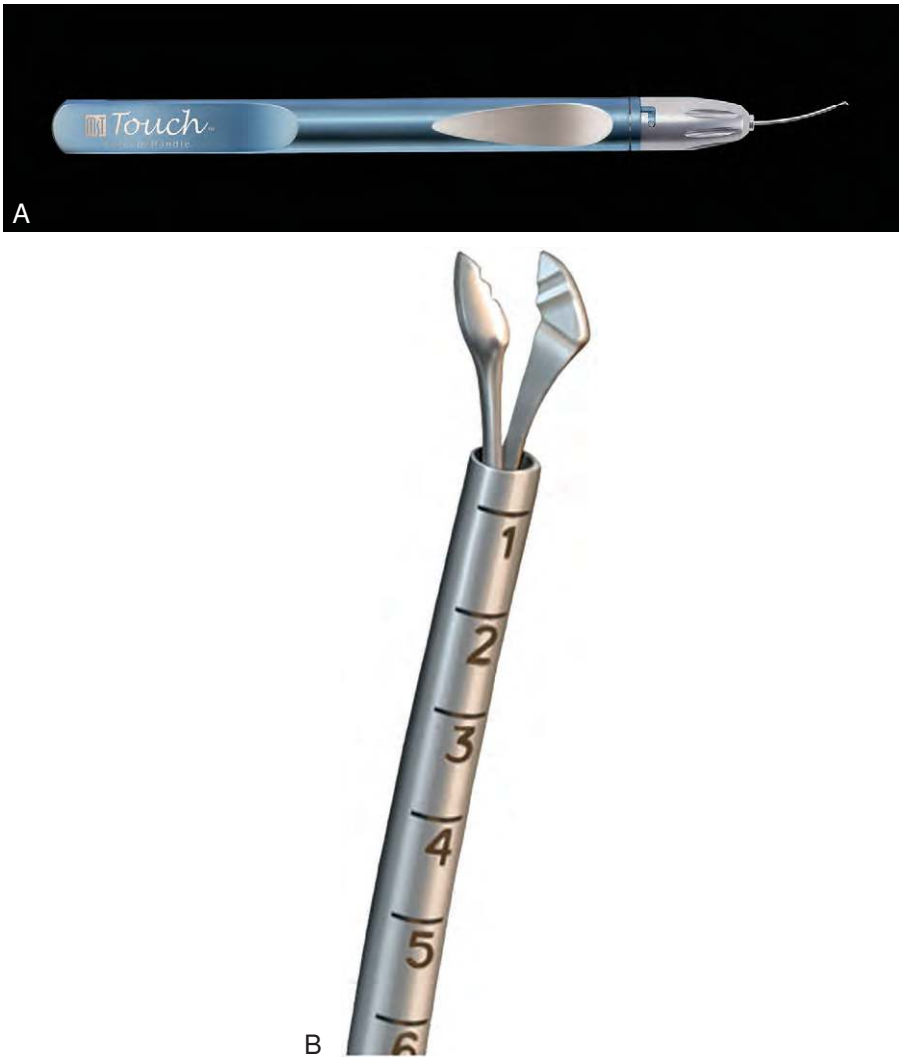

Fig. 25.3 (A) Fine/Hoffman microincision capsulorrhexis forceps on the MST Touch handle. (B) Higher magnification of microincision capsulorrhexis forceps (A and B, Courtesy MicroSurgical Technology).

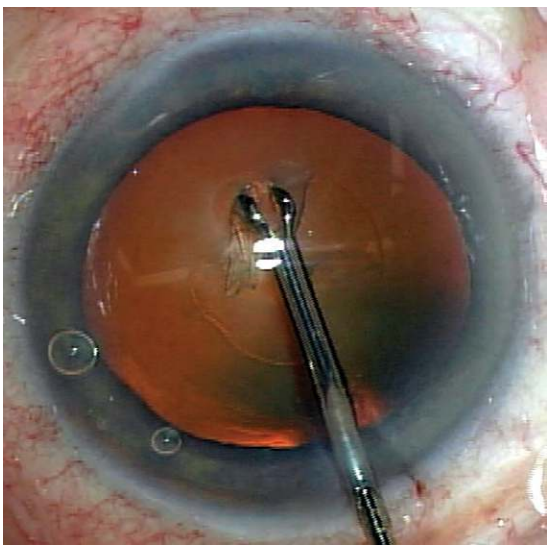

Fig. 25.4 Capsulorrhexis is created with the MST Fine/Hoffman microincision forceps.

ADVANTAGES OF BIAXIAL PHACOEMULSIFICATION

- More stable anterior chamber during capsulorrhexis construction
- More efficient hydrodissection and hydrodelineation by virtue of a higher level of pressure building in the anterior chamber prior to eventual prolapse of OVD
- Improved followability by avoiding competing currents at the tip of the phacoemulsification needle
- The irrigation handpiece can be used as an adjunctive surgical device, flushing nuclear pieces from the angle or loosening epinuclear or cortical material.
- Irrigation can be directed more anteriorly within the anterior chamber, in front of the iris plane, which prevents the billowing of floppy irides and resultant miosis in cases of intraoperative floppy iris syndrome (IFIS).
- Switching handpieces allows the lens to be approached from two different directions, which can be invaluable in cases with compromised zonules and posterior polar cataracts. Directing aspiration forces away from areas of enhanced zonular integrity rather than away from areas of zonular weakness creates a scenario that is much less likely to extend zonular dialyses or worsen lens subluxation.

Continued

ADVANTAGES OF BIAXIAL PHACOEMULSIFICATION *(CONTINUED)*

- The ability to switch the irrigating chopper and phaco needle between the two incisions is also helpful when lens material cannot be rotated to the distal location for efficient aspiration and phacoemulsification. In posterior polar cataracts, the ability to approach and aspirate all lens material without rotating the endonucleus or epinucleus minimizes the chances of placing undue stress on the fragile or compromised posterior capsule that could result in posterior capsule rupture and vitreous loss.
- The ability to switch handpieces during removal of cortex has simplified cortical clean-up, allowing for improved access to 360 degrees of the capsular fornices and lowering the risk of capsular aspiration and tears during removal of subincisional cortex.
- Microincisions can fit between 8 and 16 cut radial keratotomy (RK) incisions so that the case can be fairly routine. In an 8-cut RK, a 2.2-mm incision can be placed between the RK incisions for IOL insertion. In a 16-cut RK, the 2.2-mm incision can be placed underneath one of the RK incisions starting posteriorly enough to incorporate nonincised stroma or sclera in the roof of the incision (going through conjunctiva and sclera), which will prevent opening of the RK incision during the stress of IOL insertion.
- In the event of a posterior capsular rupture, the case can usually proceed in a safer fashion because of the ability to maintain a pressurized anterior chamber throughout most of the steps of the procedure after capsule compromise (Video 25.2).

DISADVANTAGES OF BIAXIAL PHACOEMULSIFICATION

- Maneuvering through 1.1-mm incisions can be awkward early in the learning curve. Microincision capsulorrhexis forceps are the best instrument for performing the capsulorrhexis. Although more time is initially required to learn to perform a capsulorrhexis with these forceps, the maneuvers become routine with more experience.
- Additional equipment is necessary in the form of small incision keratomes, irrigating choppers, bimanual irrigation and aspiration handpieces, and microincision capsulorrhexis forceps.
- The microincisions cannot be used to place the IOL, and a larger keratome incision needs to be made.
- Because of the size of these incisions, less fluid flows into the eye than occurs with coaxial techniques. The 21-G lumen-irrigating chopper limits fluid inflow, resulting in significant chamber instability when high vacuum levels are used and occlusion from nuclear material at the phaco tip is cleared. Thus infusion needs to be maximized, and vacuum levels usually need to be lowered below 350 mm Hg to avoid significant surge flow.

Fig. 25.5 (A) MST Duet System chopping irrigator. (B) Irrigator with horizontal chopper. (C) Irrigator with vertical chopper (A–C, Courtesy MicroSurgical Technology).

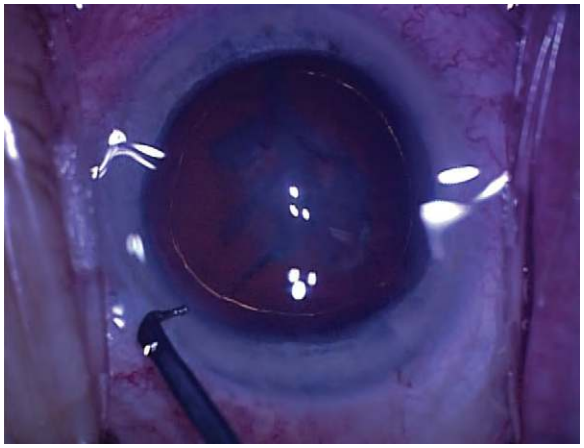

Fig. 25.6 The vertical element located on the tip of the irrigating chopper is inserted parallel with the incision until the leading edge clears the internal opening of the clear corneal incision.

Fig. 25.7 (A) Duet Bimanual irrigation tip. (B) Duet Bimanual aspiration handpiece (A and B, Courtesy MicroSurgical Technology).

SUMMARY

Ultimately, it is surgeon preference and marketplace forces that will dictate how cataract surgical technique will evolve. The hazards and prolonged recovery of large-incision intra- and extracapsular surgery eventually spurred the acceptance of phacoemulsification despite the difficult learning curve. Surgeons comfortable with their extracapsular skills disparaged phaco until the advantages were too powerful to ignore. Similar inertia was evident when transitioning to foldable IOLs, clear corneal incisions, and topical anesthesia. The future lens procedure of choice will eventually be decided by its potential advantages over traditional methods and by the collaboration of surgeons and industry to deliver safe and effective technology. We believe biaxial microincision phacoemulsification is the next step in the evolution of phacoemulsification.

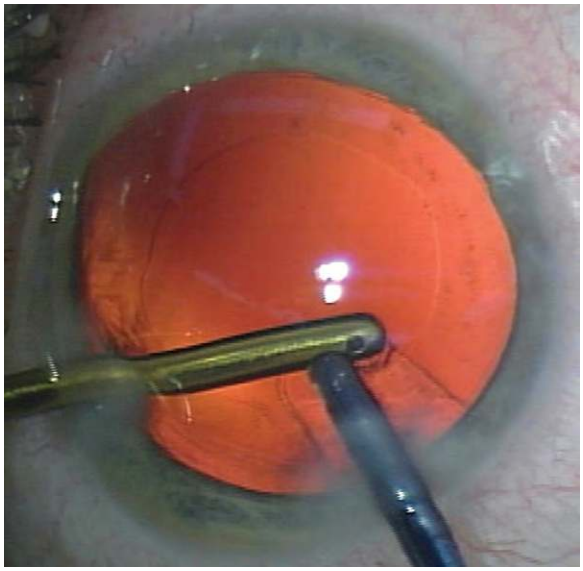

Fig. 25.8 Removal of subincisional cortex after switching handpieces between incisions.

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Femtosecond Laser-Assisted Cataract Surgery

Aditya Kanesa-thasan and Kendall E. Donaldson

CONTENTS

KEY POINTS

- Femtosecond laser technology offers new techniques for performing key steps of cataract surgery with added precision.
- This technology provides several benefits but requires that surgeons adjust their traditional technique.

INTRODUCTION

Ophthalmologists have used the femtosecond laser as a refractive tool ever since it was introduced for the creation of laser in situ keratomileusis (LASIK) flaps in 2001. The accuracy, reproducibility, and safety of femtosecond laser flap creation caused many surgeons to replace their microkeratomes with this new technology. The advantages were clear, and the safety of "bladeless LASIK" appealed to both surgeons and patients. It would be years before the technology was applied for use in cataract surgery.

In 2008 femtosecond laser-assisted cataract surgery (FLACS) was performed for the first time on a patient at Semmelweis University in Budapest, Hungary.[1] Initial versions of the technology did not have real-time anterior segment optical coherence tomography (OCT), which was later added to allow the surgeon to dynamically adjust the treatment according to the patient's lens and corneal anatomy. In 2010, the Food and Drug Administration (FDA) approved the first femtosecond laser for use in cataract surgery. In contrast to LASIK surgery, after nearly a decade, the market penetration of laser-assisted cataract surgery or FLACS has been limited. Adoption of this technology by cataract surgeons has occurred very gradually while spurring debate and controversy regarding its benefits and outcomes.

THE TECHNOLOGY

The femtosecond laser works through the process of photodisruption, which is the rapid creation of plasma and cavitation bubbles at a specific focal point without heat or damage to the tissue.[2] The laser gets its name from its extremely short pulses of laser energy (1 femtosecond = 1×10^{-15} seconds). It can be programmed to perform thousands of pulses spaced only microns apart to weaken the tissue in a predefined pattern. The process creates a series of bubbles that coalesce and create a plane within the tissue that can be manually separated. The technique requires optical clarity to focus the laser pulses within the tissue, which makes it well suited for treating the cornea and human lens.

The safe application of energy to intraocular structures requires accurate, precise imaging. Advances in OCT imaging make it possible to precisely map the exact location of each structure from the cornea to the posterior capsule for the purposes of treatment planning. It allows for the measurement and creation of surrounding safety zones, avoiding damage to critical structures. It can also be adjusted to compensate for tilt of ocular structures within each eye. Precise anatomic mapping allows for adjustments in capsulotomy diameter and centration and the placement of femtosecond corneal penetrating and arcuate incisions.

STEPS OF THE PROCEDURE

Preoperative Evaluation and Planning

Successful cataract surgery begins long before the patient arrives in the operating room with a thorough examination to anticipate any intraoperative challenges. Proper lens power requires accurate measurements. Such meticulous planning should be a prerequisite for all cataract surgery. Keratometry readings should be carefully evaluated preoperatively. Patients with very steep or flat corneas are at increased risk for an incomplete capsulotomy and femtosecond laser docking problems. For this reason, some laser platforms offer a variety of different patient interfaces (e.g., LenSx, Alcon). Any corneal opacity or fold may also block laser penetration and result in an incomplete capsulotomy. For example, a patient with a history of radial keratotomy may be at increased risk for incomplete capsulotomy, which may be overcome by increasing the laser energy for the capsulotomy step. Also, previous corneal scars or incisions should be avoided when placing new corneal incisions or arcuate incisions with the laser. Adequate pupil dilation is important to ensure proper centration and sizing of the capsulotomy. The lens density should be noted preoperatively because this may dictate adjustments to the laser parameters or the fragmentation pattern. The femtosecond laser treatment should be planned so that the surgeon knows exactly what parameters will be used in the operating room and to streamline the process of entering this data into the laser on the day of surgery.

Meeting patient expectations is a priority for all successful cataract surgeons. This begins preoperatively and extends throughout the surgical and postoperative experience. In the United States the use of femtosecond laser assistance in cataract surgery is often part of an additional premium added to the cost of cataract surgery. When patients pay this premium, their expectations are automatically heightened, and their disappointment with a complication or side effect may intensify. An honest discussion about limitations and complications is important with any new technology in cataract surgery. FLACS is often combined with presbyopia-correcting intraocular lenses (IOLs) to treat concomitant astigmatism. Consent forms should include the potential need to revert to a standard spherical monofocal IOL or to abort the FLACS portion of the planned procedure if that is deemed most appropriate by the surgeon intraoperatively.

Because we elevate patient expectations through additional out-of-pocket costs, we should prepare to spend additional time with these patients both preoperatively and postoperatively. Some practices offer discounted or free enhancements for residual postoperative refractive error to improve patient satisfaction. The femtosecond laser is an important adjunct technology that helps us to achieve our best results from the standpoint of both safety and refractive outcomes.

Patient Positioning and Docking

Docking the laser to the patient's eye is a key part of the FLACS procedure and is usually one of the most difficult for surgeons who are new to the technology. Both the patient and the surgeon need to be properly and comfortably positioned to avoid discomfort and potential complications. The surgeon needs adequate visualization of both the patient and the laser imaging system for the laser to ensure safety. Each laser platform has a different method of interfacing with the patient's eye, but all require secure fixation to minimize eye movement during the procedure. The patient needs to be supine with the neck and head in a neutral position to avoid lens tilt and to avoid having the patient interface (PI) hit the nose (with a slight head tilt toward the nose). FLACS requires precise imaging, and it is well established that significant ocular tilt is associated with suction loss and poorer quality imaging. Suction loss may require repeat applanation and repositioning of the PI, which may cause conjunctival chalasis, subconjunctival hemorrhage, and pupillary miosis. This is more common during the learning curve and was one explanation for the higher rate of complications during a surgeon's first 100 cases.[3]

POTENTIAL PITFALLS

- Key for proper laser treatment.
- Poor centration may complicate planning the laser treatment.
- The risk for suction loss is higher with poor centration and can also occur with patient movement or poor patient interface fit.
- If suction loss occurs, immediately cease laser treatment to avoid errant pulses of energy. At this point, the surgeon can attempt to redock the laser and either resume the next treatment step or abort laser treatment while completing the steps manually.

SURGICAL PEARLS

- Calm and reassuring coaching throughout the laser docking and procedure can help reduce suction loss caused by movement while increasing patient comfort throughout the procedure.
- Know the specific steps of the particular machine you are working on as each platform has a slightly different workflow

Capsulotomy

The ability to make a precisely designed, perfectly sized, and centered capsulotomy is unarguably a unique attribute of femtosecond laser technology. The capsulotomy can be created in a very fast, efficient manner. Laser settings can be altered to achieve the desired effect in different situations. Depending on the laser platform and the energy settings, a capsulotomy may be performed in less than a second. The laser pulse energy during the capsulotomy is generally between 4 to 10 μJ. Laser energy can be increased up to 10 μJ in cases where there may be capsular fibrosis/scarring or in cases with a mild corneal opacity, which may partially block laser transmission to the capsule or lens material. Both vertical and horizontal spot spacing can also be customized. Typically, horizontal spot spacing is 3 to 7 μ (the lower the number, the closer together the spots are placed) and vertical spot spacing is 10 μ. The vertical spacing may be increased to create a smoother capsulotomy, reducing the incidence of capsular tags. Each cavitation bubble expands more in the vertical meridian than in the horizontal plane.

In planning the treatment, the surgeon selects the diameter of the capsulotomy and then uses the platform software to select the centration of the capsulotomy. Some platforms offer different automatic options such as "pupil maximized" settings, which allow diameters that are optimally sized and centered within the pupil. Another useful setting is "capsule centered" in which the capsulotomy is centered on the equator of the capsular bag.

One concern is the creation of "postage stamp" perforations at the edge of the capsulotomy, which can lead to incomplete separation of the capsule or tags of unbroken tissue and is a concern with all femtosecond laser platforms.[4] Inherent in the creation of the capsulotomy, there are microscopic irregularities where the photodisruption bubbles coalesce, creating a series of pitted edges as opposed to the continuous edge of a manually torn capsulotomy. The clinical significance is the risk for anterior capsular tears arising from these irregular edges if the capsulotomy is stretched or deformed during surgery.

SURGICAL PEARLS

- Capsular tags
  - Several techniques can be employed to limit the risk for an anterior radial tear. One technique is to dimple down in the center of the cut capsulotomy, which will break tags in a controlled fashion or highlight any areas of incomplete break.
  - If there is a large section of uncut capsulotomy, use capsulotomy forceps to advance the tear (using a manual capsulorhexis technique), and consider encompassing the area of the lasered capsule to excise the area of tags.[5]
- Pupillary miosis is a well-known risk factor for surgical complications during cataract surgery.
  - FLACS has been associated with an increase in pupillary miosis, many surgeons prescribe additional preoperative dilating drops and a topical nonsteroidal agent.[1]
  - Intracameral preservative free lidocaine with epinephrine (epi-Shugarcaine) and phenylephrine/ketorolac (Omidria, Omeros) in the irrigation solution are helpful in expanding and maintaining pupil dilation for the rest of the procedure.[1,2]
  - It has been shown that the femtosecond laser is associated with release of prostaglandins into the anterior chamber (AC), which subsequently leads to pupillary miosis.[1]
  - Additional factors associated with pupillary miosis during FLACS include shallow AC depth, closer proximity of the capsulotomy and pupil margin, and longer period of suction.[1]
  - In addition, increasing delay between the FLACS steps and the phacoemulsification portion of the procedure is directly correlated with progressive pupillary miosis. For this reason, it is highly recommended that the phacoemulsification portion of the procedure is initiated within 30 minutes of completing the FLACS steps.

SURGICAL PEARLS

- Avoid pupillary miosis by pretreating patients with a nonsteroidal drop nonsteroidal antiinflammatory drug [NSAID] preoperatively, which reduces prostaglandin release and prevents intraoperative miosis.
- If a pupil expander is indicated, assure that the free edge of the capsule is properly visualized to avoid capture of the capsulotomy, which can lead to an anterior capsular tear.

Lens Fragmentation

Lens fragmentation and segmentation by the laser facilitates more efficient phacoemulsification with less energy expenditure. This has been documented for all available laser platforms. It has also created the possibility of completing phacoemulsification without any dissipated energy in even moderately dense lenses.[1]

Software guidance allows the surgeon to design a specific fragmentation pattern according to the nuclear density and according to their individual preferences. Common patterns include radial cuts to form pie-piece segments and waffle patterns, which further break these subdivisions into smaller cubes. Some surgeons prefer aligning perpendicular radial cuts in a cross shape to mimic a divide-and-conquer technique. Others prefer using segmentation grids to soften the nucleus into smaller pieces that require less phacoemulsification power to remove. Some platforms support circumferential rings, which can fragment the nucleus into cylindrical pieces that can be divided. Yet others may prefer a combination of different types of patterns. The flexibility of the software on each machine allows the surgeon to tailor the treatment to their preferred surgical technique and style.

Corneal Incisions

The surgeon has the option of using the femtosecond laser to perform corneal incisions or to manually create the incisions with a blade. Studies have shown more predictability of laser incision architecture compared with manual incisions, with less endothelial or epithelial gaping of the wound as detected by postoperative anterior segment OCT.[1] Just as with manual incisions, the architecture of femtosecond corneal incisions is important to ensure watertight wounds.

The femtosecond laser can create custom designed, precisely placed incisions for the primary phacoemulsification wound and paracentesis. Occasionally with earlier laser generations, the incisions were inadvertently placed too centrally if the software had difficulty detecting the corneal limbus. A primary wound that is placed too anterior may generate a large amount of irregular corneal astigmatism (Fig. 26.1A–B). These concerns have lessened with improvements in the laser software's ability to detect the limbus. Because the laser can only cut through clear tissue, incisions near the limbus may not fully penetrate the tissue because of limbal scarring, vascularization, pannus, or arcus senilis formation. Despite the laser's ability to create precise incisions, many surgeons still prefer to create their own wounds manually to place the incision more peripherally.

Arcuate Incisions

Arcuate incisions can be used to decrease preexisting corneal astigmatism at the time of cataract surgery with good repeatability and accuracy.[1] Most femtosecond laser platforms allow for the design of paired or single incisions including modification of the arc length, specified axis, and distance from visual axis (optical zone). In addition, some laser platforms allow for the placement of intrastromal arcuate incisions, which relax corneal stromal tissue but leave an intact zone of corneal tissue above and below. Regardless of the technique used, one advantage of femtosecond arcuate incisions is accurate placement of the incision exactly where the surgeon wants, as well as perfect targeting of the depth of the incision with anterior segment OCT guidance. Adjustments to a surgeon's typical nomograms may be necessary to match a particular laser platform's settings. There are several nomograms for both penetrating and intrastromal FLACS arcuate incisions, with both showing similar efficacy according to one review.[1] With higher levels of astigmatism (greater than 1.5 D), most surgeons agree that astigmatism correction with a toric IOL is preferable for best astigmatic correction.

Lens Removal

There are a few adjustments that surgeons must make when using the femtosecond laser. One is paying particular attention to complete hydrodissection, which makes the case much easier when done properly. The laser energy creates adhesions between the edge of the capsule and the superficial cortical material, making cortex seem more adherent and potentially more difficult to remove without effective hydrodissection. In addition, hydrodissection should be thorough but not overly aggressive, because gas bubbles may be trapped behind the lens

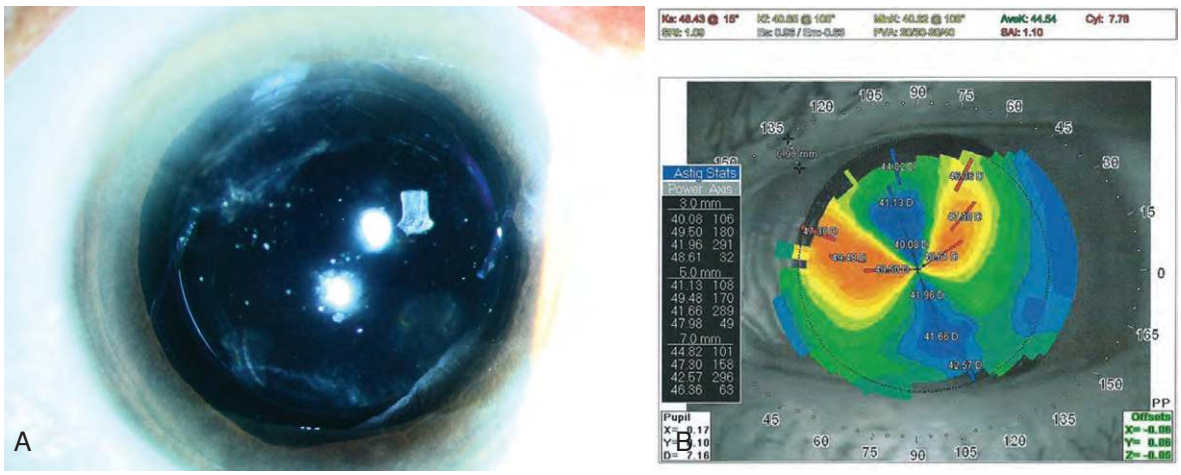

Fig. 26.1 (A) Anteriorly placed femtosecond laser cataract primary incision caused by eccentric positioning of the eye during docking with the laser, resulting in irregular astigmatism. (B) Topographic irregular astigmatism from anterior femtosecond laser wound positioning. This case highlights the importance of care with every step to ensure optimal patient outcomes.

material. After initiating hydrodissection, the nucleus can be tapped downward or tilted gently to allow posterior gas bubbles to escape forward. This technique prevents excessive stretching of the posterior capsule by trapped fluid and air bubbles. As an alternative, the lens can be split within its central cleavage planes through which the gas bubbles can then escape.

POTENTIAL PITFALLS

- Capsular block:
  - Can happen after the femtosecond capsulotomy is performed when gas bubbles created by the photodisruption migrate posterior to the lens. With these trapped gas bubbles, conventional hydrodissection can overly distend the posterior capsule and cause a posterior capsule rupture (PCR).
  - Avoid this by gently rocking the nucleus back and forth within the capsular bag before gentler hydrodissection.[15]
- Lens fragmentation pattern selection is crucial.
  - A more complex grid pattern extending to the area of the capsulotomy edge can reduce visualization of the hydrodissection cannula tip.
  - Limiting the lens fragmentation within the capsulotomy perimeter will improve visualization of the capsulotomy edge.
  - With dense lenses, a wider grid pattern may be preferable, and trypan blue dye can facilitate capsular visualization, such as in cases of corneal opacity or suspected incomplete capsulotomy.
- Cortical removal can be more challenging after FLACS compared with manual phacoemulsification.
  - Comparison of surgical cortical removal times with bimanual irrigation and aspiration showed a slight time advantage for cortical removal in FLACS cases compared with manual phacoemulsification.[1]
  - Difficulties with cortical removal can sometimes be overcome through the use of bimanual irrigation/aspiration, which is better suited for removing subincisional cortex.
  - Aspirating the cortical material in a circumferential pattern reduces tension on the zonules during cortical stripping, which is particularly important in cases associated with zonulopathy.

LEARNING CURVE OF FLACS

As with the addition of any surgical technique, there is a learning curve associated with not only the surgeon, but also the entire specialty as collective experience with the technology leads to discoveries and improvements. Over the last decade FLACS technology has matured, with advances in parameters, software, and patient interfaces leading to safer and more effective procedures. Nagy et al. showed greater challenges with earlier cases, in part because of using earlier versions of the technology.[17] Bali et al. studied surgeon learning curves and reported a decrease in docking attempts, pupillary miosis, and incomplete capsulotomies after the first 100 cases performed.[1] Both of these groups adjusted their techniques and machine settings throughout the course of their experience, which improved the experience and reduced complications over time.

AVAILABLE PLATFORMS

There are currently five available femtosecond laser platforms approved for the use in cataract surgery within the United States. Three lasers gained FDA approval in 2010, including the LenSx (Alcon), Catalys (Johnson & Johnson) and the LensAR (LensAR). Later, the Victus (Bausch and Lomb) and the Zeimer lasers entered the marketplace.

The various platforms can be differentiated based on their FDA approvals and capabilities, the PI, their size and portability, imaging, docking, and type of patient bed. Table 26.1 below illustrates and compares these key differentiating factors.

COMPARISON OF FLACS AND TRADITIONAL PHACOEMULSIFICATION

A multitude of studies have attempted to compare the outcomes of FLACS with traditional phacoemulsification. A common limitation of these studies is the difficulty in masking patients and surgeons to the procedure being performed without an effective sham treatment. Many studies did not effectively randomize patients because of the need for patients to pay the additional cost of the laser treatment. In addition, it is unclear if the results achieved with one laser system can be generalized across other platforms. Thus many published studies have potential bias or confounding variables.

Phacoemulsification Energy

Several studies have shown a significant decrease in the phacoemulsification energy required to disassemble the nucleus, with some studies showing several cases with zero phacoemulsification time after FLACS.[1–4] This is one of the primary advantages of FLACS because it prefragments the nucleus and allows some of the smaller pieces to be simply aspirated with minimal phacoemulsification energy. A meta-analysis has shown that this is not necessarily because of a decrease in phacoemulsification time, but because of a decrease in the phacoemulsification energy used while the handpiece is activated.[24]

Endothelial Cell Loss

One hypothetical benefit of femtosecond laser surgery has been reduced corneal endothelial damage associated with less phacoemulsification

TABLE 26.1 Approved Femtosecond Laser Cataract Flatforms in the United States

	Catalys	LenSx	LensAR	Victus	Zeimer
Corneal incisions	Yes	Yes	Yes	Yes	Yes
Arcuate incisions	Yes	Yes	Yes	Yes	Yes
Anterior capsulotomy	Yes	Yes	Yes	Yes	Yes
Lens fragmentation	Yes	Yes	Yes	Yes	Yes
Corneal flap	No	Yes	No	Yes	Yes
Patient interface	Nonapplanating suction ring	Curved applanation	Nonapplanating		Nonapplanating
Imaging	3D SD-OCT, video microscope	3D SD-OCT, video microscope	3D ray tracing CSI	3D SD-OCT, video microscope	3D SD-OCT

CSI, XXX; *3D*, three-dimensional; *SD-OCT*, spectral-domain optical coherence tomography.

Donaldson Kendall E, et al. Femtosecond Laser-Assisted Cataract Surgery. *J Cataract Refract Surg*. November 2013;39(11):1753–1763. https://doi.org/10.1016/j.jcrs.2013.09.002

energy. Most studies have reported a trend toward less endothelial loss with FLACS compared with traditional phacoemulsification, but this was not statistically significant in all studies.[1–4,28] Some studies noted decreased corneal edema and central corneal thickness in the early postoperative period compared with traditional phacoemulsification.[30,31] Other studies have shown no statistical difference in endothelial cell loss between the two techniques, especially with longer follow-up times.[32–35] A study by Abell et al. examined the effect of femtosecond corneal incisions and found that cases with femtosecond corneal incisions had greater endothelial cell loss and that the cohort with the least endothelial loss were those with FLACS with manual corneal incisions.[36] Evidence suggests that there is a small, measurable difference in initial endothelial cell loss, which is favorable for FLACS over PCS, but that this may not be clinically significant in the long term.

Capsular Complications and Vitreous Loss

Several studies showed that there was a higher risk for anterior capsular tags and tears with FLACS compared with manual phacoemulsification alone, a risk common to multiple platforms studied.[37–39] However, a later meta-analysis by Chen et al. showed no difference in anterior capsular tears, possibly because of increased surgeon experience.[40]

Similarly, there has been mixed experience reported for PCR in the setting of FLACS. A 2016 meta-analysis by Popovic et al. found a significantly higher risk for posterior capsule tears in FLACS cases compared with traditional phacoemulsification.[41] However, the 2020 femtosecond laser-assisted versus phacoemulsification in cataract surgery (FEMCAT) study showed no significant difference between FLACS and traditional phacoemulsification in terms of PCR or vitreous loss.[42] A Cochrane review also showed no conclusive difference in anterior or posterior capsule complications.[43] Of note, one study of a community private practice group showed decreased incidence of vitreous loss for all surgeons after conversion from manual phacoemulsification to FLACS.[44] The incidence of both anterior and posterior capsule tears appears lower in more recent studies, suggesting improvements in laser parameters and surgeon adjustment.

Capsulotomy Size and Centration

Several studies have shown that the size, circularity, capsular overlap, and centration of a FLACS capsulotomy exceeds the reproducibility of a manual capsulotomy.[45–50] Although the clinical necessity of this is unclear, certain complex lens designs, such as multifocal IOLs, may demand greater precision for optimal outcomes. Some studies have shown a statistically significant decrease in IOL tilt, although the magnitude of the effect is small and the clinical significance is unclear.[51,52]

Visual and Refractive Outcomes

A Cochrane review of the literature found no evidence for a significant difference in uncorrected or best corrected distance visual acuity when comparing FLACS with phacoemulsification alone.[53] Most other studies have found similar findings.[54–56] The precision of the capsulotomy created by the femtosecond laser could hypothetically limit IOL tilt and promote more evenly distributed capsular contraction around the IOL, which could achieve more predictable effective lens positioning. In several studies, the spherical mean absolute error (MAE) was shown to be significantly lower in FLACS cases compared with traditional phacoemulsification, with a higher percentage of patients within 0.5 and 1.0 D of the refractive target.[57–61] However, other studies have shown no difference in refractive outcomes or even superiority of phacoemulsification alone over FLACS.[62–64] In cases in which FLACS outperformed PCS, the average difference in MAE in these studies was less than 0.25 D, which, although statistically significant, is clinically insignificant.

Postoperative Inflammation

FLACS has different effects on postoperative AC inflammation compared with phacoemulsification alone. One study showed that AC flare was significantly lower in FLACS cases 1 day and 4 weeks postoperatively and that decreased flare was significantly correlated with decreased phacoemulsification energy and fluid used.[65] Another study also showed lower rates of cell and flare postoperatively.[66] The decreased amount of phacoemulsification ultrasound energy required to remove the lens may explain this decrease in AC inflammation.

Despite trends of limited postoperative inflammation, there are still inflammatory cascades that are triggered by the femtosecond laser. Studies by Schultz et al. have shown that there is significant AC prostaglandin release during FLACS, particularly after the capsulotomy step.[67] These increases in prostaglandin release may provoke miosis immediately after the femtosecond laser is performed. Further investigation by this group and others have shown that NSAID pretreatment significantly lowers aqueous prostaglandin levels and improves control of pupillary miosis after FLACS.[68]

The known effect of prostaglandin release associated with FLACS has also led investigators to inquire about the risk for cystoid macular edema (CME), which is also associated with increased prostaglandin levels during cataract surgery. When comparing FLACS and traditional phacoemulsification CME rates have been similar in most studies.[69–71] A Cochrane review and meta-analysis both showed a trend toward less CME in FLACS cases compared with phacoemulsification alone, which was not statistically significant.[72,73] There was one study by Ewe et al. that showed a statistically higher incidence of CME in FLACS compared with phacoemulsification (0.8% vs. 0.1%), however, the authors attributed this to a software update with an increase in laser energy settings.[74] Further study is needed to determine whether there is a clinical difference.

Elevated Intraocular Pressure

Major randomized trials have not found a statistically significant difference in intraocular pressure (IOP) elevation after FLACS compared with traditional phacoemulsification.[75,76] However, one by Ewe et al. showed a significantly significant increase in postoperative IOP elevation in the FLACS group (3.04% vs. 0.79%), all of which resolved with short-term medical treatment.[77]

THE UTILITY OF FLACS IN COMPLEX CASES

Dense Nucleus

FLACS has specifically shown a reduction of endothelial cell loss in hard nucleus cases compared with traditional phacoemulsification.[78] Another series also showed less phacoemulsification energy, postoperative inflammation, faster return to preoperative central corneal thickness, and faster stabilization of postoperative visual acuity.[79]

Shallow Anterior Chamber

In one study comparing outcomes in eyes with shallow AC, patients randomized to FLACS or conventional phacoemulsification showed significantly lower phacoemulsification energy, central corneal thickness, reduced AC inflammation in the early postoperative phase, and faster visual recovery for the FLACS group compared with the traditional phacoemulsification group.[80]

Corneal Endothelial Dystrophy

As discussed earlier, studies have shown a trend toward reduced endothelial cell loss in large cohorts, and this finding has been replicated

in cases of Fuchs endothelial dystrophy as well. In a comparative case series by Yong et al., patients with Fuchs dystrophy who underwent FLACS had lower endothelial cell loss compared with traditional phacoemulsification in both mild and moderate/dense lens cases.[81] One limitation of this study is that it was not randomized, and the cohort that underwent FLACS had significantly lower endothelial cell density preoperatively. The findings would still imply that even for these patients at higher risk, FLACS achieved outcomes that exceeded expectations of traditional phacoemulsification.

Traumatic Cataract, Subluxed Lenses, and Zonular Dialysis

In cases of previous trauma or subluxation of the crystalline lens, performing a manual capsulorrhexis can be challenging without the normal countertraction of the zonules. Femtosecond laser has been trialed in some of these extreme cases with good results. For example, Conrad-Hengerer et al. described a case of an intralenticular metallic foreign body in which a femtosecond laser capsulotomy was able to be performed safely and the anterior capsular disc removed with the foreign body embedded.[82] In these traumatic cases, using the femtosecond laser before entry of the AC with an instrument can limit the risk for worsening any preexisting weaknesses in the capsule, which may lead to a radial tear.

White Cataract

One of the more challenging cases for even experienced cataract surgeons is the white cataract, which can be intumescent and have increased intralenticular pressure. With the advent of FLACS, surgeons have used the speed of the femtosecond laser to rapidly decompress the AC pressure to produce similar results to a standard femtosecond laser-assisted capsulotomy. Two studies by Chee et al. and Conrad-Hengerer et al. showed that the majority of cases were able to achieve complete capsulotomies, although there was a risk for tags and incomplete capsulotomy in some cases.[83] Another study by Titiyal et al. showed that, compared with standard manual capsulorrhexis, femtosecond capsulotomies were more circular and uniformly sized.[84] In both cohorts there was one radial anterior capsular tear (1/40) without posterior extension, implying that, although FLACS is faster, it does not eliminate the risk for radial tears. In addition, there were capsular microadhesions in about half of the FLACS cases, which were able to be converted to circular capsulotomies with manual assistance. The authors attributed capsular tags to the presence of white capsular fluid that leaked into the AC during the capsulotomy step. Schulz et al. published a technique using a minicapsulotomy to release capsular fluid, followed by redocking after the capsular fluid had been cleared so that a standard-sized capsulotomy could then be performed. However, this technique still had residual tags in a third of cases.[1] Although the femtosecond laser offers an additional tool for these complex cases, it still requires vigilance on the part of the surgeon to address capsular problems as they arise.

Multifocal and Accommodative Intraocular Lenses

Many surgeons prefer to implant multifocal IOLs with the aid of FLACS, including corneal relaxing incisions. Despite this, there is surprisingly little literature comparing the outcomes of multifocal lenses with and without FLACS. One earlier study by Lawless et al. compared the results of placement of a diffractive bifocal lens and found comparable refractive and visual outcomes with or without the use of FLACS.[86] A more recent study used aberrometry to compare multifocal IOL outcomes and demonstrated significant improvement in internal tilt and higher order aberrations and patient satisfaction in the FLACS cohort over traditional phacoemulsification.[87] A large comparative study by Ang et al. showed no difference between FLACS and traditional phacoemulsification in refractive outcome, UDVA, UNVA, or CDVA, including a subgroup analysis for multifocal lenses, multifocal toric lenses, or accommodative lenses.[88] Although many surgeons believe that FLACS gives them more predictability to their outcomes in these advanced lens technology cases, the data do not support a clinically significant difference.

Pediatric Cataract

Pediatric cataract cases are challenging for many reasons ranging from the concomitant conditions associated with them, the requirement for general anesthesia, the long-term amblyopia treatment, and the notable technical difficulties that occur during surgery. FLACS helps overcome two of the primary technical issues that arise with pediatric cataracts. The capsule is more elastic in children, resulting in unintentional enlargement of the capsulotomy. This may lead to lens displacement and the inability to accurately predict the effective lens position. FLACS can make a perfectly sized capsulotomy that can be programed into the laser based on the Bochum formula, accounting for the age-controlled elasticity of the lens capsule to achieve the correct size capsulotomy.[1] In addition, the femtosecond laser can create a precise posterior capsulotomy, allowing the surgeon to circumvent the high rate of posterior capsule opacification, which occurs in the early postoperative period.[1]

COST EFFECTIVENESS OF FLACS

Given the additional cost of FLACS compared with traditional phacoemulsification, increased interest has been placed on justifying this additional cost to the healthcare system. In the large randomized FEMCAT study, the authors found FLACS added an additional cost of around 305 euros and was less effective by their measures than traditional phacoemulsification.[91] An earlier study by Abell et al. also struggled to find cost effectiveness within their model and proposed that an advantage would require either a significant decrease in the cost of FLACS or a larger improvement in outcomes over phacoemulsification alone.[92] Providing cost-effective benefits to cataract surgery remains a challenge for FLACS.

SUMMARY

The femtosecond laser has become a useful tool for many cataract surgeons, particularly for complex cases and for the correction of astigmatism with limbal relaxing incisions. A multitude of studies suggest that FLACS requires less phacoemulsification energy and produces less trauma to the anterior segment, although the long-term benefits and the cost effectiveness of the intervention remain debatable. Further frontiers for FLACS include integration between the office and the operating suite, allowing the creation of specific surgical plans that would ultimately be executed with the femtosecond laser through the guidance of intraoperative aberrometry. We are fortunate to have continually evolving technology in cataract surgery providing us with more advanced tools to provide the best outcomes for our patients.

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27

Cortical Removal

Steven H. Dewey

CONTENTS

KEY POINTS

- Cortex remaining after nuclear removal is variable in amount and adherence.
- Access to remaining cortex is particularly challenging in the subincisional space.
- Techniques and instruments are available to improve access to any remaining cortex.
- Reduction in capsule damage is achieved with refined silicone and polymer tips.

INTRODUCTION

Removing cortex is an afterthought. After spotting a potentially challenging case in the office, planning a change to one's surgical approach is straightforward. But does one plan a cortical removal strategy? During the case, and only then, does one have the chance to see the character and amount of remaining material.

Adding to the potential complexity, the things that make a case challenging—small pupils, loose zonules—also affect the things that prestage cortical removal. Hydrodissection is simply difficult in the face of a shallow anterior chamber (AC) with potential iris prolapse. In pseudoexfoliation cases, one may be appropriately hesitant to rotate the nucleus. Deploying a capsular tension ring (CTR) will trap cortex.

Generally, cortical removal is one of the safer steps in phaco-no sharp blades or needles to induce iatrogenic damage. However, before the availability of silicone-tipped handpieces, between a quarter to a half of capsule ruptures occurred during cortical removal[1–3] (Video 27.1).

CORTEX: MANAGING THE INCONSISTENCIES

To advance one's technique, it can be helpful to separate the components of cortical removal into the following:

- Access
- Acquisition
- Manipulation
- Removal

A standard coaxial irrigation and aspiration (I/A) handpiece provides reasonable access to cortex through the primary incision: irrigation maintains a deep AC, and the tip reaches 270 degrees opposite the incision. An angled tip improves the range of access, and an angled silicone-tipped handpiece can allow aspiration closer to the capsule with less risk for rupture.[4] However, a poorly constructed primary incision that fails to maintain a stable AC or prevent iris prolapse will impede efficient I/A. Access can be improved with the use of biaxial I/A.

The objective of acquisition is to engage the cortex with enough vacuum to gain hold, but not so much that the material is aspirated before manipulation can take place. The tip of the handpiece, with the aspirating port facing up, is placed under the anterior capsule distal to the incision. Occlusion of the 0.3-mm lumen is easily achieved, and precise foot pedal control allows one to acquire the wedged-shaped section of cortex.

Manipulate the cortex by peeling the material toward the center of the pupil for aspiration away from the iris. Repeat this around the circumference of the capsulotomy. Effective manipulation and removal depend on both the adherence of the cortex to the capsule and the cortex to itself. Greater amounts of cortex adherent to itself and not the capsule may be easily removed. In contrast, a small amount of cortex that is very adherent to the capsule (as in a corticocapsular adhesion[5]) may be exceptionally challenging to remove.

A visually satisfying technique involves pulling the wedge centrally and simultaneously moving the tip in a circumferential fashion along and under the edge of the capsulotomy. Starting in or near the subincisional space, this "hurricane" maneuver may allow the entire cortical bowl to be removed in one step.[6] This effect is dependent on the cortex being poorly adherent to the capsule, self-adherent enough to bring the subsequent material forward, and soft enough to collapse into the tip's lumen. One distinct advantage of the "hurricane" maneuver is that the tangential stripping motion appears to reduce stress to the zonules compared with standard centripetal stripping.

Denser cortex—a cortical wedge, or outer epinuclear material—is freed from the capsule but is resistant to simple aspiration, which presents a challenge. One can use a second instrument to crush the material held in place at the tip of the aspirating port or displace it out of the incision using viscoelastic.

A larger cortical wedge or denser epinuclear fragment may require reinsertion of the phaco needle for evacuation. The fragment may be close to the incision, allowing for the needle to contact the fragment

without fully inserting the tip and irrigating ports. Be careful to fully insert the irrigation ports into the AC to maintain chamber depth and to not aspirate the capsule. A blunt instrument to tent the capsule posteriorly also helps avoid capsule engagement. Likewise, intraocular lens (IOL) placement before removing this last portion of cortex will also protect the posterior capsule.

TECHNIQUES FOR ROUTINE CHALLENGES

Subincisional Cortex (Table 27.1)

Access to subincisional cortex is almost impossible using a standard straight I/A coaxial handpiece without rotating an active aspirating port into a potentially dangerous posterior direction. Angled tips, especially angled silicone tips, are tremendous improvements in efficiency and safety, but they do not access this space directly.

TABLE 27.1 Options for Accessing and Removing Subincisional Cortex

- Effective hydrodissection
- Aspiration techniques/devices
  - Metal or silicone-tipped I/A handpiece
  - Biaxial I/A system
- Irrigation techniques/devices
  - Straight cannula through main incision or side port
  - J-cannula through main incision
- Physical displacement
  - IOL rotation
  - Viscoelastic dissection

Orienting an angled tip slightly diagonally and posteriorly, just below the edge of the capsulotomy, comes as close to direct subincisional access as possible. When attempting this, it is critical to maintain the foot pedal in position one to maintain irrigation. This inflates the anterior segment and distends the posterior capsule away from the aspirating port. Gently depressing the foot pedal into position two will allow occlusion of the aspirating port with the cortex directly under the capsulotomy. Pulling this material once occlusion is achieved may strip the subincisional cortex effectively. With practice, this can be the first step of the hurricane maneuver previously described.

Biaxial Irrigation and Aspiration

As opposed to coaxial I/A in which both irrigation and aspiration are on one device, biaxial I/A allows for separation of irrigation from the aspiration device.[7–9] This requires two smaller (~1.0-mm) paracentesis-type incisions, approximately three clock hours apart, to allow for bimanual approach with the right and left hands. Using a biaxial handpiece through the much larger primary incision will cause significant incisional leakage and potential shallowing of the AC. Each of these two separate incisions allow for access to cortex for 270 degrees opposite each incision. To preserve the small water-tight incision and prevent corneal distortion known as *oar-locking*, an hourglass-shaped incision can be created by entering slightly diagonally and then realigning the blade on retraction to create an X-shaped incision (Kenneth Rosenthal, MD, personal communication, circa 2001) (Fig. 27.1).

Irrigation is typically inserted with the nondominant hand and aspiration with the dominant hand. The access to cortex opposite the

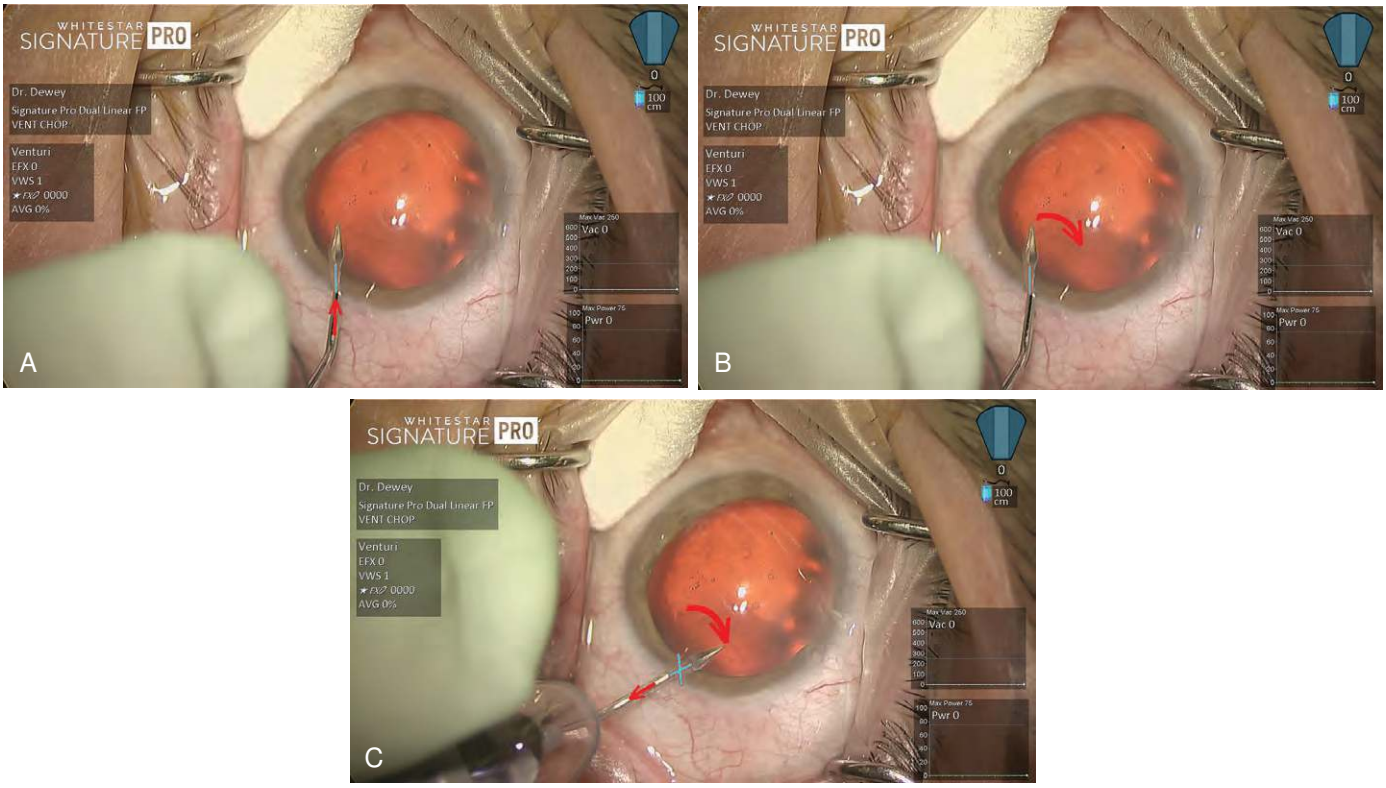

Fig. 27.1 (A) The MVR blade is inserted fully on a slight diagonal approach. (B) With the shaft stable in the incision, the tip of the blade is redirected approximately 45 degrees. The shaft will not widen the incision. (C) The MVR blade is withdrawn along the new orientation. The resulting incision is wider both internally and externally, with the "waist" of the incision the narrowest. This configuration allows for the greatest instrument manipulation with the least corneal distortion and wound leakage.

Biaxial Irrigation and Aspiration

- Each incision provides 270 degrees of access to cortex opposite the incision.
- Increasing separation of the incisions improves access. Two clock hours apart is insufficient, four clock hours apart is ideal, and six clock hours apart maximizes the range of access to cortex but is impractical.
- The irrigating handpiece can retract the iris or capsule for improved aspirating tip access.

Pitfalls of Biaxial Irrigation and Aspiration

- Typical biaxial instrument ports are too small for IOL insertion; enlargement of one of the biaxial ports or creation of a separate larger incision is necessary for IOL insertion.
- For phacoemulsification, the range of available instruments is limited compared with standard coaxial techniques.
- The Intrepid Transformer handpiece provides outstanding access to the subincisional space through the detachable aspiration port, but the remaining irrigation handpiece does not allow for iris or capsule retraction because of the limitations of size.

incision is accomplished as it is with coaxial I/A. In small pupil and intraoperative floppy iris syndome cases, the irrigating handpiece can be used to retract the iris or capsule to provide better access for the aspirating handpiece to challenging areas. The cannulas are switched to the alternate incision to access the remaining cortex.

Biaxial aspiration has typically required dedicated instrumentation. A recent innovation is an I/A handpiece that starts as a coaxial instrument but that can be disengaged into separate irrigation and aspiration instruments during the procedure as needed (Intrepid Transformer IA Handpiece[10]).

Irrigate Then Aspirate: J-Cannula Irrigation[11]

Cortical removal, particularly subincisional cortical removal, was far riskier in the early 1990s. There were no silicone sleeves to protect the capsule, no biaxial techniques, and, to make matters worse, the manufacturing of metal I/A tips was lacking in refinement, leaving sharp burrs inside aspiration ports[4] (although this problem isn't completely remedied yet[12–14]).

While assisting, I observed a surgeon attempt to aspirate cortex using a J-cannula but instead aspirated the capsule. He refluxed to disengage the capsule, and this wave of fluid unleashed a large flourish of subincisional cortex. Failing to recognize the surgeon's frustration, I calmly mentioned that the technique for clearing subincisional debris was really fascinating. The observation was not well received at the time, but it did allow me to think more about how to manipulate subincisional cortex before accessing it.

A 26-g McIntyre-Binkhorst J-cannula is firmly secured to a Luer-Lock 5-cc syringe filled with balanced salt solution (BSS). The short leg of the "J" has to be flared away from (not parallel to) the long leg. This is a bimanual technique in which the dominant hand controls the plunger and the nondominant hand maintains the barrel of the syringe (Video 27.2).

To insert the cannula, keep the plane of the cannula parallel to the plane of the incision, short leg of the "J" first (Fig. 27.2). The chamber typically maintains stability. When the cannula tip is adjacent to the capsule during irrigation, the shaft of the cannula will open the incision to allow fluid egress. When withdrawing the cannula, gently irrigate and reverse the insertion step.

Using this technique for subincisional cortex only, start by aspirating all of the cortex for 270 degrees opposite the incision. Once this material is cleared, place the tip of the cannula between the remaining subincisional cortex and the capsule and irrigate while gently moving the tip from side to side. Do not irrigate too vigorously. The cortex should hydrate, and, with carefully controlled irrigation pressure, the cortex is displaced from the subincisional space. This facilitates any conventional aspirating technique for cortical cleanup.

With practice, one can use the J-cannula to displace the subincisional cortical material before aspirating *any* of the cortex. This can be performed as your surgical scrub is converting from phaco to I/A.

Small amounts of cortex will frequently flow out of the incision along with the irrigating fluid. This is a function of the amount of cortex, the fluid vortex created by the irrigation, and the position of the shaft of the cannula relative to the plane of the incision. With experience, more cortex can be dislodged from the capsule and flushed directly out of the incision.

Three potential problems may arise during this technique:

- First, avoid emptying the syringe before removing the J-cannula from the incision. Doing so may make it difficult to remove the cannula without catching the iris or capsule.
- The second is exceptionally rare and occurs when a sudden patient movement toward the incision allows the cannula to catch on the distal capsule around the equator. The author prefers taping the patient's

J-Cannula Irrigation Surgical Technique

- A 26-g J-cannula is attached to a 5-cc Luer-Lock syringe, or a 30-g J-cannula is attached to a 3-cc Luer-Lock syringe.
- The short leg of the "J" is advanced into the incision until the tip is in the anterior chamber.
- Once the tip is in, the cannula is rotated until the shaft is parallel with the incision.
- The tip of the cannula is lowered into contact with the posterior capsule. Irrigation should be performed at this point to keep the chamber inflated as the shaft of the cannula opens the incision.
- The tip of the cannula is placed between the cortex and capsule to direct a fluid wave into the corticocapsular plane. This is the same anatomic plane for hydrodissection but without the bulk of the nucleus to impede flow or access.
- Irrigate until the cortex is freed and sufficiently displaced from the capsular fornix for aspiration in the iris plane.
- Continue with lower pressure irrigation to elevate the tip away from the capsule, and rotate the cannula to allow the "J" to become parallel with the incision.
- Retract the "J" to the incision, and remove it from the incision by engaging the curve of the "J" with the internal incision and rotating the cannula in the direction opposite the tip.

Advantages to J-Cannula Irrigation

- Any amount of cortex can be irrigated from the capsular bag to facilitate aspiration.
- At no time is an aspirating port placed in a region of poor visualization, such as the subincisional space.
- The irrigation is atraumatic to the zonules and avoids the traction that can occur when adherent cortex is aspirated.
- Cortex can be flushed out of the eye with sufficient experience.
- Posterior capsule polishing is achieved simultaneously.

Pitfalls to J-Cannula Irrigation

- J-cannula irrigation is a bimanual technique that requires a cooperative patient and steady eye.
- Emptying the syringe before removing the cannula may necessitate viscoelastic inflation of the anterior chamber.
- The J tip may inadvertently hook the iris, capsulotomy, or incision. This includes the distal capsule at the equator under rare circumstances.
- Distorting the incision with the irrigating instrument can cause iris prolapse.

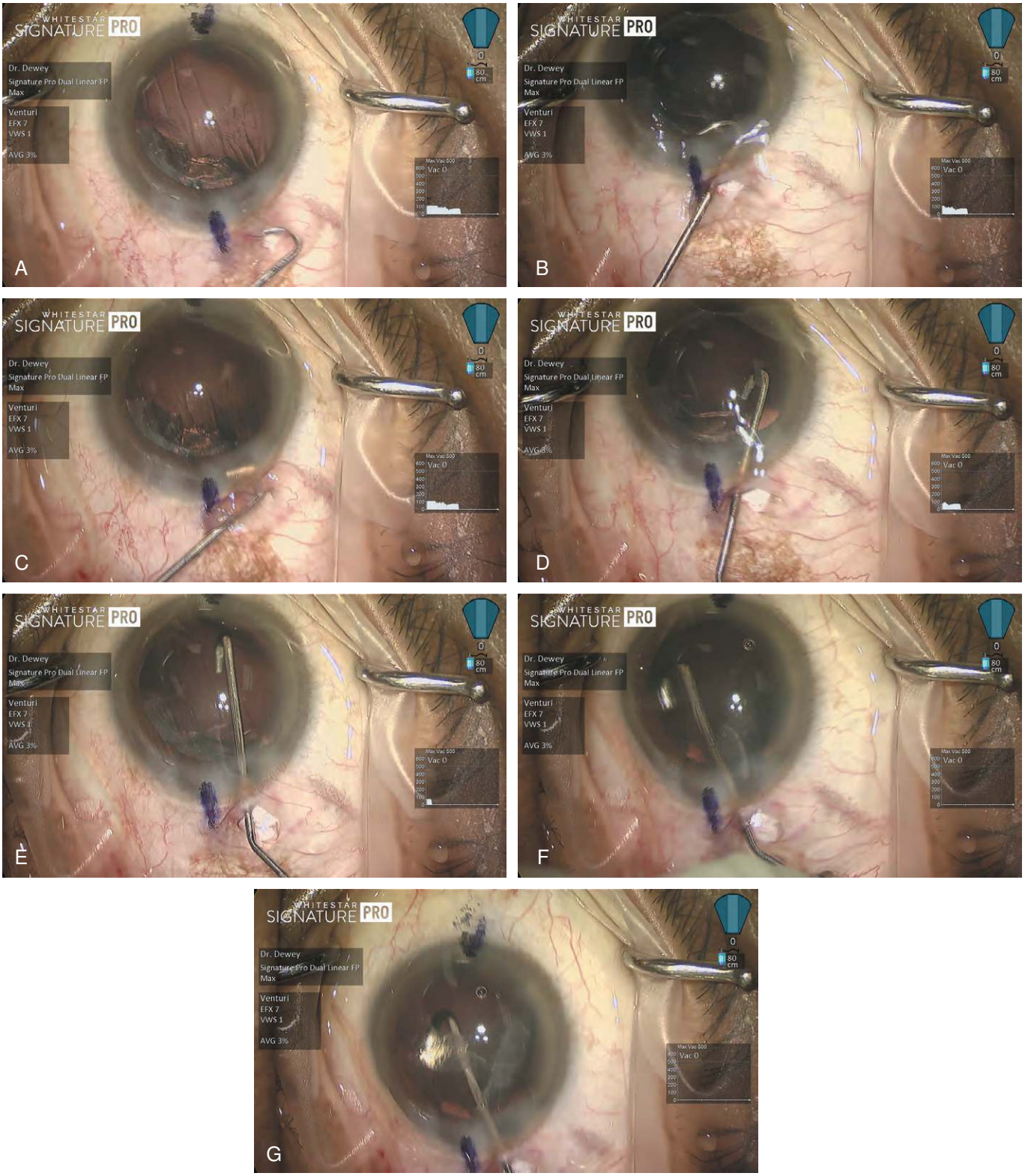

Fig. 27.2 (A) The J-cannula is twisted to orient the cannula parallel to the incision. (B–C) The tip of the cannula is inserted into the incision, rotating the tip until it is inside the anterior chamber. (D–E) The shaft of the cannula is rotated to orient the "J" vertically, bringing the tip into contact with the posterior capsule. (F–G) Gentle pressure is applied to the plunger, directing the flow of BSS against the posterior capsule. By gently sweeping the tip from side-to-side, the irrigation flow displaces the subincisional cortex. (H–I) By keeping the shaft of the cannula oriented with the tip of the cannula against the posterior capsule, the incision remains open, and the irrigating flow carries the cortex out of the eye. (J) The shaft of the cannula is rotated to bring the "J" parallel to the incision. (K–L) The cannula is twisted to remove the tip of the "J" last, and withdrawn from the incision. With the "J" parallel to the incision, the incision remains closed and the chamber remains stable.

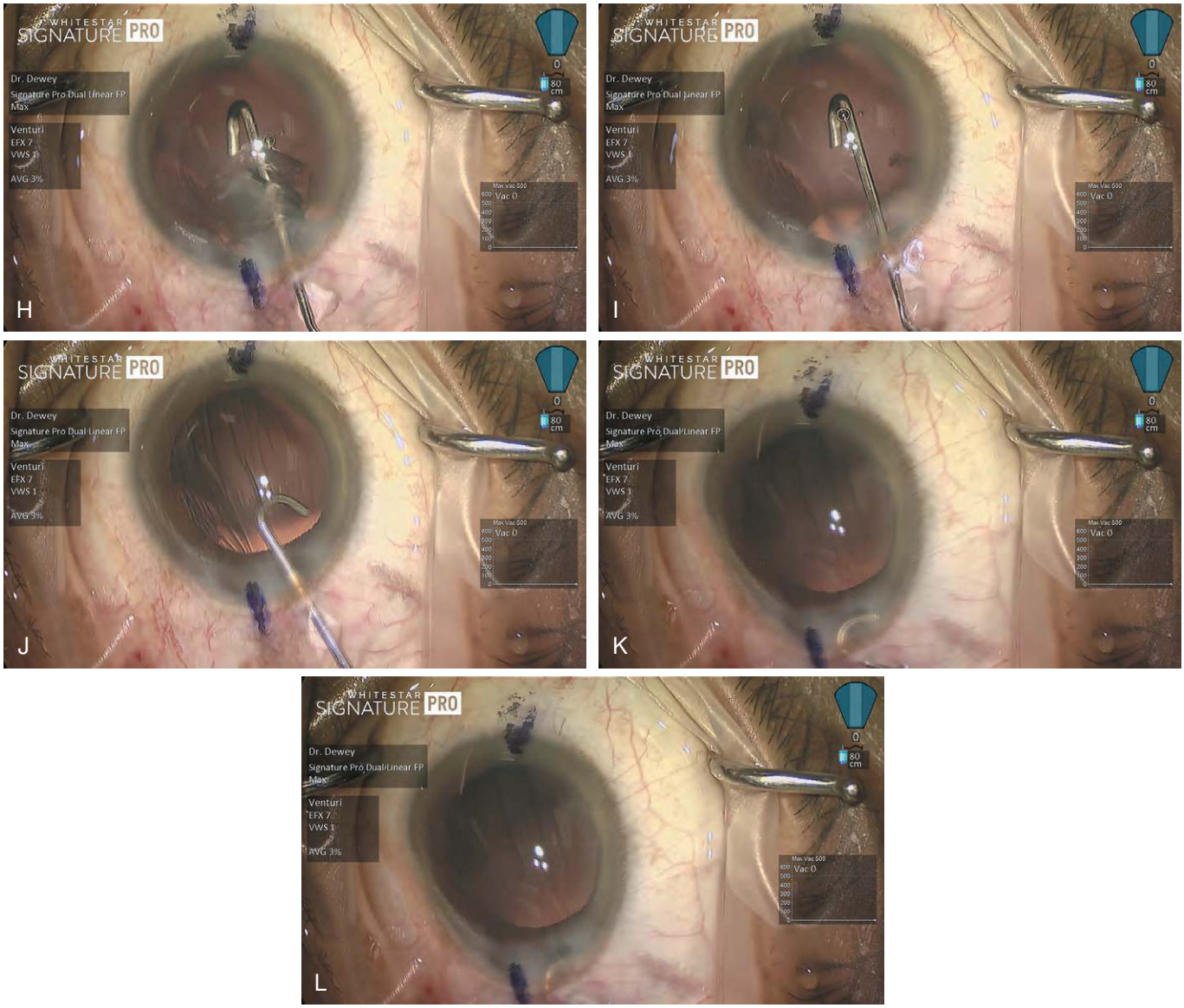

Fig. 27.2 Cont'd

head to avoid this risk. Both situations are remedied by inflating the AC with viscoelastic using the nondominant hand through the sideport incision, and rotating the J-cannula out of its trapped position.

- The third arises from too much material leaving the incision at once and catching the iris in the process. Although the potential for iris prolapse from misdirected irrigation always exists, being mindful of this will prevent this problem. Observe both the action of the cortex and the relationship of the iris to the incision. If prolapse appears imminent, simply stop the irrigation, retract the J-cannula, and perform standard I/A. Repeat the process, and reposit the prolapsing iris with viscoelastic as necessary.

If the iris does prolapse, stop irrigating. Depress the incision to equalize the pressure, and slide the shaft of the cannula toward the area of prolapsing iris. This typically allows the iris to return to its normal configuration. Take care to inflate the AC before attempting removal of the cannula to avoid hooking the iris.

Continuing to monitor the cannula shaft position will expedite the learning curve. With experience, even the distal 180 degrees of cortex can be removed by angling the cannula tip.

CAPSULE POLISHING

J-cannula irrigation effectively polishes the posterior capsule with hydrostatic force. The tip of the cannula is placed against the capsule, and the irrigating fluid is simply directed toward the capsule. Radial wisps of cortex will disappear. By sweeping into the equatorial fornices of the capsule, material too peripheral to visualize will be displaced. This can also be used to dissect free a posterior subcapsular plaque that is not overly adherent.

CORTICAL REMOVAL AND FEMTOSECOND LASER-ASSISTED CATARACT SURGERY

When using a femtosecond laser, one quickly notices that there is a lot more cortex, and it is unusually adherent. There are two reasons for this: (1) Lens segmentation creates a pneumatic delineation, with this effect being proportional to the degree of segmentation performed. This potential space prevents the hydrodissection wave from remaining in the corticocapsular plane. (2) The cutting for the capsulotomy

Advantages to Direct Irrigation of Cortex in FLACS

- Any amount of cortex can be irrigated from the capsular fornix for easier aspiration.
- The aspirating port is visualized at all times.
- The irrigation is atraumatic to the zonules and avoids the traction that can occur when adherent cortex is aspirated. This is important with FLACS in which the cortex is especially adherent because of the changes in the effects of hydrodissection.

Pitfalls to Direct Irrigation of Cortex in FLACS

- Unlike standard cataract surgery in which removal of the nucleus assists in the staging of cortical removal, in FLACS cases, increased integrity of the cortex improves the facility of this technique. (Less disruption of the cortex during nuclear removal improves the usefulness of the direct irrigation technique.)
- Posterior capsule polishing is required to avoid significant posterior capsule opacification.

takes place anterior and posterior to the anterior capsule, creating a fused gray layer of cortex adherent to the underside of the capsulotomy.

In femtosecond laser-assisted cataract surgery (FLACS) cases, after the nucleus is removed, a straight 27-g cannula tip can be placed against or under the capsulotomy, across from the incision, and between the capsule and cortex[15] (Fig. 27.3). Simple irrigation will access the corticocapsular plane because it does in standard hydrodissection. The residual body of cortex will balloon out of the capsule, forming a distinct "inner circle." The cortex can be simply aspirated (Video 27.3).

Most frequently, there is a discontinuity in cortex, and the "inner circle" is partial or absent. The cortex can be irrigated in a sequential fashion by placing the tip under the capsulotomy (Fig. 27.4). Once the cortex is loosened from the anterior capsule, any removal technique will be useful. The author prefers the J-cannula technique at this stage because of the convenience of simultaneously removing cortex and polishing the posterior capsule.

STRATEGIES FOR STUBBORN CORTEX

Physical displacement of cortex may be necessary to achieve adequate cortical removal as a result of any number of circumstances. Although this is infrequent, physical displacement can be accomplished in a number of ways (Video 27.4).

Adherent cortex can be loosened by rotating the IOL within the capsular bag. The stiffer haptics of three-piece IOLs may be more effective at doing so. Distending the capsular bag with either viscoelastic or infusion from an AC maintainer is necessary to prevent the IOL from tucking and tearing the capsule during rotation. The author's preference is to rotate the IOL clockwise with a Lester hook at the optic-haptic junction. IOL rotation loosens the residual cortical material to facilitate repeated attempts at aspiration. For subincisional cortex the IOL can be displaced peripherally to act as a barrier between the capsule and I/A tip to prevent inadvertent aspiration of the capsule.

Adherent cortex in the visual axis can be difficult to access or acquire. Place the tip of the viscoelastic cannula gingerly against the capsule, and use the viscoelastic to create space between the cortex and capsule (Figs 27.5 and 27.6). Continuing capsule inflation displaces the cortex anteriorly and creates space for IOL insertion as appropriate.

An older option was to place the IOL and then remove the cortex. This protected the posterior capsule from microscopic burrs on the metal I/A tip.[16] In cases of localized zonular deficiency, this allows the IOL and CTR to be placed before tugging on stubborn cortex.

Physical Displacement of Stubborn Cortex

- If the posterior capsule is relatively clear, place the IOL in the bag. Rotating the IOL will allow the haptics to loosen and displace the remaining cortical material.
- If adherent cortex is covering the posterior capsule, use viscoelastic to separate the cortex from the capsule.
- If the zonules are weak and the nucleus has been removed, use viscoelastic to displace the cortex anteriorly before placing the CTR and IOL. This avoids capsular traction associated with cortical aspiration before securing IOL placement.

Pitfalls to Physical Displacement

- The cortex is even less accessible than it was before.
- The ability of haptics to displace the cortex is limited.
- Posterior capsule opacification is more likely to occur.

The tip of the viscoelastic cannula gingerly punctures the cortex after nuclear removal. The cannula is tracked along the posterior capsule, displacing the cortex anteriorly as the capsule is inflated with viscoelastic. When successful, the displaced cortex will wrap anteriorly around the edges of the capsulorrhexis. If one is placing a CTR, it is introduced posterior to the body of remaining cortex, to prevent the CTR from trapping the cortex. The IOL is then inserted into the capsular bag.

Cortical Removal With an Open Posterior Capsule

- At the first sign of a posterior capsular defect, stop. Do not withdraw or remove any surgical instruments from the eye.
- Assess the extent of the damage, and use viscoelastic to stabilize the AC before removing any hollow-lumen instrument. Although a solid instrument such as a chopper will open the incision to create a pressure gradient during its removal, a hollow instrument is more likely to have vitreous incarcerated in the lumen. Thus remove the solid instrument first, and use viscoelastic to inflate the AC and optimally displace vitreous posterior to the capsule.
- If vitreous is present in the AC, perform vitrectomy.
- Cortex can be removed by aspiration with the vitrectomy handpiece with the cutting function turned off.
- Once the AC is free of vitreous, use a 25-, 26-, or 27-g cannula on a syringe partially filled with BSS to engage the residual cortex. Aspirate gently to remove accessible cortex.
- It is advisable to strip the cortex toward the posterior chamber (PC) tear to avoid shearing forces that can extend/expand the PC tear.
- A second or third side port incision may be necessary to achieve access to the remaining cortex with the cannula.
- Replace the volume removed with BSS or viscoelastic to prevent collapse of the globe or extension of the posterior capsule tear.
- The viscoelastic can also be used to displace the cortex from the capsule, depending on the situation, with removal through the cannula achieved as before.
- At some point in the process the decision is made to either place the intended IOL in the posterior capsule as originally intended, place a three-piece IOL in the sulcus (with potential optic capture in the capsulotomy), or choose a fixation technique independent of the capsule. The amount of remaining cortex must be balanced against achieving an optimal optical outcome for the patient. Too much residual cortex may delay the recovery but is not likely to impact the final visual outcome. Overly aggressive cortical removal may threaten the proper IOL placement by further damage to the capsule, and this may reduce the final visual outcome and possibly long-term IOL stability.

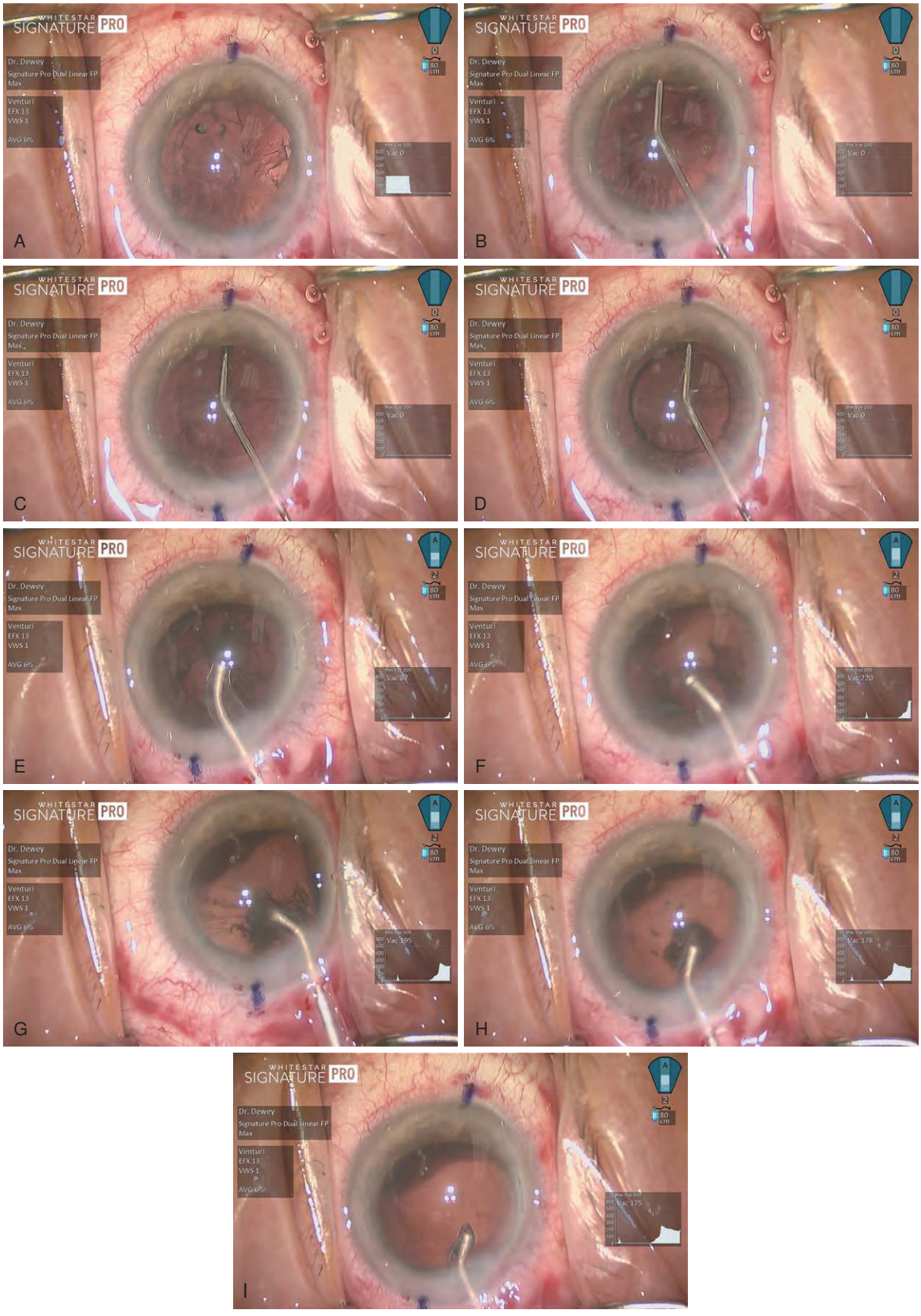

Fig. 27.3 (A) Cortex remains intact after removal of the femtosecond laser segmented nucleus. (B)The tip of the irrigating cannula is placed under the anterior capsule opposite the primary incision. (C) Puncture the cortex under the anterior capsule and begin irrigation. (D) Continued irrigation separates the cortex from the capsule. Distention of this space prolapses the cortex through the capsulotomy, creating the "O" sign. (E–I) Many times the cortex is completely disinserted and removes easily with the preferred standard I/A tip. Even partial disinsertion improves the efficiency of cortical removal.

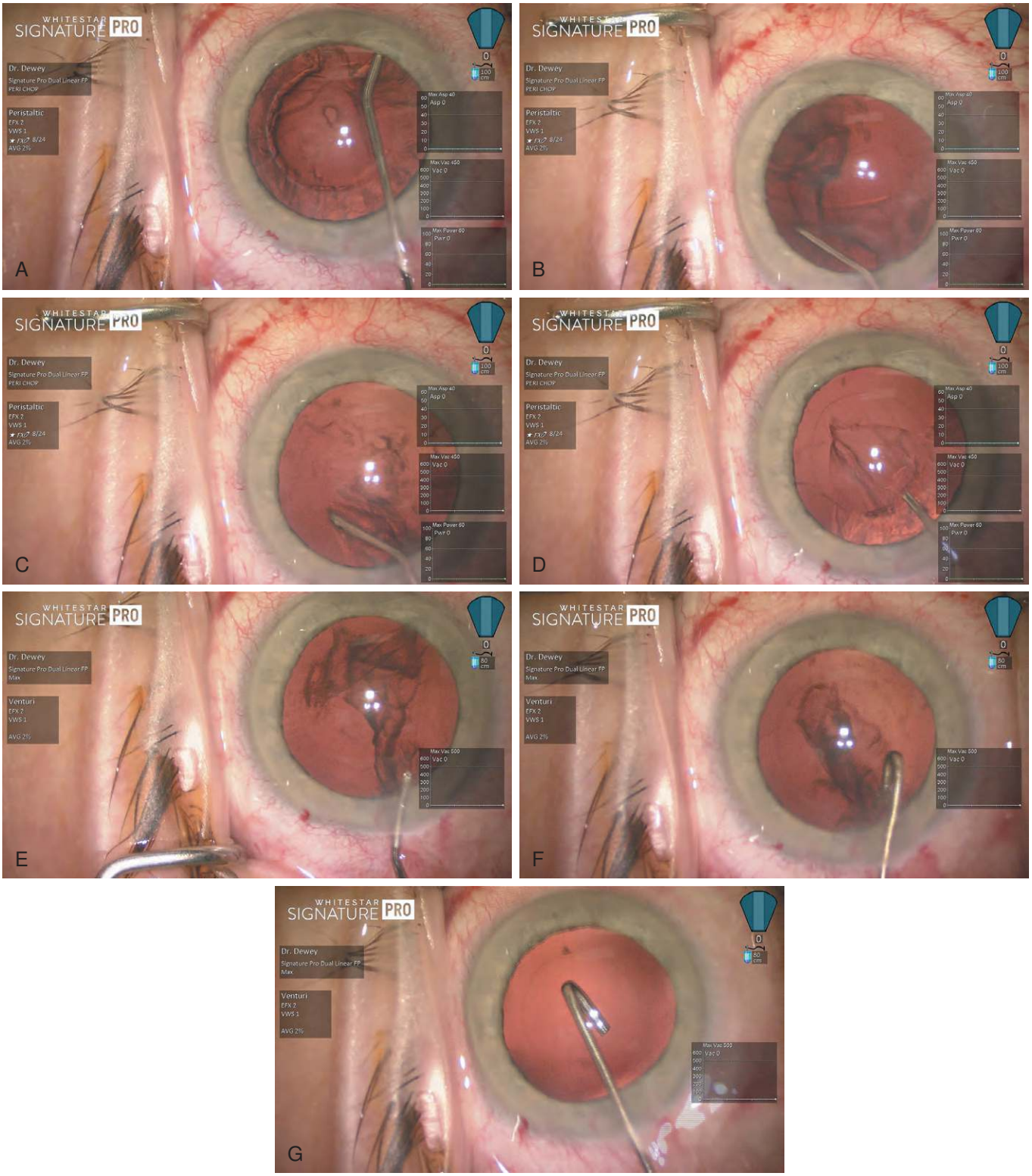

Fig. 27.4 (A) Cortex is not intact after removal of the segmented nucleus. (B-C) Irrigation follows the curve of the capsule and separates the cortex from the capsule. (D–E) Continued irrigation peels the cohesive cortex from the capsule. (F–G) J-cannula irrigation displaces the subincisional cortex out of the eye.

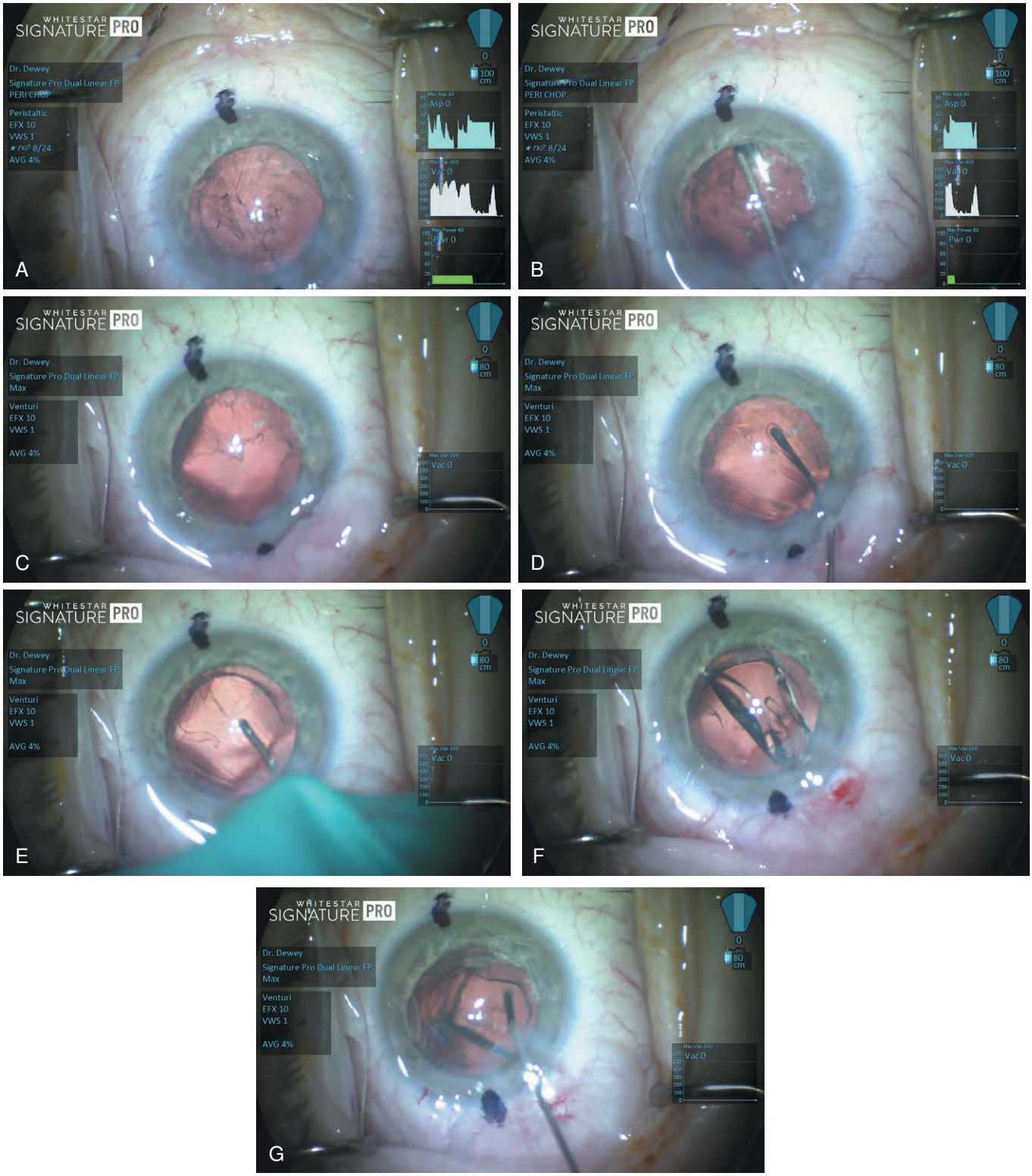

Fig. 27.5 (A) Intact cortical layer adherent to the capsule. (B) J-cannula irrigation displaces the proximal cortex. (C) Cortical remnants distal to the incision. (D)The tip of the viscoelastic cannula is placed between the cortex and capsule. (E) Continued inflation of this potential space displaces the cortex anteriorly, wrapping around the capsulorhexis. (F) The IOL is inserted posterior to the displaced cortex. (G–H) IOL rotation dislodges cortex. (I–J) Direct irrigation displaces cortex through the main incision. (K–L) I/A clears the remaining cortex and viscoelastic. (M) End.

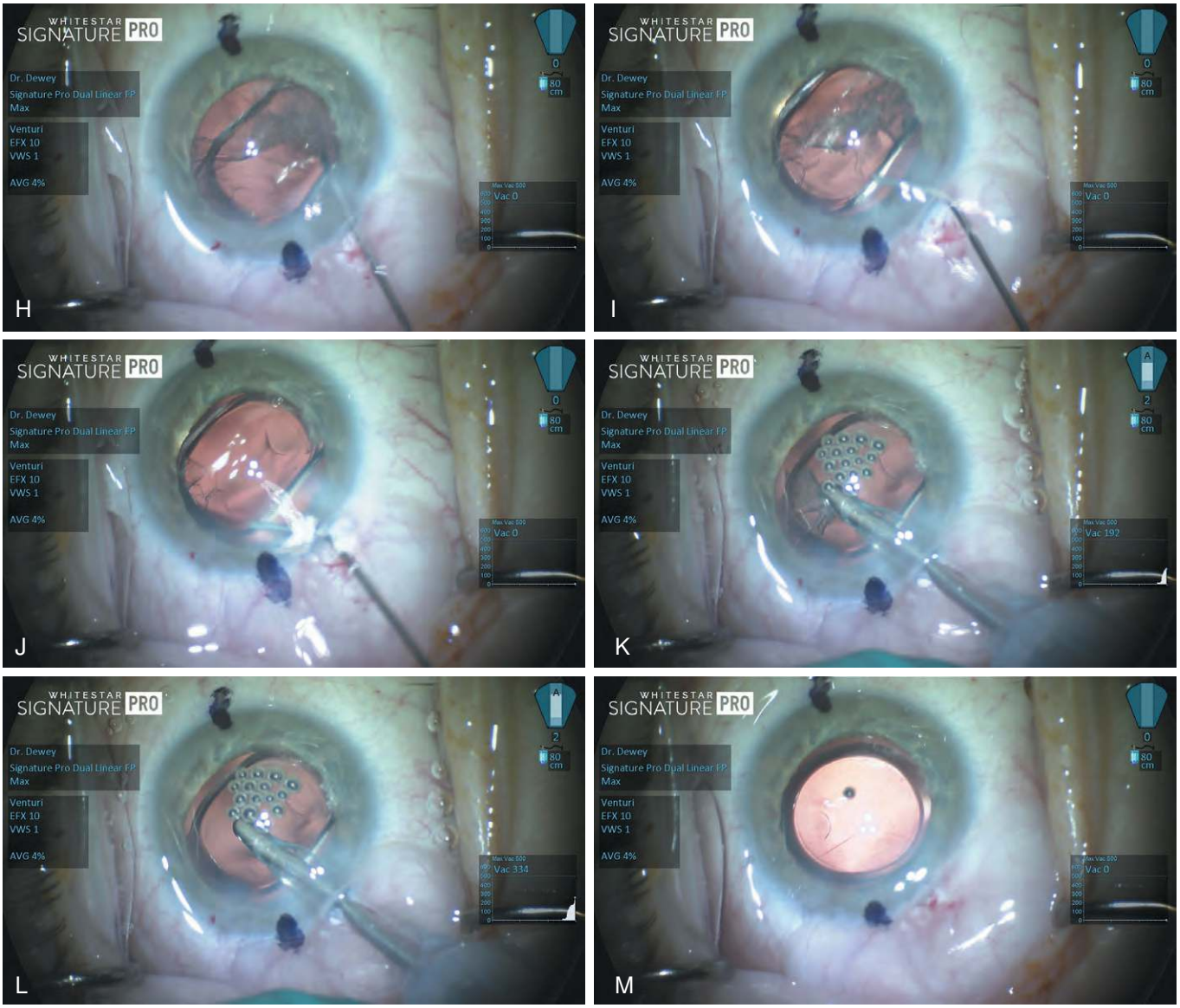

Fig. 27.5 Cont'd

Cortex may be trapped posterior to the optic or in the periphery of the capsule by the haptics or the CTR. The Henderson CTR has notches that are designed to improve cortical removal under these circumstances.[17]

CORTICAL REMOVAL AFTER POSTERIOR CAPSULE RUPTURE

An open posterior capsule presents challenges proportional to the size of the defect. If it is small, the primary objective is to prevent enlargement. Convert the tear to a continuous curvilinear capsulotomy if possible. Dispersive viscoelastic is used to tamponade the defect if vitreous has not prolapsed through. Nuclear fragments can be suspended with viscoelastic near the cornea for later removal.

Unfortunately, vitreous aspirates as easily as cortex, but aspirating vitreous is a dangerous situation at best. It is up to the surgeon to choose whether a limbal or pars plana incision for anterior vitrectomy is appropriate for an open capsule with vitreous prolpase[18] (See Chapter 47). Once the prolapsed vitreous has been excised, control of the capsular tear is the next concern.

"Dry" cortical removal refers to aspiration without simultaneous irrigation and can be used after PCR without vitreous prolapse. A straight or J-cannula of appropriate gauge—25, 26, or 27 g—is attached to a partially filled BSS syringe, and the cortex is aspirated without active irrigation. The aspirated volume is periodically replaced with viscoelastic to maintain a stable globe. Although tedious, this process can prevent a posterior capsular tear from extending.

The same instruments used for a biaxial anterior vitrectomy can be used for a variation of biaxial cortical removal. The cutting mode of the vitrectomy handpiece must be turned off. Because the vitrectomy tip lumen is much larger than 0.3 mm, there must be enough cortex to create an occlusion and build vacuum in a peristaltic system. In a Venturi system, occlusion is not necessary to generate enough vacuum to aspirate cortex.

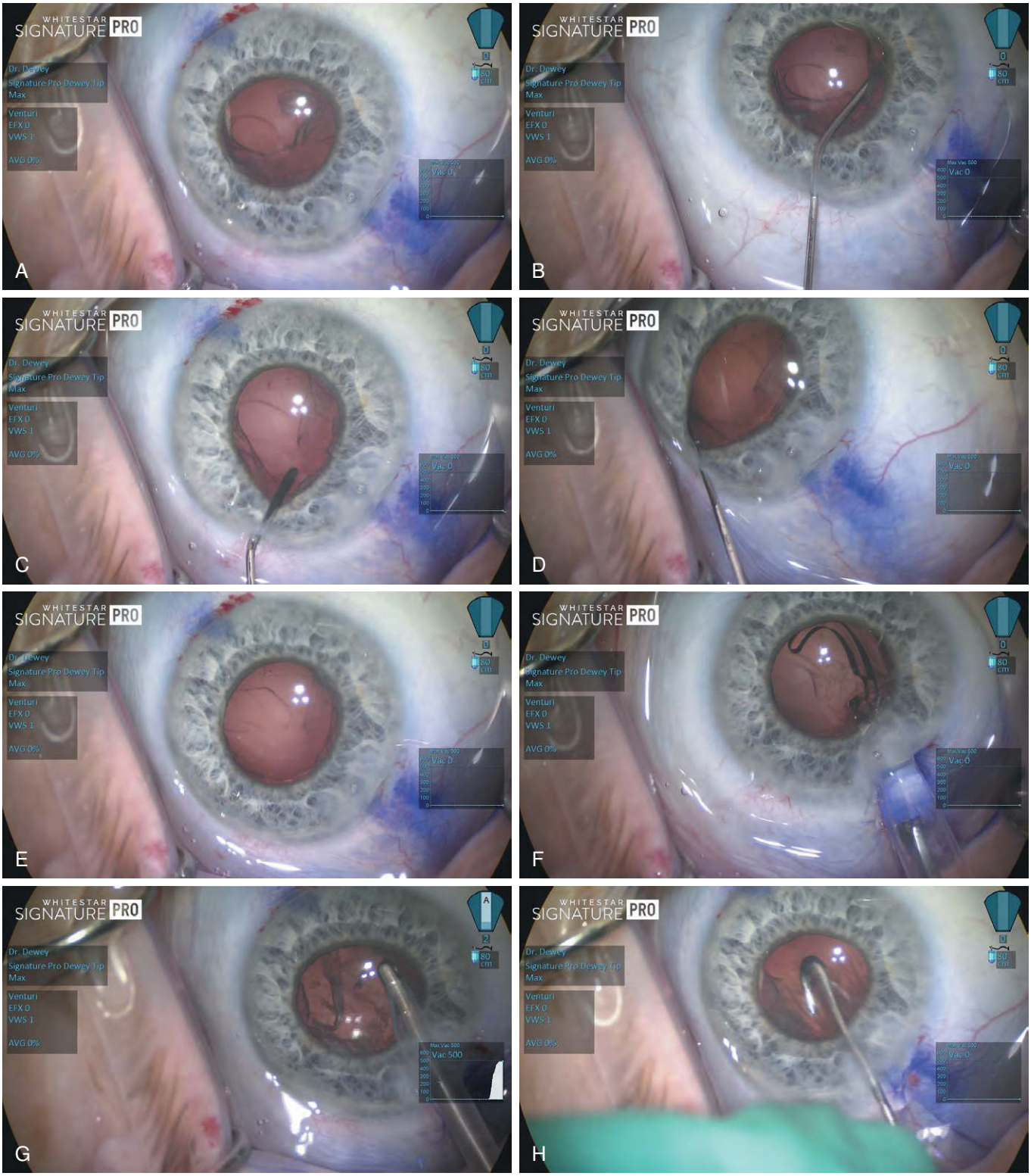

Fig. 27.6 (A) After nuclear removal, the posterior capsule is noted to be open in the presence of copious adherent cortex. No vitreous is prolapsing. (B) The tip of the viscoelastic cannula is slipped between the cortex and capsule, creating space by injecting viscoelastic. (C–D) Viscoelastic displaces cortex from the subincisional cortex and beyond. (E) The posterior capsule is clear, with the cortex displaced anteriorly in preparation for IOL insertion. The opening in the capsule remains unchanged in size. (F) IOL insertion. (G) With the capsule protected by the IOL, automated I/A removes all accessible cortex. (H–I) Gentle J-cannula irrigation disrupts cortex. (J–N) Automated I/A removes the disrupted cortex (N) End.

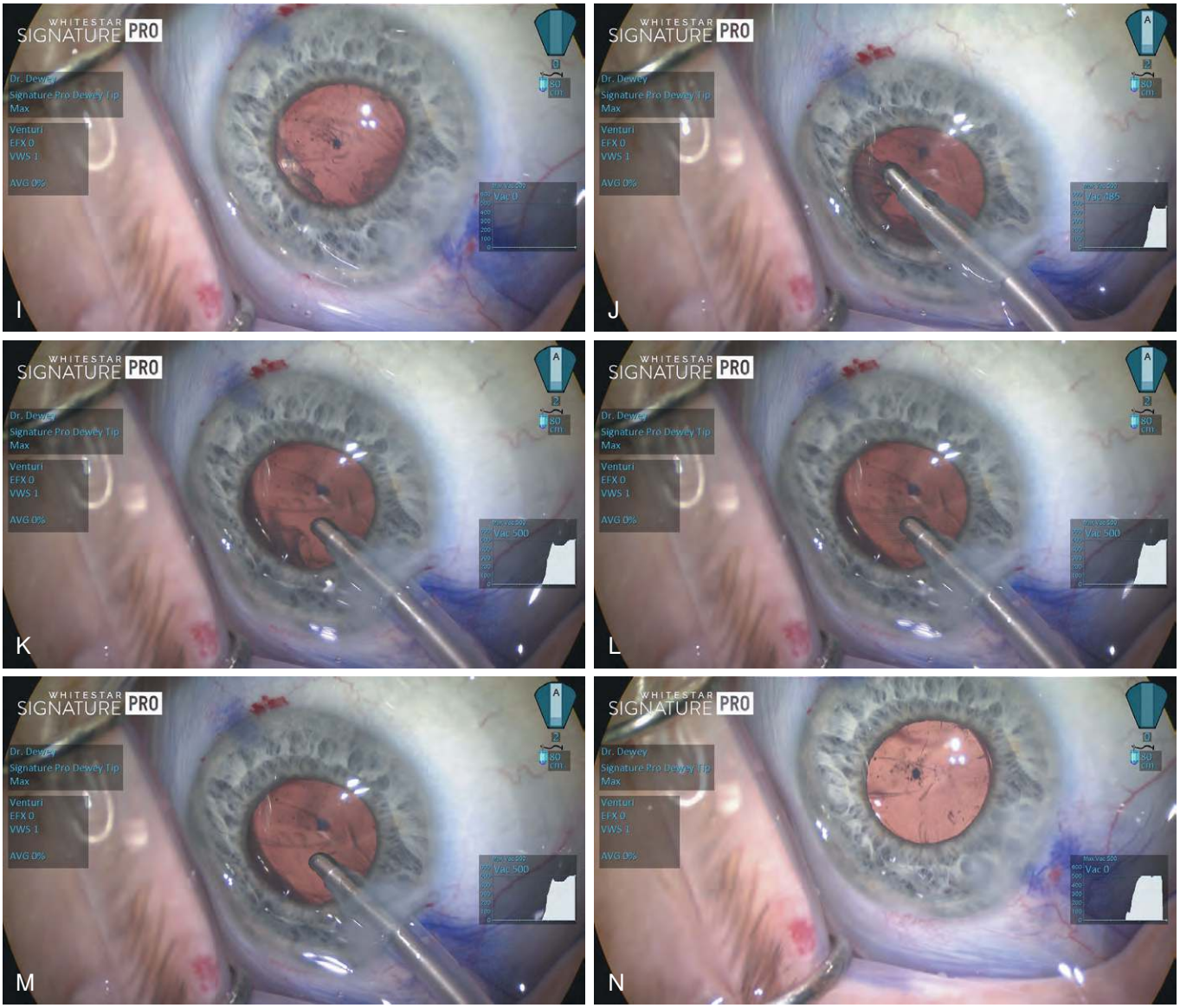

Fig. 27.6 Cont'd

Capsule Polishing

- Residual cortical debris can result in the rapid formation of posterior capsule opacification postoperatively.
- The utility of capsule polishing should be weighed against the risk for capsule rupture, both in regards to the operative situation ieces stabilize the capsule focally with low leve and with the need for an intact capsule based on the surgical plan (a toric IOL, for example).
- When performing capsule polishing, gentle overlapping circular motions will allow a sandblasted tip, a water jet, or a silicone tip to engage the capsule safely and remove the residual debris.
- Less polishing is generally better as continued engagement with the posterior capsule only increases the risk for rupture.

CAPSULE POLISHING

Any amount of residual material remaining on the posterior capsule can impede recovery of vision. The first decision is whether thorough cleaning of the capsule is warranted. Although the usual answer is yes, certain circumstances, such as patient movement during surgery, make a subsequent yttrium-aluminum-garnet capsulotomy the optimum choice rather than risking capsule damage that would impede perfect IOL support.

Capsule polishing is achieved with three basic mechanisms: (1) by directed irrigation, (2) by mechanical polishing with direct instrument contact, or (3) by mechanical polishing augmented by vacuum. Regardless of the instrument or technique, polishing is achieved with overlapping circular motions. Contact with the capsule must be gentle but adequate. Damage can occur with inadvertent snagging, which can stretch the capsule beyond its tensile strength. Too much downward force can stretch the capsule or zonules as well. An unidentified burr can unexpectedly pierce the capsule.

As discussed in the section on J-cannula irrigation, directed fluid can separate these adherent fibers with hydrostatic force. A straight cannula can be used as well. Mechanical polishing can be achieved safely with a sandblasted tip on any number of rounded or circular reusable instruments or cannulas. Silicone-tipped polishers, such as the Terry Squeegee, effectively reduce the risk for snagging by reducing

potential adherence to the capsule. Mechanical polishing benefits from viscoelastic to keep the capsule relatively taught, which prevents instrument snagging.

Silicone-tipped I/A handpieces stabilize the capsule focally with low levels of vacuum. Although generally safe, these instruments should be inspected for defects that may expose the inner metal structure. Simply rotate the aspirating port against the capsule, and move the tip in an overlapping, circular motion. Avoid vacuum-based polishing in cases of potential zonular instability.

Fibrotic plaques may remain adherent to the capsule, particularly in long-standing posterior subcapsular cataracts. These may be removable by finding a flap or creating a loose edge. The author uses the blunt tip of a viscoelastic cannula. By placing this tip around the margins of the plaque and gently rubbing while slowly ejecting viscoelastic, a potential space may be identified and expanded. Once a loose flap or edge is created, it can be grasped with blunt capsule forceps and peeled. Plaque removal does not have to be complete to provide improved optical clarity. In posterior polar cataracts, the plaque may be intrinsic to the capsule, and caution should be exercised as plaque removal may result in an open posterior capsule.

SUMMARY

Fortunately, the skills necessary for thorough cortical removal are relatively fundamental. By practicing for the unexpected challenge—perhaps by performing "dry" cortical removal on a routine case—one can develop enough experience to deal with the challenging cases on a routine basis. This absolutely pivotal step—removing the last remnants of the cataract in preparation for IOL implantation—can be handled in a myriad of methods, all without the benefit of advanced planning, but always with the benefit of advanced preparation.

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Video 27.1: Cortex: A Different Perspective.
Video 27.2: J-Cannula Irrigation.
Video 27.3: Cortical Removal Simplified in FLACS.
Video 27.4: Viscodissection and IOL Rotation.

PART V

Astigmatism Management

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28

Preoperative Evaluation and Considerations of Astigmatism

Warren E. Hill, Douglas D. Koch, Li Wang, Mitchell P. Weikert, and Adi Abulafia

CONTENTS

INTRODUCTION

Corneal astigmatism is a common condition; a large cataract surgery database shows that greater than 57% of the eyes have 0.75 diopters or more of total corneal astigmatism (Fig. 28.1).

How does astigmatism affect quality of vision? This is a huge, complex topic because the impact of astigmatism on vision depends on many factors: amount, regularity, meridian, pupil size, and other aberrations.[1]

WHAT WE KNOW ABOUT ASTIGMATISM

- Distance visual acuity decreases as myopic, hyperopic, or mixed astigmatism increases.
- Near visual acuity decreases with hyperopic astigmatism but improves with myopic astigmatism.
- The effect of astigmatism is generally independent of axis. However, the benefit for near vision depends on the alphabet. For the Latin alphabet with a predominance of vertical lines, against-the-rule (ATR) astigmatism with mild myopia can benefit reading.[2]
- A progressive ATR shift occurs with age whether or not an individual undergoes cataract surgery.[3]
- In the presence of typical higher order aberrations, correction of astigmatism below 0.50 D shows minimal practical benefit.
- 0.75 D of astigmatism reduces visual acuity to 20/25.[4]
- Pseudoaccommodative presbyopia-correcting intraocular lenses (IOLs) are sensitive to astigmatism, and refractive astigmatism of 0.50 D or less is needed to achieve their full potential, particularly for intermediate and near.[5]
- Some patients may prefer to retain their preexisting astigmatism, content with sacrificing some clarity in exchange for an enhanced depth of focus.
- Considering these factors, our goal is to reduce astigmatism to 0.50 D or less in any patient desiring optimal visual clarity.

This means that more than half of our cataract patients may benefit from astigmatism correction.

Corneal astigmatism can be corrected by three different methods (Table 28.1). The first method—corneal relaxing incisions (CCRI)—is discussed in detail in Chapter 29. Bioptics is another approach for the correction of corneal astigmatism. By this method, the patient is targeted for a myopic refraction. After the postoperative refraction has stabilized, LASIK/PRK is undertaken to correct the residual refractive astigmatism and any remaining undesired refractive outcome. This has the advantage of offering a relatively precise correction but has the disadvantage of requiring two separate procedures, along with two opportunities for complications and two separate charges to the patient. In general, bioptics is not widely utilized.

For many surgeons, the correction of corneal astigmatism using a toric IOL has the advantage of requiring a single procedure. With careful planning, achieving a goal of a postoperative refraction astigmatism equal or less than 0.50 D can be accomplished with high success rates.

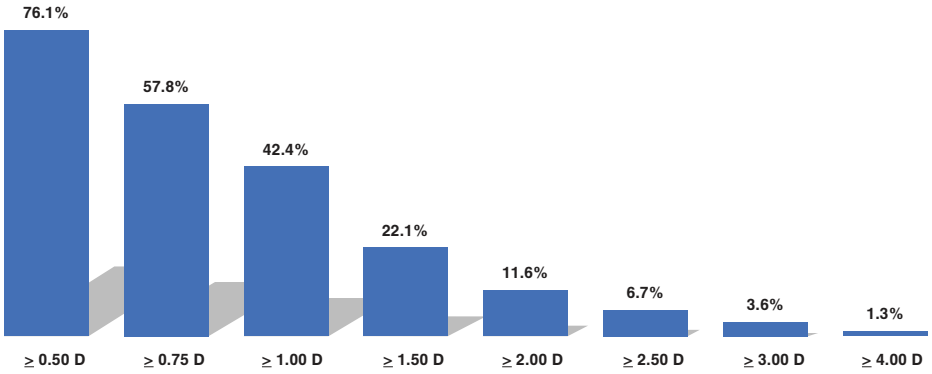
THE MEASUREMENT OF CORNEAL ASTIGMATISM

Measuring Devices

There are many ways to measure corneal astigmatism preoperatively. Of course, the goal is to have accurate and repeatable measurements that allows treatment that results in the least amount of residual postoperative astigmatism. In general, this requires that we know two components: the power difference between principal meridians (which are generally orthogonal, unless the astigmatism is irregular) and the orientation of the steep meridian. A common misconception is the assumption that the measurement of corneal astigmatism should be the same with multiple instruments. It is helpful to keep in mind that different devices often measure different areas of the astigmatic cornea and may also employ different algorithms. Expecting Placido-based simulated Ks, Scheimpflug Ks, OCT Ks, and the various forms of autokeratometry to all return the same value may be unrealistic. Measurements by three or more different instruments will typically produce three or more different values and should not be considered interchangeable.

The Ocular Surface

Ocular surface disorders (OSDs) should be diagnosed and treated because optimizing the ocular surface goes a long way toward improving the quality and consistency of keratometry and topography.[7] This topic is covered in detail in Chapter 3.



* 5,866 consecutive eyes, IOLMaster 700 (TK). Ophthalmology department, SZMC, Jerusalem, Israel

Fig. 28.1 The distribution of the total corneal astigmatism in cataract patient population, measured by a SS-OCT based device.

TABLE 28.1 Comparison of the Various Methods for the Correction of Corneal Astigmatism[6]

Procedure	Advantage	Disadvantage	Patient Cost	Physician Reimbursement
Corneal relaxing incisions	Simple, familiar	Lower precision	+1	+1
LASIK / PRK	Precise	Requires second procedure	+3 to +4	+2 to +3
Toric IOL	Precise	Currently lacks higher correction	+2	+2

Keratometry	
Ocular surface (improvement necessary?)	NORMAL
K1 & K2 SD (maximum value, each eye)	±0.25 D
Avg K power difference (between eyes)	< 1.25 D
Avg K power (each eye)	> 40.00 D and < 48.00 D
Steep meridian SD (maximum value, each eye)	±3.5°
AST (maximum value, each eye)	< 4.25 D
Reflected LED images (all meridians)	GOOD QUALITY

Fig. 28.2 Validation criteria for keratometry measurements.

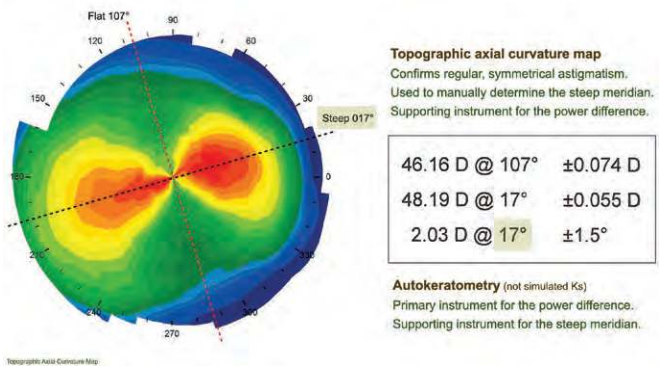


Fig. 28.3 Axial curvature topographic map demonstrating regular astigmatism within the central 4.0 mm of the corneal vertex. A manually determined steep meridian validates the steep and flat meridians by autokeratometry, which provides the power difference between meridians.

Data Validation

Data validation is a fundamental requirement for accurate measurements. Hence, one should try to make a habit not to cruise on "autopilot" mode during the measurement process but rather develop a method of measurement validation. Validation criteria for two commonly used biometers can be found within the users' manual of each device and online in Dr. Hill's website: https://doctor-hill.com/iol-power-calculations/optical-biometry/validation-guidelines/ (Fig. 28.2).

The use of contact lenses should be documented. Cessation of soft lens wear prior to preoperative corneal measurements is recommended between 48 hours to 1 week, and rigid gas permeable lens wear should be discontinued at least 4 weeks beforehand. For patients who have used rigid gas permeable contact lenses for many years, it may be useful to postpone biometry until stable topography and keratometry measurements can be demonstrated 2 weeks apart.

How to Choose the Proper Radius/Keratometry Values

Data integration from several measuring devices can be confusing; what works best is to first develop a plan.

Step 1: Using a topographic or tomographic axial curvature map, we first look to see how the power is distributed across the anterior cornea within the central 4 mm zone.

Step 2: Make sure that the power distribution is suitable for a toric IOL implantation. Regular astigmatism is represented by a pair of symmetric astigmatic power lobes straddling the corneal vertex (often referred to as a *bow tie*), with the center of both astigmatic lobes being aligned along the same meridian (Fig. 28.3). If the power distribution on different sides of the corneal vertex is unequal, the astigmatism is asymmetric. If a single meridian cannot be drawn through both lobes, it is irregular. Early in the process, this simple method forces us to carefully look at the cornea when deciding about the appropriateness of a toric IOL implantation. A topographic/tomographic axial curvature map is considered a primary instrument for manually determining the steep meridian. A primary instrument is one that is well suited to a given task and always provides the correct information when presented in a specific way.

Step 3: Determine the orientation of the steep meridian. If a line is drawn through the center of each astigmatic lobe and the corneal vertex, where this line intersects the axis scale in the periphery is, by definition, the steep meridian. If the steep meridian cannot be identified, each lobe is aligned with a different meridian, or things are quite asymmetric, the patient may not be a toric IOL candidate.

Step 4: Next we need to confirm that the measurements taken by autokeratometry agree with the manually determined steep meridian. Corneal astigmatism has both magnitude and direction. Without validation of the steep meridian, auto-Ks alone may not be reliable for determining the magnitude or orientation of the corneal astigmatism. With the steep meridian validated, the measured power is more likely to be correct (Fig. 28.3). If we are certain about the steep meridian, but the autokeratometer is telling us something different, then the Ks by keratometry are most likely being measured at an incorrect location. This is not uncommon when the power distribution is irregular. When this kind of disconnection occurs, one should pause until the discrepancy can be identified. One approach is to settle this discrepancy by repeating the measurements. Another option is to use software that generates an integrated K value, based on several measuring devices. An example for such a software is the K calculator feature on the Barrett online toric calculator, which calculates a new integrated K values based on a vector median of the measurements from 3 similar devices. (https://ascrs.org/tools/barrett-toric-calculator). A third option is to measure the central corneal power using a manual keratometer. By this method, the steep meridian is set manually to the value determined manually using a topographic/tomographic axial curvature map, then remeasure the corneal power 90° to this. This approach provides the power difference between the two principal meridians.

THE POSTERIOR CORNEA

A key component in successful toric IOL selection is factoring the posterior cornea into the calculation. For over a century, it has been recognized that refractions typically have less with-the-rule (WTR) astigmatism or more against-the-rule (ATR) astigmatism than was found in anterior corneal measurements.[8] It was speculated that this was because of either the crystalline lens or the posterior cornea.[9] Current technology has demonstrated that some combination of both typically produces an ATR refractive effect. Key studies elucidating the impact of posterior corneal astigmatism include the following:

- Using the Galilei dual-Scheimpflug tomographer, Koch and colleagues reported that the posterior cornea is steeper along the vertical meridian in over 80% of eyes.[10] Because the posterior cornea is a minus lens, a posterior cornea that is steeper vertically creates ATR refractive astigmatism, with a mean magnitude in their study of 0.30 + 0.15 D. However, the magnitude ranged up to 1.00 D, and orientation ranged from 0 to 90 degrees.
- A subsequent Pentacam study by Tonn et al. reported that the percentage of corneas with the posterior cornea oriented steep vertically decreased from 97% in eyes with anterior WTR astigmatism to 59% in eyes with anterior ATR astigmatism, with corresponding increases in oblique and horizontal orientation.[11]
- A clinical study by Koch et al. demonstrated that failure to incorporate posterior corneal astigmatism into toric IOL calculations could cause roughly 0.5 D of overcorrection of WTR astigmatism and roughly 0.25 D of undercorrection of ATR astigmatism.[12]
- From these data, the Baylor nomogram was developed, which in turn led to development of several other regression-based toric IOL calculation formulas that incorporate the effect of posterior corneal astigmatism. The Baylor nomogram essentially advises surgeons to slightly overcorrect ATR astigmatism and undercorrect WTR astigmatism.

There are three approaches for incorporating posterior corneal astigmatism into toric IOL calculations:

1. Mathematical models based on regression data.
2. Intraoperative aberrometry. A recent study reported that this technology is not superior to mathematical models.[13]
3. Direct measurement of posterior corneal astigmatism, which is potentially most accurate. Although measurement technology is improving, reported outcomes to date for the direct measurement of posterior corneal astigmatism are, at best, marginally superior to mathematical models based on regression.

Fortunately, much work is being done to improve posterior corneal measurements and their incorporation into toric IOL calculations (see Chapter 30).

LENS TILT

IOL tilt may induce astigmatism. Crystalline lens and IOL tilt can be measured using ultrasound biomicroscopy, Purkinje reflection device, Scheimpflug camera system, or optical coherence tomography (OCT). Recent studies[14,15] demonstrated that the preoperative crystalline lens tilt can be used to predict the postoperative IOL tilt. Findings regarding lens tilt in our study are summarized as follows:

- The crystalline lens and IOL are tilted horizontally around the vertical meridian with anterior displacement of the nasal portion (Fig. 28.4).
- The mean magnitude and range of tilt was 3.7 degrees (range 0.4 to 6.9 degrees) for the crystalline lens and 4.9 degrees (range 1.6 to 10.7 degrees) for IOLs.
- There was strong correlation between the tilt magnitude and direction of preoperative crystalline lens tilt and postoperative IOL tilt.
- There was often mirror-image symmetry for both crystalline lens and IOL tilt between right and left eyes.
- The magnitude of lens tilt was greater in short eyes and in eyes with larger angle alpha.
- Using ray tracing software,[16] Weikert and colleagues investigated the astigmatism induced by IOL tilt. They found that induced astigmatism increases with increasing tilt and IOL power. For toric IOLs, the astigmatism induced by horizontal tilt of IOL around the vertical meridian varies depending on the alignment and the amount of toricity in the tilted IOLs.
- Aspheric IOL: Induces ATR astigmatism. For 5° and 10° of IOL tilt, respectively, the induced astigmatism levels are 0.11 D and 0.44 D for +22 D aspheric IOLs, and higher up to 0.14 D and 0.56 D for +28 D aspheric IOLs.
- Toric IOL aligned at 90° (with higher power aligned horizontally): Increases ATR astigmatism and results in overcorrection. For 5° and 10° of IOL tilt, respectively, the induced astigmatism values are 0.13 D and 0.52 D for a +22 D SN6AT6, and 0.15 D and 0.63 D for a +28 D SN6AT6.
- Toric IOL aligned at 180° (with higher power aligned vertically): Decreases the WTR astigmatic effect of the toric IOL and produces under correction. For 5° and 10° of IOL tilt, respectively, the induced astigmatism amounts are 0.09 D and 0.37 D for a +22 D SN6AT6, and 0.12 D and 0.48 D for a +28 D SN6AT6.

In summary, preoperative crystalline lens tilt can be used to predict the postoperative IOL tilt. The clinical impact of astigmatism induced by IOL tilt will increase in eyes with greater amounts of IOL tilt and

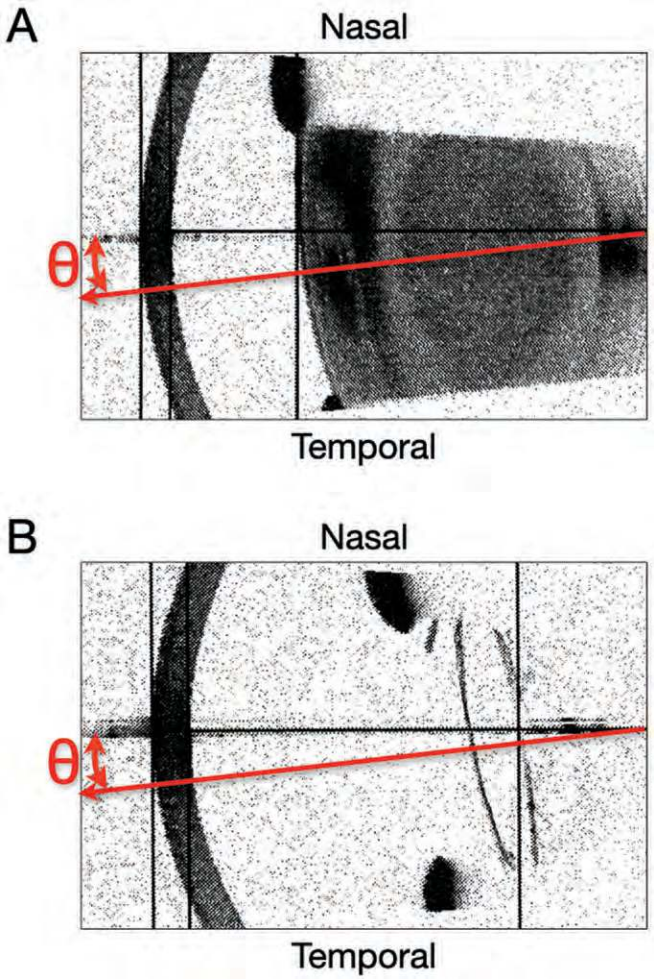


Fig. 28.4 IOL Master images of a left eye showing (A) crystalline lens tilt angulated with the nasal border anteriorly displaced and the temporal border posteriorly displaced, and (B) intraocular lens tilt that correlates with preoperative crystalline lens tilt.

higher IOL power, such as in short eyes with large angle alpha. We hope that in the future biometers will provide lens tilt data to incorporate into toric IOL calculations.

TORIC IOL CALCULATORS

The first generation of toric IOL calculators were quite straightforward, using solely anterior based corneal measurements, the cylinder effect of the toric IOL at the corneal plane (fixed ratio), and a mean value for corneal surgical induced astigmatism (SIA) for the prediction of the postoperative astigmatic refraction. Today, most of the toric IOL calculators are more sophisticated, incorporating additional features such as:

- Calculation of the cylinder power of a toric IOL at the corneal plane, based on the estimated effective lens position (ELP) of the toric IOL.
- Mathematical models to compensate for differences between anterior corneal based measurements and postoperative refraction. Hence, they include adjustments for factors such as the posterior corneal astigmatism, physiologic IOL tilt and potentially any additional unknown inherent factors.[17]
- Predicted postoperative refraction, including both the sphere and astigmatism components.
- Toric IOL calculators are covered in more details in Chapter 30.

CORNEAL SURGICALLY INDUCED ASTIGMATISM

Corneal surgically induced astigmatism (SIA) refers to the amount of the change in total corneal astigmatism that was induced by the cataract surgical incisions. We suggest 0.10 D as a starting point for a temporal, 2.4 mm clear corneal incision. However, ideally, each surgeon should routinely preform consistent corneal incisions during cataract surgery and calculate a personal corneal SIA for OD and OS separately by measuring the preoperative and postoperative (at least 1 month, ideally 3 month) corneal measurements. It is recommended to use the centroid (mean vector) values.[18] Free online corneal SIA tools are available at www.SIA-calculator.com and at the ASCRS (https://ascrs.org/tools/corneal-sia-tool) https://education.escrs.org/downloads/ websites.

Because of differences in the corneal diameter, regional thickness, and rigidity from one patient to the next, a consistent value for surgically induced astigmatism is difficult, if not impossible, to predict. The commonly held belief that the flattening produced by a clear corneal incision made at 180 degrees would induce the same amount of steepening at 90 degrees appears to be incorrect. It is for this reason that a 2-dimensional average of the magnitude (how much) and the orientation (which meridian) for a series of patients is now used with toric calculators.

TORIC IOL CALCULATORS FOR THE UNUSUAL CORNEAS

Post-Corneal Refractive Surgery

Patients with previous corneal refractive surgery have high expectations for uncorrected visual acuity and spectacle independence after the cataract surgery. This expectation is further increased for those receiving premium IOLs. Correcting corneal astigmatism in these eyes can be challenging because of the presence of varying amounts of irregular astigmatism, and it is not possible to accurately estimate the magnitude of posterior corneal astigmatism from anterior corneal measurements.

Preoperatively, we recommend using as many devices as possible to measure corneal astigmatism, including corneal topographers and biometers. Our criteria for recommending toric IOL implantation are as follows:[19]

- Regular bow-tie corneal astigmatism within the central 4 mm zone
- Difference in corneal astigmatism magnitudes of ≤0.75 D between two devices
- Difference in the astigmatism meridians of ≤15° between two devices (for postrefractive cases)

For IOL toricity selection, we estimate 0.3 D of posterior corneal astigmatism with the steep meridian aligned vertically in each eye and target a mild undercorrection (approximately 0.3 D) in eyes having WTR corneal astigmatism, full correction in eyes with oblique corneal astigmatism, and mild overcorrection (approximately 0.3D) in eyes with ATR corneal astigmatism.

The Barrett True-K Toric calculator (https://apacrs.org) can also be used for toric IOL calculation in eyes with previous corneal refractive surgery.

Keratoconus and Eyes After Endothelial Replacement Surgery

In keratoconic eyes, selecting a toric IOL can be challenging because of significant irregular astigmatism. However, for older patients with documented stable disease, acceptable outcomes are possible with toric IOLs. Our criteria for toric IOL implantation in these eyes are as follows:

Potential keratoconus toric IOL candidates:

- Older than 55 years
- Mild to moderate keratoconus, with stable findings
- History of satisfactory vision with glasses prior to development of cataract, such that RGP contact lens wear was not required
- No central corneal scarring
- For the estimation of toric IOL power:
  - Agreement of the steep meridian on manifest refraction, a topographic axial power map, and autokeratometry. This agreement should be within a few degrees and reproducible.
  - Estimation of the steep meridian and the power difference based on the above.
  - Assurance that that there is a toric IOL available that can correct all, or most of the corneal astigmatism.
  - Mildly undercorrecting the astigmatism and mildly overcorrecting the spherical component.

In eyes that have undergone endothelial replacement surgery, toric IOLs can be used. For these eyes, we apply the same criteria that we use for keratoconic eyes, with the same caveat that perfect results are not to be expected. These fall into three categories:

- In eyes after penetrating keratoplasty (PKP), corneal astigmatism—both regular and irregular—frequently occurs. These eyes are challenging because they can have large amounts of posterior corneal astigmatism, which may also be irregular. Toric IOL implantation is reasonable, assuming healthy graft status with no likelihood of repeat surgery for at least 10 or preferably more years.
- In post-DSAEK eyes, we know that there can be steepening of the posterior corneal surface. Hence, an additional spherical power of about +1.25 D is recommended. Posterior corneal astigmatism can be induced. Clues to its magnitude are the change in refractive astigmatism after DSAEK surgery.
- In post-DMEK eyes, the anterior corneal surface is often quite regular, and the induced posterior corneal astigmatism may be minimal. These eyes can be excellent candidates for toric IOLs, even with combined DMEK and cataract surgery. In these eyes, an additional spherical power of about +0.50 D is recommended.

SINGLE-ANGLE AND DOUBLE-ANGLE PLOTS FOR ASTIGMATISM DATA PRESENTATION

Correct astigmatism analysis requires doubling the angle to transform the astigmatism data into 360-degree Cartesian coordinates. One can display this as single-angle or double-angle plots. Although single-angle plots are attractive because they match what we see in a phoropter, we recommend the latter. The concept of double-angle plots can be easily understood as illustrated in Fig. 28.5. Double-angle plots allow us to show the 95% confidence ellipse for the data and to see the spread of the data clearly with accurate representation of their relative position to all the other points, and, more importantly, they allow accurate depiction of the centroid and the standard deviation of the centroid. The minor and major semi diameters of the 95% Confidence Ellipse are not simply the SD of x and the SD of y after doubling the angles; there is a Hotelling Transformation to determine

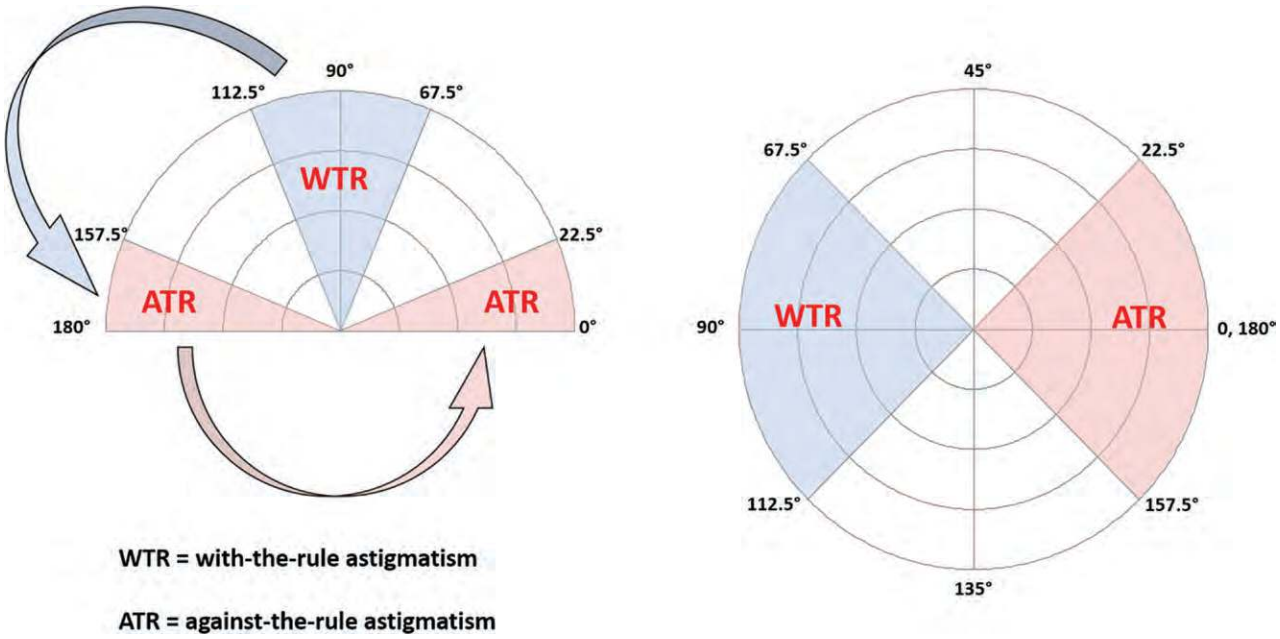


Fig. 28.5 Single-angle plot versus double-angle plot. In a double angle plot, the WTR eyes are grouped together on the left side of the figure and the ATR eyes are grouped together on the right (ATR = against-the-rule; WTR = with-the-rule).

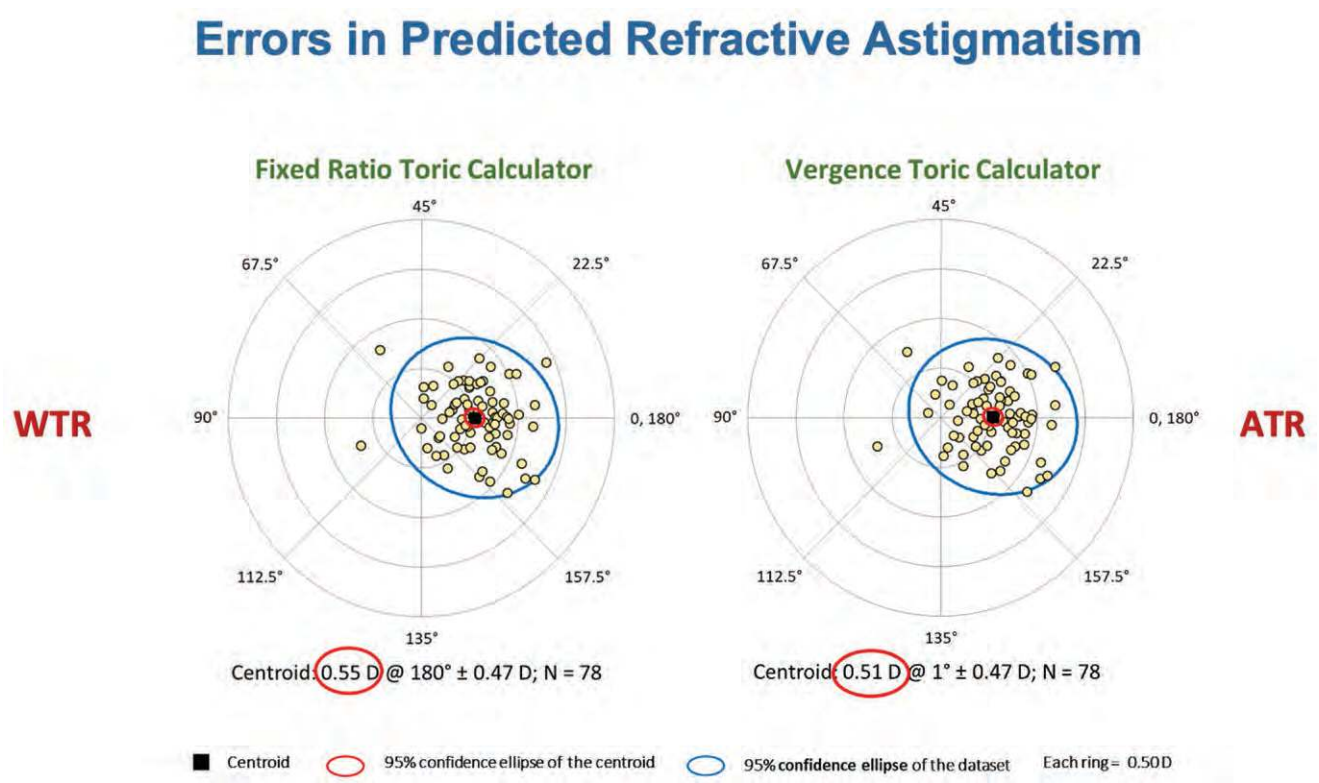


Fig. 28.6 Double-angle plots of the errors in predicted residual astigmatism by two standard toric IOL calculators, based on anterior corneal measurements. Both calculators present ATR prediction errors.

the correct orientation and size of the ellipse for a given probability value as described by Næser.[20] Recent work suggests that astigmatism values are not normally distributed and that they often are better displayed with convex polygons and analyzed with statistical methods designed to address non-Gaussian distribution.[21] More importantly for the reader, once one gets the concept of the doubled-angle plots, the data are visually so much easier and more accurate to interpret (Fig. 28.6).

SUMMARY

Toric IOLs are an excellent solution for patients with preexisting corneal astigmatism who undergo cataract surgery. Carful preoperative planning will usually achieve excellent postoperative refractive results for these patients.

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Corneal Incisional Approaches for Reducing Astigmatism During Cataract Surgery

Li Wang and Douglas D. Koch

CONTENTS

KEY POINTS

- Corneal incisional approaches for reducing astigmatism during cataract surgery include manual peripheral corneal relaxing incisions (PCRIs) (also called *limbal relaxing incisions* [LRIs]) and femtosecond laser-assisted corneal relaxing incisions (CRIs).
- Penetrating femtosecond CRIs have the potential benefit of titrating their effect postoperatively. Intrastromal femtosecond CRIs are placed in the stroma without penetrating the anterior and posterior corneal surfaces and have the potential benefit of avoiding wound gape, inflammation, and patient discomfort.
- Careful preoperative evaluation is crucial to detect ocular surface diseases and topographic abnormalities that could worsen outcomes.
- Corneal astigmatism should be measured with at least two devices, and posterior corneal astigmatism should be taken into account when determining the amount of astigmatism to correct.
- Longer corneal penetrating incisions >45° on the horizontal meridian and >60° along the vertical meridian can predispose to wound gape.
- Outcomes of various studies demonstrated that corneal incisional approaches are effective in reducing small amounts of preexisting corneal astigmatism.

INTRODUCTION

Residual astigmatism after cataract surgery may reduce uncorrected visual acuity. In eyes implanted with multifocal IOLs, even 0.5 diopter (D) of astigmatism can reduce the distance visual acuity by 1 to 2 lines.[1] Corneal incisions are an essential tool for reducing small amounts of corneal astigmatism for which toric IOLs are not indicated or not available.

This chapter discusses corneal incisional approaches, preoperative evaluation and planning, surgical procedures, outcomes, and complications.

CORNEAL INCISIONAL APPROACHES

Manual or femtosecond laser-assisted corneal incisions are used to correct small amounts of preexisting corneal astigmatism. These incisions cause flattening of the cornea in the incisional meridian and steepening 90° away. The coupling ratios (flattening to steepening) are typically close to 1 and therefore have no effect on the spherical equivalent. However, larger incisions or those located more centrally can have higher coupling ratios that induce net corneal flattening and therefore a mild hyperopic shift.

MANUAL CORNEAL INCISIONAL APPROACHES

In the past, transverse corneal incisions located within the central 5 to 7 mm zones have been used. Although these can correct 2 D or more of astigmatism, they pose the risk for inducing irregular corneal astigmatism and reducing quality of vision. This has prompted a transition in technique in most instances to arcuate incisions placed at zones of 8 mm or more, with a goal of correcting at most 1 to 1.5 D of astigmatism. These incisions are referred to as peripheral corneal relaxing incisions (PCRIs) (or limbal relaxing incisions [LRIs], which is a misnomer because the incisions are not placed in the limbus).

Manual incisional options for treating astigmatism actually include three options:

- Operating on steep meridian: This approach can be used if the main cataract incision is >3 mm because smaller incisions induce minimal astigmatism and are not effective in reducing corneal astigmatism.[2]

- Opposite clear corneal incisions: With this approach, the main clear corneal cataract incision and another incision 180° away are placed along the corneal steep meridian.
- Peripheral corneal relaxing incisions: This is our preference. The main cataract incision is placed at the surgeon's preferred location, presumably inducing minimal or at least predictable astigmatic change, and PCRIs are centered at the corneal steep meridian in the peripheral clear cornea.

FEMTOSECOND LASER-ASSISTED CORNEAL INCISIONAL APPROACHES

Using femtosecond laser technology, corneal relaxing incisions (CRIs) can be performed in two ways:

- Penetrating CRIs: The incisions penetrate the anterior corneal surface and are typically set at 80% corneal depth. The potential benefit of penetrating CRIs is that these incisions can be left closed, opened intraoperatively under guidance from intraoperative aberrometry, or opened postoperatively as needed to titrate their effect.
- Intrastromal CRIs: The incisions are placed in the stroma without penetrating the anterior and posterior corneal surfaces, typically with 20% of the posterior and anterior cornea uncut. Intrastromal incisions can be used to treat low amounts of astigmatism, up to 0.75 to 1.00 D. The potential benefit of intrastromal CRIs is less chance of wound gape, inflammation, and patient discomfort.[3]

PREOPERATIVE EVALUATION AND PLANNING

Thorough and careful preoperative evaluation and planning are crucial in avoiding postoperative surprises and unhappy patients.

- Ocular surface disease (OSD) detection: Any OSD, most commonly dry-eye disease, can reduce the quality of corneal topography and accuracy of corneal power and astigmatism measurements preoperatively. Ocular surgery and, in particular, relaxing incisions can exacerbate uncontrolled OSD and lead to worsened vision, increased symptoms, and overall dissatisfaction postoperatively.[4] In patients presenting for cataract surgery evaluation, 80% have at least one abnormal tear test.[5]
- Corneal topography/tomography evaluation: This is essential to rule out irregular corneal astigmatism, ectatic disorders, abnormally thin corneas, or contact lens-induced corneal distortion. Placido-based imaging is helpful in detecting surface abnormalities. Corneal topography also detects asymmetric astigmatism, which can be addressed with incisions of asymmetric length.
- Corneal astigmatism determination: It is important to determine the magnitude and steep meridian of the corneal astigmatism with at least two devices, and also take into account posterior corneal astigmatism, surgically induced astigmatism, and lens tilt.[6–8] To compensate for the shift toward ATR with age, we target mild residual WTR astigmatism of around 0.2 D. Details regarding the consideration of preoperative astigmatism is discussed in Chapter 28.

NOMOGRAMS

When adopting a nomogram, it is advisable to closely follow the surgical technique that was used to generate the nomogram. Surgeons can then modify the nomogram later based on own surgical outcomes.

Manual PCRIs

- There are numerous nomograms available that provide incision length and number based on a patient's age and magnitude and the steep meridian of the astigmatism.

TABLE 29.1 Baylor Nomogram for Manual Peripheral Corneal Relaxing Incisions (PCRIs) During Cataract Surgery Combined With a Temporal 2.4 mm Clear-Corneal Incision

Preop keratometric astigmatism (D)	Age (years)	Number	Incision length (degree)
WTR (70 - 110°)			
1.25–1.75	<65	2	45*
	≥65	2	35
>1.75	<65	2	60
	≥65	2	50
ATR/oblique			
0.4–0.8	–	2	30**
0.81–1.2	–	2	40
≥1.2	–	2	45

*Or one incision of 50 degrees if asymmetric astigmatism
**Or single incision of 35 to 40 degrees if asymmetric astigmatism

- The Baylor PCRI nomogram (Table 29.1) incorporates our data on posterior corneal astigmatism.[6] It is designed for use in combination with a 2.4 mm temporal corneal incision and placement of the PCRIs at the end of surgery.
- There are online calculators, such as the Limbal Relaxing Incision Calculator from Johnson and Johnson (www.jnjvisionpro.com/calculators-tools).

Femtosecond Penetrating CRIs

To prevent the risk for incisional gape that induces irregular astigmatism, we recommend limiting the penetrating incision length to 45° for incisions made along the horizontal meridian and 60° for incisions centered on the vertical meridian.

- Baharozian and colleagues[9] proposed the modified Donnenfeld nomogram, which is a modification of the manual Donnenfeld limbal relaxing incision nomogram to 70% of the suggested treatment for WTR, 80% for oblique, and 100% for ATR astigmatism. This adjustment was applied to avoid overcorrections by taking into account of two factors: (1) the smaller optical zones used with femtosecond penetrating CRIs, compared with manual LRIs on which Donnenfeld nomogram was based; and (2) the effect of posterior corneal astigmatism.
- Using the LenSx laser system, we proposed a nomogram from results of penetrating CRIs placed at a diameter of 8.0 mm and a depth of 90%.[10] Based on age and preoperative corneal WTR or ATR astigmatism, the nomogram displays the expected total net corneal changes induced by certain lengths of paired CRIs (Table 29.2).
- Using the Catalys laser platform, in a recent two-center study,[11] we developed a nomogram based on results of penetrating CRIs with a 9-mm optical zone and 20% uncut posterior (Table 29.3). The table lists the net corneal change along the CRI meridian based on incision length and preoperative anterior corneal astigmatism obtained from the IOLMaster 700.

Femtosecond Intrastromal CRIs

- Julian Stevens developed a calculator for intrastromal CRIs using the Catalys laser (femtoemulsification.com).
- Using the Catalys laser platform, in a recent two-center study,[11] we developed a nomogram based on results of intrastromal CRIs with 20% uncut anterior and 20% uncut posterior at an

TABLE 29.2 Femtosecond Laser Penetrating Corneal Relaxing Incision Nomogram (LenSx Laser System, 8 mm Optical Zone, and 90% depth): Net Corneal Change (D) Along the Steep Meridian Based on Age and Length of Corneal Relaxing Incision in Eyes With WTR and ATR Corneal Astigmatism[10]

Paired Incision Length (°)	50 years	60 years	70 years	80 years
WTR eyes				
20	-	-	-	-
25	-	-	-	0.06
30	0.06	0.14	0.23	0.31
35	0.31	0.40	0.48	0.57
40	0.57	0.65	0.74	0.82
45	0.82	0.91	0.99	1.08
50	1.07	1.16	1.25	1.33
55	1.33	1.42	1.50	1.59
60	1.58	1.67	1.76	1.84
ATR eyes				
20	-	0.05	0.13	0.22
25	0.22	0.30	0.39	0.48
30	0.47	0.56	0.64	0.73
35	0.73	0.81	0.90	0.98
40	0.98	1.07	1.15	1.24
45	1.24	1.32	1.41	1.49
50	1.49	1.58	1.66	1.75
55	1.74	1.83	1.92	2.00
60	2.00	2.08	2.17	2.26

–: not applicable.

8.0 mm optical zone (Table 29.4). The table lists the net corneal change along the CRI meridian based on incision length and preoperative anterior corneal astigmatism obtained from the IOLMaster 700.

SURGICAL PROCEDURE

Precise meridional alignment is crucial for accurate astigmatic correction. Either manual marking or image guidance alignment systems can be used. We believe that accuracy is comparable for the two approaches, assuming meticulous attention to the manual marking process.[12] To avoid the problem of failure of an automated system to capture the eye image intraoperatively, we mark all eyes in the preoperative area with patient sitting upright and looking straight ahead. Details regarding alignment methods are described in Chapter 30.

Manual PCRIs

The key equipment needed for performing the manual PCRIs includes a marker and a blade. Various markers are available, such as the Sinskey hook, Koch LRI markers (Fig. 29.1a) (ASICO, Inc., Chicago, IL, USA), and Mastel Arcuate Corneal Compass (see Fig. 29.1b) (Master Precision Surgical Instruments, Inc., Rapid City, SD, USA). A large number of blade types and designs are available. We prefer a triangular or thin trapezoidal blade with a single footplate, which allows good visibility while making the incision. For more central corneal incisions, an adjustable micrometer knife is desirable.

PCRIs can be performed at the beginning or near the end of surgery. The techniques include the following:

- Mark the eye at 3 and 9 o'clock or some other combination of the 3, 6, 9, and 12 o'clock positions with the patient sitting upright, and note the precise location of the marks relative to the intended sites.
- Set the diamond blade at 600 µm or 90% of depth based on intraoperative pachymetry readings.
- Using a degree gauge, mark the corneal steep meridian and the length of the incisions.
- To make the incision, stabilize the eye with forceps or an incision guide. Insert the blade at the end of the intended incision adjacent to the site of globe fixation. It is preferable to move or pull the blade away from the point of fixation rather than push toward it.
- Pause while the blade reaches full depth.
- Move the blade slowly to complete the incision.
- See Video 29.1 for demonstration of two systems for making PCRIs.

Special considerations regarding the location of PCRIs:

- If the PCRI is in the same meridian as the cataract incision, place it at the end of the surgery by extending the main cataract wound.
- If the PCRI overlaps one's typical meridian for a paracentesis incision, options include making the paracentesis peripheral to the PCRI, or, our preference, move the paracentesis to either side, leaving at least 1 mm of uncut cornea between the 2 incisions.[2]

FEMTOSECOND CRIs

All major femtosecond laser platforms are capable of performing CRIs during the cataract surgery. The treatment parameters may vary depending on the laser system. With the Catalys laser system, typical penetrating incision parameters are penetrating anterior, 20% uncut posterior, and 90° side-cut angle at a 9.0 mm optical zone. The intrastromal incision parameters are 20% uncut anterior, 20% uncut posterior, and 90° side cut angle at an 8.0 mm optical zone. The surgical techniques are as follows:

- Mark the eye as described above.
- Program the laser parameters.
- Place patient under the laser and anesthetize the eye.
- Apply suction ring and laser interface.

TABLE 29.3 Paired Penetrating Corneal Relaxing Incision (CRI) Nomogram (Catalys Laser System, 9 mm Optical Zone, and 80% depth): Net Corneal Change (D) Along the CRI Meridian Based on Incision Length and Preoperative Anterior Corneal Astigmatism Obtained From the IOLMaster 700 in Corneas That Have With-the-Rule (WTR), Oblique, and Against-the-Rule (ATR) Corneal Astigmatism[11]

	Corneal relaxing incision length*							
Preoperative corneal astigmatism (D)	25°	30°	35°	40°	45°	50°	55°	60°
WTR eyes								
0.8	0.06	0.14	0.22	0.30	0.38	0.46	0.54	0.62
0.9	0.10	0.18	0.26	0.34	0.42	0.50	0.58	0.66
1.0	0.15	0.23	0.30	0.38	0.46	0.54	0.62	0.70
1.1	0.19	0.27	0.35	0.43	0.51	0.58	0.66	0.74
1.2	0.23	0.31	0.39	0.47	0.55	0.63	0.71	0.78
1.3	0.27	0.35	0.43	0.51	0.59	0.67	0.75	0.83
1.4	0.31	0.39	0.47	0.55	0.63	0.71	0.79	0.87
1.5	0.35	0.43	0.51	0.59	0.67	0.75	0.83	0.91
Oblique eyes								
0.5	0.02	0.10	0.18	0.26	0.34	–	–	–
0.6	0.06	0.14	0.22	0.30	0.38	–	–	–
0.7	0.10	0.18	0.26	0.34	0.42	–	–	–
0.8	0.14	0.22	0.30	0.38	0.46	–	–	–
0.9	0.18	0.26	0.34	0.42	0.50	–	–	–
1.0	0.22	0.30	0.38	0.46	0.54	–	–	–
1.1	0.27	0.35	0.42	0.50	0.58	–	–	–
1.2	0.31	0.39	0.47	0.55	0.63	–	–	–
1.3	0.35	0.43	0.51	0.59	0.67	–	–	–
1.4	0.39	0.47	0.55	0.63	0.71	–	–	–
1.5	0.43	0.51	0.59	0.67	0.75			
ATR eyes								
0.3	0.39	0.47	0.55	0.63	0.71	–	–	–
0.4	0.43	0.51	0.59	0.67	0.75	–	–	–
0.5	0.48	0.56	0.64	0.71	0.79	–	–	–
0.6	0.52	0.60	0.68	0.76	0.84	–	–	–
0.7	0.56	0.64	0.72	0.80	0.88	–	–	–
0.8	0.60	0.68	0.76	0.84	0.92	–	–	–
0.9	0.64	0.72	0.80	0.88	0.96	–	–	–
1.0	0.68	0.76	0.84	0.92	1.00	–	–	–
1.1	0.72	0.80	0.88	0.96	1.04	–	–	–
1.2	0.76	0.84	0.92	1.00	1.08	–	–	–
1.3	0.80	0.88	0.96	1.04	1.12	–	–	–
1.4	0.84	0.92	1.00	1.09	1.16			
1.5	0.89	0.97	1.04	1.12	1.20			

*We recommend an upper limit of 45 degrees for incisions in oblique and horizontal meridians. –: not applicable.

- Create the penetrating or intrastromal incisions.
- For penetrating incisions, dissect them open intraoperatively or leave them closed with the option to open them postoperatively to increase the effect.

OUTCOMES

Manual PCRIs

- In a previous study, we analyzed the effectiveness of PCRIs in correcting corneal astigmatism during cataract surgery. PCRIs significantly decreased preoperative keratometric astigmatism. The net corneal changes did not regress from 1 day to 4 months postoperatively.[13]
- Ouchi and Kinoshita[14] evaluated clinical outcomes of LRIs combined with cataract surgery. Eyes with keratometric astigmatism ≥0.75 D were randomly assigned to non-LRI group or LRI group. The uncorrected distance visual acuity was significantly better and postoperative residual cylinder was significantly lower in the LRI group than in the non-LRI group.

FEMTOSECOND PENETRATING CRIs

Outcomes of femtosecond penetrating CRIs combined with cataract surgery were reported for the VICTUS and LenSx lasers.[10,15–17] The main outcomes were as follows:

- Mean preoperative corneal astigmatism was reduced significantly.

TABLE 29.4 Paired Intrastromal Corneal Relaxing Incision (CRI) Nomogram (Catalys Laser System, 8 mm Optical Zone, and 20% Uncut Anterior and 20% Uncut Posterior): Net Corneal Change (D) Along the CRI Meridian Based on Incision Length and Preoperative Anterior Corneal Astigmatism Obtained From the IOLMaster 700 in Corneas That Have With-the-Rule (WTR), Oblique, and Against-the-Rule (ATR) Corneal Astigmatism[11]

	Corneal relaxing incision length							
Preoperative corneal astigmatism (D)	25°	30°	35°	40°	45°	50°	55°	60°
WTR eyes								
0.8	-	-	0.07	0.16	0.25	0.33	0.42	0.51
0.9	-	0.04	0.12	0.21	0.30	0.38	0.47	0.56
1.0	-	0.09	0.18	0.26	0.35	0.44	0.52	0.61
1.1	0.05	0.14	0.23	0.31	0.40	0.49	0.57	0.66
1.2	0.10	0.19	0.28	0.36	0.45	0.54	0.63	0.71
1.3	0.13	0.24	0.33	0.42	0.50	0.59	0.68	0.76
1.4	0.16	0.29	0.38	0.47	0.55	0.64	0.73	0.81
1.5	0.26	0.34	0.43	0.52	0.61	0.69	0.78	0.87
Oblique eyes								
0.5	0.04	0.13	0.22	0.30	0.39	0.48	0.56	0.65
0.6	0.09	0.18	0.27	0.36	0.44	0.53	0.62	0.70
0.7	0.15	0.23	0.32	0.41	0.49	0.58	0.67	0.75
0.8	0.20	0.28	0.37	0.46	0.54	0.63	0.72	0.81
0.9	0.25	0.35	0.42	0.51	0.60	0.68	0.77	0.86
1.0	0.30	0.39	0.47	0.56	0.65	0.73	0.82	0.91
1.1	0.35	0.44	0.52	0.61	0.70	0.79	0.87	0.96
1.2	0.40	0.49	0.58	0.66	0.75	0.84	0.92	1.01
1.3	0.45	0.54	0.63	0.71	0.80	0.89	0.97	1.06
1.4	0.50	0.59	0.68	0.77	0.85	0.94	1.03	1.11
1.5	0.56	0.64	0.73	0.82	0.90	0.99	1.08	1.16
ATR eyes								
0.3	0.34	0.42	0.51	0.60	0.68	0.77	0.86	0.94
0.4	0.39	0.47	0.56	0.65	0.74	0.82	0.91	1.00
0.5	0.44	0.53	0.61	0.70	0.79	0.87	0.96	1.05
0.6	0.49	0.58	0.66	0.75	0.84	0.92	1.01	1.10
0.7	0.54	0.63	0.72	0.80	0.89	0.98	1.06	1.15
0.8	0.59	0.68	0.77	0.85	0.94	1.03	1.11	1.20
0.9	0.64	0.73	0.82	0.90	0.99	1.08	1.17	1.25
1.0	0.70	0.78	0.87	0.96	1.04	1.13	1.22	1.30
1.1	0.75	0.83	0.92	1.01	1.09	1.18	1.27	1.35
1.2	0.80	0.88	0.97	1.06	1.15	1.23	1.32	1.41
1.3	0.85	0.94	1.02	1.11	1.20	1.28	1.37	1.46
1.4	0.90	0.99	1.07	1.16	1.25	1.33	1.42	1.51
1.5	0.95	1.04	1.13	1.21	1.30	1.39	1.47	1.56

–: not applicable.

- The percentages of eyes with postoperative refractive astigmatism of ≤0.50 D ranged from 44% to 95.8%.
- Stability of femtosecond penetrating CRIs was well-maintained over 5 years.

FEMTOSECOND INTRASTROMAL CRIs

Using the Catalys and LenSx lasers, studies reported the results of femtosecond intrastromal CRIs combined with cataract surgery.[18–20] The main results were as follows:

- Corneal astigmatism was significantly reduced.
- The percentages of eyes with postoperative refractive astigmatism of ≤0.50 D ranged from 32.1% to 42%.
- Regression of 0.11 D occurred between 1 and 6 months after intrastromal CRIs.

PROSPECTIVE COMPARATIVE STUDIES

- Manual PCRIs vs. toric IOLs: In a randomized study in eyes with preoperative corneal astigmatism between 1.0 and 2.0 D, Leon et al.[21] reported that these two surgical procedures significantly decreased refractive astigmatism, but toric IOL implantation was more effective and predictable compared with the LRIs. In patients with preoperative corneal astigmatism between 0.75 D and 2.0 D, Nanavaty et al.[22] found that there was no difference in visual acuity, although more toric IOL patients gained ≥1 line of vision.

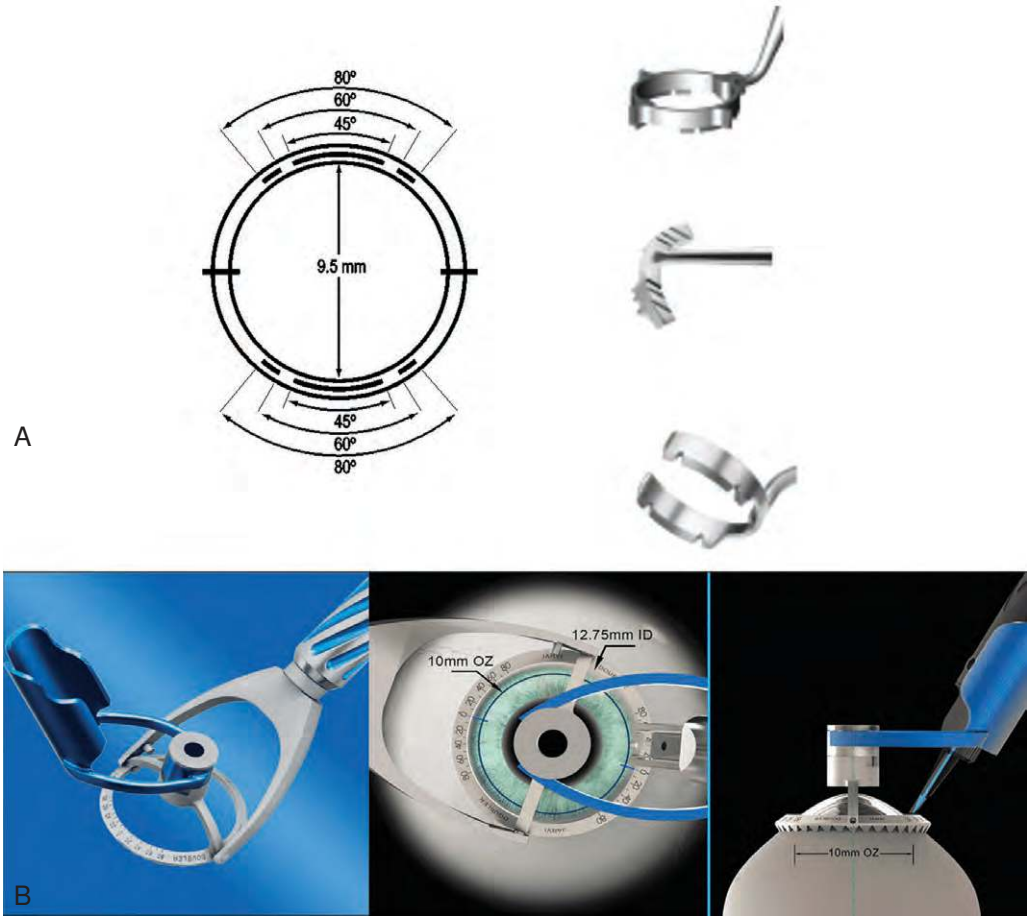

Fig. 29.1 Manual corneal relaxing incision markers. (A) Koch LRI markers (Courtesy ASICO Inc., asico.com). (B) Mastel Arcuate Corneal Compass. Courtesy Master Precision Surgical Instruments, Inc., Mastel.com.

Hirnschall et al.[23] reported that toric IOLs and PCRIs both reduced astigmatism; however, toric IOLs reduced astigmatism to a higher extent and were more predictable.

- Manual PCRIs combined with multifocal IOLs vs. multifocal toric IOLs: Prospectively, Gangwani et al.[24] compared the outcomes and found that the mean residual refractive astigmatism was lower in the toric IOL group than that in the PCRI group (0.45 D vs. 0.72 D).
- Manual LRIs vs. femtosecond intrastromal CRIs: In a randomized case-controlled trial, Roberts and colleagues[25] reported that femtosecond intrastromal CRIs achieved a smaller difference vector and less postoperative refractive astigmatism than manual LRIs. Postoperative refractive astigmatism of <0.50 D was achieved in 44% of eyes in the femtosecond CRIs group and 20% in the manual LRIs group.
- Femtosecond penetrating CRIs vs. intrastromal CRIs: In a prospective randomized two-center study,[11] we found that penetrating CRIs and intrastromal CRIs were equally effective in reducing corneal astigmatism. The percentages of eyes with postoperative refractive astigmatism of ≤0.5 D were 84% and 76% in the penetrating CRIs and intrastromal CRIs groups, respectively.

Factoring in these studies and our own data, we reserve relaxing incisions to treat anticipated postoperative astigmatism of over 0.5 D, generally with a maximum of 1.5 D. Toric IOLs are used to correct one or more diopters, again considering that we attempt to leave all eyes with around 0.25 D of WTR astigmatism to account for drift with age.

POTENTIAL COMPLICATIONS

The possible complications of corneal incisional approaches for reducing astigmatism during cataract surgery are listed in Box 29.1. Excessively long anterior corneal penetrating incisions should be avoided because they are prone to wound gape, especially when placed along the horizontal meridian. In our experience and as reported in the peer-reviewed literature, sight-threatening complications are rare. Close postoperative follow-up may help in early detection and timely management of these complications.

BOX 29.1 Potential Complications

- Over- or undercorrection
- Dry eye
- Irregular corneal astigmatism
- Epithelial defects
- Epithelial ingrowth into incision
- Perforation with hypotony
- Wound gape
- Visual loss
- Infection

SUMMARY

Corneal incisional approaches are effective and safe in correcting low amounts of corneal astigmatism during the cataract surgery. The key takeaways are summarized below:

- Perform careful preoperative evaluation to detect ocular surface disease.
- Obtain corneal topography to rule out irregular astigmatism and corneal pathology, such as keratoconus and pellucid marginal degeneration.
- Measure corneal astigmatism with at least two devices, and take into account of posterior corneal astigmatism and a possible slight against-the-rule contribution of IOL tilt when determining the amount of astigmatism to correct.
- Limit the length of penetrating corneal incisions up to 45° along the horizontal meridian and 60° along the vertical meridian.
- Ensure precise alignment of the incisions on intended corneal meridian.
- Consider toric IOLs for corrections of >1 diopter.

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Video 29.1 Corneal relaxing incisions performed using two systems.

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Toric Intraocular Lenses: Selection and Alignment Methods

Graham Barrett, Douglas D. Koch, and Li Wang

CONTENTS

KEY POINTS

- The ability to accurately predict the required toric cylinder for an IOL is essential to the success of refractive cataract surgery and requires appropriate formulae that consider posterior corneal astigmatism.
- Measurements of corneal astigmatism can vary and are best performed with more than one instrument with a method to construct a mean or median vector from these instruments.
- Accurate alignment is essential, particularly for higher toric cylinder powers, and can be achieved with computerized limbal vessel registration to identify landmarks or smart phone apps to determine an accurate reference axis in relation to the desired meridian for the toric IOL.

INTRODUCTION

There is no benefit from leaving residual astigmatism. Low levels of astigmatism do not assist intermediate or near vision and impaired contrast, and reading speed is evident with residual astigmatism in the 0.5 D to 0.75 D range.[1,2] Patient satisfaction correlates with low levels of astigmatism,[3] and with toric IOLs we are able to achieve within 0.5 D residual astigmatism for the majority of our patients.[4] Many consider that patients who present with ~0.5 D of anterior corneal astigmatism would not benefit from a toric IOL. This is mistaken because measurements of the anterior cornea do not consider the contribution of the posterior cornea,[5] surgical-induced astigmatism (SIA), and IOL tilt[6]; in addition, the error in prediction of residual astigmatism is ~ 0.33 D (standard deviation of 0.18 D). As with spherical prediction, a target close zero is required if the aim is for residual astigmatism within 0.5 D. A large cataract surgery database shows that greater than 76.1% of the eyes have 0.50 D of total corneal astigmatism or more.[7] The logic therefore suggests that ~80% of the patients require a toric IOL, as in my practice in Australia (GDB) where the cost of a toric IOL is reimbursed by insurance.

Selecting an IOL for patients in this context requires accurate **prediction**, reliable **measurements**, and precise **alignment**.

Definitions

- Fixed ELP (effective lens position) calculators: Fixed ELP calculators such as the legacy Alcon calculator measured the astigmatism based on the K values of the anterior cornea and then used vector math to determine the required IOL cylinder based on a fixed effective lens position, or ELP.[8]
- Dynamic ELP calculators: The next generation of calculators such as the original Holladay toric calculator incorporated the predicted ELP to calculate the required toric cylinder to correct measured corneal astigmatism.[9]
- Regression-based posterior cornea calculators: Current toric calculators such as the Abulafia-Koch and Johnson & Johnson account for the against-the-rule impact of the posterior cornea and other factors such as IOL tilt.[10]
- Back-calculated toric calculators: The new Holladay toric calculator is based on the concept of the back-calculated SIA, which accounts for all factors that contribute to the difference between the preoperative K-reading and the ideal, back-calculated K-reading.[11] The total SIA is calculated using the Gaussian vergence formula.
- Theoretical model-based toric calculators: The Barrett toric calculator uses the ellipticity of the cornea to explain why the posterior cornea contributes approximately 0.5 D of ATR cylinder. It is not primarily population based but calculates a unique theoretical value based on the ocular parameters.[12,13]
- Mean absolute residual refractive astigmatism: Astigmatism magnitude independent of axis.
- Centroid error in predicted residual refractive astigmatism: The mean geometric vector and considers both astigmatism/cylinder power and axis or meridian.
- Surgically induced astigmatism (SIA): Commonly used to refer to the corneal SIA induced by surgical incision but can also be used to refer to total corneal astigmatism associated with surgery.

Comorbidities

Dry Eye: An unstable tear film caused by dry eye may compromise keratometry and biometry should be repeated or delayed until this has been addressed.[13]

Pterygium: Pterygia can induce corneal astigmatism and lead to asymmetry that can limit the vision after cataract surgery.

Corneal Scars: Central corneal scars can impact potential acuity and cause irregular astigmatism.

Salzmann Nodules: Degenerative nodules of the corneal surface can cause irregular astigmatism and unreliable keratometry.

Anterior corneal dystrophies: Dystrophies such as epithelial basement membrane and Thiel-Behnke can cause marked irregularity of the anterior corneal surface.

Keratoconus: Keratoconus and pellucid marginal degeneration are relatively common causes of irregular astigmatism and may preclude toric IOLs if the potential for corrected acuity has always been poor prior to the development of cataract. Forme fruste changes may only be evident on corneal topography or tomography, which is one of the reasons this examination should be included in all cases where toric lenses are considered. Toric IOLs can still be used in this context, but the information is essential in setting expectations. In general, we believe that keratoconus eyes can be implanted with toric IOLs if:

- The ectasia has stabilized.
- Topography or tomography is fairly uniform over the central 3 mm with a fairly regular bowtie pattern
- The magnitude and meridian of astigmatism is fairly consistent among the refraction and more than one corneal measurement.
- The patient does not want contact lens correction postoperatively.

PREOPERATIVE MANAGEMENT

Prediction

There are several different toric calculators available, and the prediction error varies depending on the principles upon which the method is based. The differences are best illustrated by comparing the outcomes in a series of 617 eyes that I (GDB) have evaluated in my own patients.

Analyzing outcomes using postoperative Ks and actual alignment of the toric IOL, I (GDB) found these results:

- With the legacy Alcon toric calculator that uses a fixed ELP and does not account for the posterior cornea, only 43% have a prediction within 0.5 D of predicted residual astigmatism (mean absolute residual cylinder), and the mean vector or centroid error is approximately 0.5 D of against-the-rule astigmatism (Fig. 30.1).
- With dynamic ELP calculators that consider the ELP but not the posterior cornea, the error in predicted residual astigmatism (mean absolute residual cylinder) is again within 0.5 D of predicted residual astigmatism in only 43% of eyes; there is again an overall against-the-rule trend with a centroid error of -0.5 D @ 87.7% (Fig. 30.2).
- Using a mathematical model-based toric calculator that accounts for factors such as the posterior cornea and IOL tilt either by regression (Abulafia-Koch) or a theoretical model (Barrett), the centroid error is typically close to zero, and 83.6% and 88.2%, respectively, have a prediction error (mean absolute residual cylinder) within 0.5 D in the same data set (Fig. 30.3).
    - The importance of considering the posterior cornea in being able to accurately predict toric IOLs with adequate accuracy for refractive cataract surgery is clearly evident, as originally reported by Koch et al.[14]

Note that these calculations are based on postoperative keratometry measurements, so actual results will vary in the clinical setting using preoperative corneal readings. It is important to understand a key difference between the Barrett and Abulafia-Koch calculators compared with the Holladay back-calculated toric calculator. For the former two, surgeons should enter the SIA based on estimation or their prior calculations, whereas the Holladay calculator incorporates the estimated SIA for a temporal 2.4-2.7-mm clear corneal incision, so no additional value for SIA should be used.

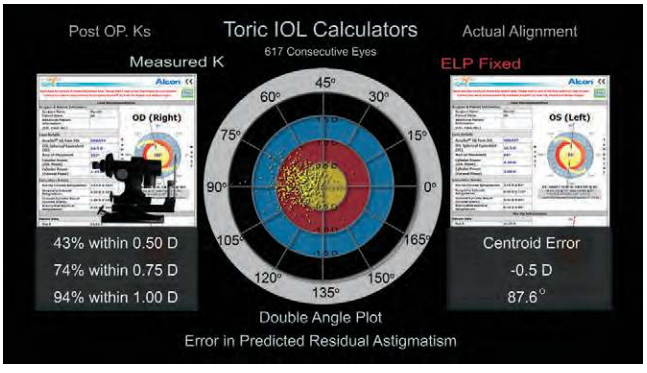

Fig. 30.1 Error in predicted residual astigmatism in 617 eyes for fixed ELP Legacy Alcon toric calculator, calculated with post op Ks and measured alignment of toric IOL. Percentage of eyes within 0.5 D of predicted residual astigmatism (mean absolute residual astigmatism), centroid error, and double angle plot display of individual vector error.

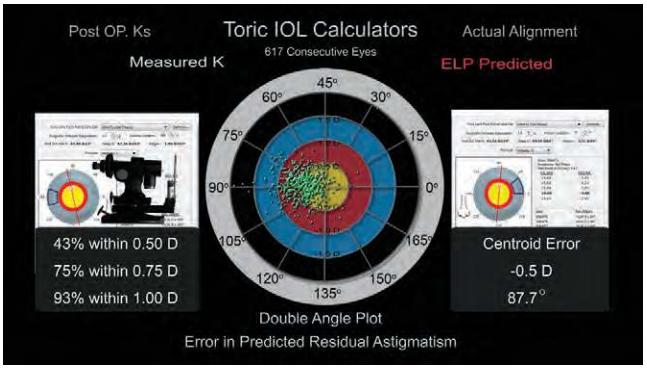

Fig. 30.2 Error in predicted residual astigmatism in 617 eyes for Dynamic ELP calculator, calculated with postoperative Ks and measured alignment of toric IOL. Percentage of eyes within 0.5 D of predicted residual astigmatism (mean absolute residual cylinder), centroid error and double angle plot display of individual vector error.

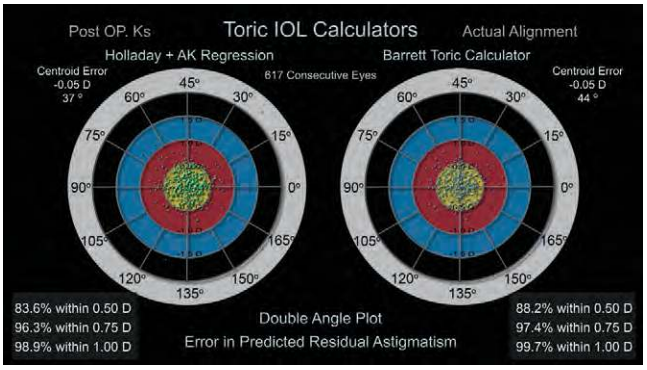

Fig. 30.3 Error in predicted residual astigmatism in 617 eyes for toric calculators that account for the posterior cornea either by regression (Abulafia-Koch) or a theoretical model (Barrett), calculated with post op Ks and measured alignment of toric IOL. Percentage of eyes within 0.5 D of predicted residual astigmatism (mean absolute residual cylinder), centroid error and double angle plot display of individual vector error.

Refractive Target

We (DDK and LIW) first proposed leaving toric IOL patients with a small amount of with-the-rule astigmatism to account for the tendency for corneas to drift against-the-rule over time as reported by Hayashi et al.[15]

- The target would be the toricity that leaves the eye with the smallest amount of with-the-rule refractive astigmatism.
- Concerns have been raised that patients with against-the-rule or oblique astigmatism might be bothered by changing the refractive axis.

  - This would be caused by a change in meridional magnification with spectacle correction.
  - Fortunately, this is not a concern with small amounts of refractive astigmatism.
  - In addition, the goal is spectacle independence for as many years as possible.
- A disadvantage of this approach would be excessive overcorrection impairing uncorrected acuity.

History

A history of previous refractive surgery is critical in selecting the appropriate formula, not only for spherical prediction but also for toric calculation. A specific toric calculator (e.g., the True K toric calculator [apacrs.org]) is advantageous in this context.

A history of previous contact lens wear is important, and our recommendation is to avoid soft contact lens wear for a minimum of 1 week prior to biometry. A history of rigid contact lens wear is more challenging. It often takes several weeks for the corneal shape and astigmatism to revert to normal and stabilize. We measure corneal topography in RGP patients on their initial visit and then at 2- to 3-week intervals until curvature stabilizes. This can be difficult for high myopes and changing to soft contact lens wear during this period can be helpful.

Slit Lamp Exam

Examination of the anterior segment should focus on the cornea, lens, and the ocular surface and lids.

- The lid margin may show evidence of meibomian gland dysfunction, which may need to be treated prior to biometry. Similarly, an unstable tear film caused by dry eye may compromise keratometry, and biometry should be repeated or delayed until this has been addressed with frequent lubricants.
- The presence of pterygia should be noted and whether these are quiescent with little impact on corneal astigmatism or have extended sufficiently to contribute to the measured corneal astigmatism and particularly to asymmetry. This will be confirmed by topography, and in some circumstances removal prior to surgery is preferred.
- Likewise, corneal scarring or degenerative (Salzmann) nodules that impact on the measured astigmatism may require removal or phototherapeutic keratectomy prior to cataract surgery.

Fundus examination is also important as in any cataract evaluation, particularly to assess the macula. Routine macula OCT is recommended to detect epiretinal membranes, which may contribute to reduced acuity in the presence of cataract. This does not preclude the use of toric IOLs, but the potential impact of macular problems does need to be discussed with patients prior to cataract and will influence the selection of the type of IOL if detected.

Measurements

Accurate measurements of axial length, keratometry, anterior chamber depth (ACD) lens thickness, and white to white are all the cornerstones for predicting the required spherical and toric power required for the desired refractive outcome in an individual patient.

Although parameters such as the axial length and ACD and predicted spherical lens power do impact the calculation of the toric lens power required to correct preexisting astigmatism, the measurement of the corneal power and astigmatism is the most important factor that determines the required toric cylinder and required meridian for alignment.

Measuring the Anterior Corneal Surface

- As mentioned, the ocular surface should be optimized and pterygia removed if required, but it is not uncommon for the measured corneal astigmatism to vary on different occasions and with different instruments.
- We recommend measuring the cornea with at least two devices: the biometer and topographer or tomographer.
- Topography or tomography provides a graphical display of the power distribution of the corneal surface, and it is quite sobering to notice how frequently the mires are not orthogonal with an irregular distribution. This is more evident with lower levels of astigmatism, and many surgeons resort to repeat measurements after lubricants as a strategy to provide more accurate measurements. This can be helpful, but sometimes the topography is unchanged, and repeating measurements on all patients can be a logistical challenge.
- The concept of considering multiple instruments as secondary devices to validate the measurement of a primary or preferred device for the magnitude and meridian of astigmatism is well established, but the process is subjective and can be time consuming.
- Furthermore, because astigmatism has both a magnitude and direction, it is invalid to combine the axis of astigmatism from one device with the magnitude of the cylinder from another, as commonly practiced.

To simplify the process of combining multiple instruments, I (GDB) have incorporated a "K calculator" as part of the online Barrett toric calculator. This method allows the user to select the keratometry of up to three devices and provides an integrated K using appropriate vector mathematical calculation.

- If two devices are selected, the integrated K is the mean of the two devices, and, if three devices are selected, then the integrated K is the median of the three devices.
  - The latter measure of central tendency de-emphasizes outliers and proved to be the most accurate predictor with the lowest prediction error of residual astigmatism when analyzing my own patients undergoing toric IOL implantation using preop Ks and the measured post alignment of the IOL.
  - I (GDB) use this approach for all toric calculations using the IOLMaster and Lenstar biometers and the anterior surface measurement of the Pentacam topographer.
  - The percentage of cases predicted to be within 0.5 D of residual astigmatism is ~71% using the Lenstar and improved to 78% with the integrated K (presented by GDB at the 2018 annual meeting of ASCRS).
- The integrated K proved to be as accurate as the keratometry of a single device in predicting spherical outcome.

The concept of using an integrated K from multiple devices is an effective and efficient method to measure the astigmatism of anterior corneal surface and reduced the necessity for repeat measurements and the complexity of interpreting the measurements of multiple instruments.

Measuring the Posterior Corneal Surface

There is widespread agreement that the posterior cornea must be considered in predicting the correct toric IOL required for an individual patient.

If ignored, patients with preexisting against-the-rule astigmatism will have a mean undercorrection of ~0.3 D and those with preexisting with-the-rule astigmatism will be overcorrected by ~0.5 D.[14]

The posterior cornea can be measured using Scheimpflug based tomographers or swept source OCT biometers. In a comparative study, however, theoretical models for prediction of the posterior cornea were more accurate than predictions that used a conventional toric calculator using measurements that included the posterior corneal power such as True Net Corneal Power.[16] The reason is that not all unexplained

postoperative astigmatism post-cataract surgery is due to the posterior cornea.

The online Barrett toric calculator has an option to use the measured posterior cornea as an option to the theoretical prediction and recognizes that not all residual astigmatism is caused by the posterior cornea. The visual axis is not aligned with the optical axis, which induces apparent IOL tilt, and the toric calculator includes an algorithm for this component whether the posterior corneal astigmatism is based on a theoretical prediction or direct measurement.

Comparisons using this method have demonstrated it to have an equivalent prediction accuracy as the default predicted (PCA) and may be more accurate for unusual corneas such as keratoconus and for eyes that have undergone previous refractive surgery.[17] The Barrett TK formula within the IOLMaster 700 selectively uses the measured posterior corneal values (PK1 and PK2) and not the TK value and is therefore equivalent to the online formulae that use the Measured PCA.[17,18]

IOL Selection

- The majority of toric IOL misalignments are caused by misalignment at the time of surgery or occur in the first few hours after implantation.
- Certain IOL models tend to rotate more than others in the immediate postoperative period.
- Toric misalignment is more likely in high myopes, and CTRs are often used to reduce this likelihood. However, we have not found this to be necessary and do not use CTRs in patients with high myopia.
- Toric IOLs are not readily available in very low- or very high-powered IOLs or beyond a maximum toric IOL cylinder power greater than 6 diopters. Custom toric IOLs may be ordered in these circumstances, such as keratoconus.

SURGICAL PROCEDURE

Preoperative Management

Alignment

The impact of toric IOL misalignment is often quoted as a loss of 3.3% of astigmatism correction for every 1° of toric IOL misalignment, such that 10° misalignment ends in about 33% loss of astigmatic effect. This is a simplification, as the impact of misalignment depends on the power of toric cylinder and furthermore is not a linear relationship.

One of us (GDB) used this calculation to estimate that the astigmatic error occurring because of misalignment is:

ASTIGMATIC ERROR = 2.5% of toric Cylinder per Degree of Misalignment.

The impact of misalignment is a function of the sine/cosine mathematical relationship required for vector calculation such that for a given toric cylinder, the astigmatic error per degree is greater close to the desired meridian and less for larger misalignments close to 90 degrees (Fig. 30.4).

A variety of alignment methods are available:

- Freehand marking is adequate to achieve these aims, but it requires careful attention to the marking process if one hopes to achieve less than 0.50 D of residual astigmatism in the majority of patients. Typically, reference marks are made at the presumed 180-degree meridian, and the toric meridian is marked intraoperatively with the assistance of a gauge or adjustable marker in relation to the reference meridian.
  - The critical element in this method is verification of the actual position of the marks. One of us (DDK) makes a drawing of the actual location of the marks relative to the 180-degree meridian, thereby minimizing error caused by assuming that the marks are perfectly located.
  - In a study comparing this method to an automated alignment system[19], there was no difference in accuracy of IOL alignment between manual and automated, with a mean alignment error of < 3 degrees for both methods and no IOLs misaligned by 10 degrees or more.
- Several other innovative methods have been developed to improve accuracy of marking:
  - Slit-lamp axis markers: The Rousseau (Rhein Medical, Inc.) dual-tip slit lamp mounted axis marker is designed to mark the X & Y coordinates at the 6 and 9 o'clock positions for accurate axial alignment. The 11 mm inner diameter and 13 mm outer diameter radial axis marks cover the limbus. The device can also be rotated to specific etched degree marks to allow for marking all astigmatic axes.
  - Steinert/Oliver smartphone marker (Rhein Medical, Inc.): The Steinert/Oliver smartphone marker is a device that can be plugged into any smartphone ear jack. With a level app, the device makes reference radial marks at 3 and 9 o'clock or at the desired final axis on the eye for placement of toric lenses and limbal incisions.
  - Velazquez Gravity Marker: This is a device with four blades and hind weight gravity system for LRI/toric IOL implantation. It marks the horizontal and vertical meridians of the visual axis. The outer ring protects blades from damage, the internal marks help check the IOL alignment at the end of surgery, and the central 5 mm ring serves as a guide for capsulorrhexis.
  - RoboMarker: The RoboMarker is a self-leveling corneal marker with preinked, sterile, disposable tips and an integrated fixation light. Advantages are no marking pen needed, no waiting for autoclaves, and no lights or beeps to adjust to level during marking.
  - Spirit level markers (Neuhann): The spirit level markers use a bubble level for identifying the horizontal axis. The Neuhann toric marker with Tabo system (ASICO LLC) has markings of 0 and 180 degrees at the handle and opposite the handle.
- Marking the corneal limbus at the slit lamp is also widely used, and some studies have suggested that these methods are more accurate than freehand.
- One drawback, however, is that there tends to be movement or recoil from the patient with these methods that can lead to errors.

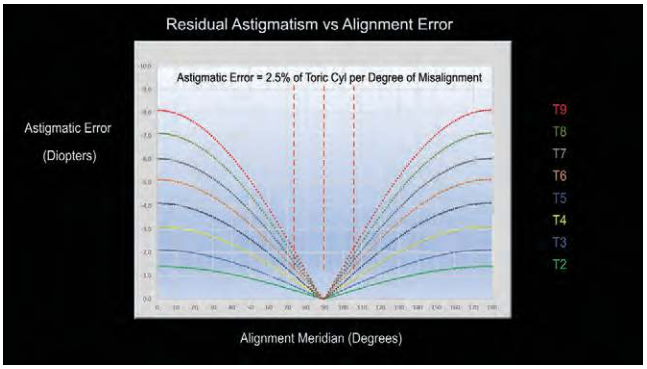

Fig. 30.4 Graph of the residual astigmatism per degree of alignment error for toric IOLs of different cylinder powers (T2 = 1.0 Cyl. T3 = 1.5 Cyl. T4 = 2.25 Cyl. T5 = 3.0 Cyl. T6 = 3.75 Cyl. T7 = 4.5 Cyl. T8 = 5.25 Cyl. T5 = 6.0 Cyl).

- Another approach is to identify limbal or iris features as with the aid of photographs or drawings, using these landmarks to identify the desired alignment meridian.
- Computerized image-guided location of the meridian for toric IOL alignment is a more sophisticated derivative and is increasing in popularity. These include the Callisto (Carl Zeiss Meditec) and the Verion (Alcon) systems. The technology uses limbal vessel or iris registration to identify landmarks that are used to determine a reference axis in relation to the desired location for the toric IOL.
  - Preoperative images from a biometer or topographer are transferred to the operating microscope, with the desired meridian for alignment displayed in the surgeon's eye piece as an overlay to facilitate alignment.
- Alternatively, certain femtosecond machines can make corneal marks or create tags in the rhexis edge that can be used for direct alignment with the toric IOL, the advantage of the latter being the avoidance of errors in parallax that can occur with image overlay.
- Intraoperative aberrometry is favored by some as a useful method to locate the correct meridian in eyes with high levels of astigmatism, but the technology may not be as reliable with low toric IOL cylinder powers.

An alternative to computerized image guided devices is to use the inbuilt accelerometer within a smart phone to accurately identify the orientation of a freehand marked reference meridian.

One of us (GDB) developed the toriCAM app and dual axis marker for this purpose, and there are several other apps now available for this purpose.

- The reference meridian can be set on the dual axis marker according to the app independently from the desired alignment meridian from the calculator.
- Ink is then applied to the toric blades on the marker, the reference indicators of the marker are aligned with the reference marks, and, when applied to the cornea, the desired meridian for alignment is identified.

One of us (GDB) uses the toriCAM app and marker together with an image guided system, and typically they are in agreement. Erroneous registration can occasionally occur, and, when differences are noted, the marker is checked to be sure it is aligned correctly. If so, the app is favored as this is less prone to error. The workflow of image-guided systems is attractive but certainly not obligatory for accurate alignment. Tips for accurate alignment with toriCAM are available in Table 30.1

Some studies comparing various alignment methods showed that manual marking and digital marking are equally effective guides for toric IOL alignment.[19–21] However, studies by Elhofi et al., Zhou et al., and Mayer et al. reported significantly greater accuracy with digital marking compared with manual marking.[22–24] Mayer et al.[23] also obtained favorable results with regard to mean deviation from the target induced astigmatism and mean toric IOL alignment time in the digital group.

TABLE 30.1 Tips for Accurate Alignment with ToriCAM

Steps in Alignment	Details
• Sit up patient on bed/table.	Hang legs over side of bed.
• Have patient look at assistant's upheld finger.	Have both eyes open.
• Approach from side and dry limbus with spear held in R hand at 3 and 9 o'clock.	Hold eye open with fingers of left hand.
• Drop spear and use thin-tip felt disposable marker to mark 180-degree meridian.	Marks don't have to be exactly 180 degrees, as app will identify actual reference meridian.
• Cover opposite eye with patch – have patient look directly at LED light in camera.	Surgeon selects light on and intensity and desired exposure.
• Use edge of left hand as a bridge between patient's forehead and camera for stability.	Hold camera in right hand.
• Align red reference marker in app with limbal marks.	Take photos with camera and select logo to display photos. Choose photo with best alignment.
• Set reference meridian on dual axis marker to that recorded by the app.	Set toric meridian on dual axis marker to that which is provided by calculator.

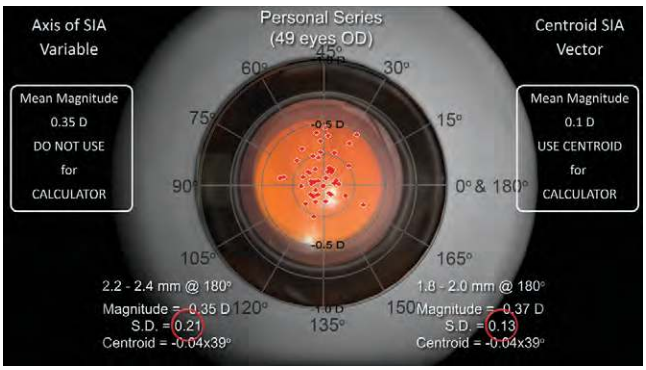

Fig. 30.5 Double-angle plot of vector difference in astigmatism between pre- and postoperative keratometry illustrates that both the magnitude and meridian of the induced corneal astigmatism are variable. Although the mean magnitude of the absolute astigmatism is 0.35 D, the mean vector that considers the meridian, i.e., the centroid value is typically 0.1 D. The centroid value should be used for toric calculators. The centroid is similar for smaller incisions, but the standard deviation is smaller and there are fewer outliers.

Intraoperative Management

Surgical Incision

The surgically induced corneal astigmatism (SIA) that occurs as a consequence of small-incision phacoemulsification is difficult to predict:

- The mean magnitude of SIA may be as much as 0.4 to 0.5 D on average, but, contrary to expectations, the axis of induced SIA is not necessarily aligned with the incision meridian and is quite variable (Fig. 30.5).
- The centroid value is the mean vector that takes into account the axis and the amount of SIA and is typically in the range of 0.12 D for a 2.2- to 2.4- mm temporal incision. This is the value that should be entered into a toric calculator such as the Barrett or Abulafia-Koch method. If the toric calculator has an assumed value derived as part of the regression, then the value of SIA can be left as zero.
- Because the astigmatism induced by a keratome incision is so variable, there is little point in attempting to align the incision along the steep meridian of measured anterior corneal astigmatism.
- However, surgical incisions that are vertical tend to induce greater and even more variable SIA, as the incision is closer to the visual axis.
- Although the SIA centroid value for a larger 2.8- mm incision may not be dissimilar, there will be greater variability, which will reduce the ability to predict the residual astigmatism.

Summing this up, we recommend a 2.2- to 2.4- mm clear corneal temporal incision to minimize the risk for unexpected SIA that can

negatively impact the prediction of residual astigmatism after cataract surgery.

Capsulorrhexis

The creation of a symmetric rhexis, whether manually or with femtosecond laser, is important to improve spherical prediction and maintain toric IOL alignment.

- A rhexis size of 4.5 to 5 mm is desirable to assure 360-degree overlap of the edge of the IOL.
- There are various corneal markers to facilitate the creation of a central reproducible rhexis, and image-guided systems can provide a circular overlay during capsulorrhexis to assist in this step.
- Clinical experience is also helpful, and many surgeons find that they are able to create a consistent overlap of the toric IOL edge without ancillary devices. Careful observation of the overall corneal diameter and pupil size in relation to the desired rhexis size plays a key role in this process, and experienced surgeons are always aware of and will adjust to the larger limbal diameters in myopes and smaller corneal diameters in small eyes while judging the desired rhexis diameter.

The nucleus is removed and cortex aspirated in the conventional manner with no specific adjustments when using a toric IOL. We do not use a CTR to reduce the chance of misalignment routinely or when using toric IOLs in myopic patients. I (GDB) evaluated the error in alignment at 1 month in a large series of patients with toric IOLs and did not find a relationship with axial length.

IOL Insertion and Alignment

The bag is inflated with viscoelastic, and there are many different options for alignment with the overlay or ink marks. One of us (GDB) prefers one with relatively low viscosity, such as Provisc or Healon10.

Many currently available toric IOLs are somewhat difficult to rotate, which is of course an advantage in preventing postoperative rotation away from the intended alignment.

- For these IOLs difficult to rotate:
  - One can directly align the lens marks at the desired meridian for alignment.
  - Press on the optic with the coaxial I/A tip a while removing the viscoelastic.
  - Tap on each quadrant, without aspirating behind the lens unless significant residual viscoelastic is noted behind the lens (GDB's approach). If the latter is required, the lens often maintains its position, and little or no rotation is typically required.
  - One of us (DDK) routinely aspirates the OVD from behind the toric IOL.
- Alternatively, one can place the IOL 15 to 20 degrees counterclockwise from the intended meridian, completing the small required rotation to align the IOL after the OVD has been removed.
- Hydrating the incision prior to removing the viscoelastic with the coaxial I/A can minimize the likelihood of chamber shallowing that could cause the IOL to rotate.

There has been discussion about the possible merits of leaving the IOP normal to prevent postoperative rotation. We leave the eye inflated to an estimated pressure of approximately 20 to 25 mm Hg and have not found that leaving the eye partially deflated is indicated for the IOLs we use (Alcon, Bausch & Lomb, Johnson & Johnson).

Outcomes With Toric IOLs

- In normal eyes without previous corneal surgery, studies using formulas that account for posterior corneal astigmatism reported that 52% to 95.2% of eyes had postoperative refractive residual astigmatism ≤0.50 D, and 88% to 100% had refractive residual astigmatism ≤1.00 D after toric IOL implantation.[12,16,25–29]
- In eyes with previous LASIK or PRK, Cao et al. reported that 80% to 84% of eyes had postoperative residual astigmatism ≤0.50 D and 95% to 100% had residual astigmatism ≤1.00 D after toric IOL implantation. The three inclusion criteria were as follows:
  - Regular bow tie astigmatism was within central 3-mm zone.
  - Difference in corneal astigmatism magnitude between two devices (the IOLMaster and Lenstar in our study) was ≤0.75 D.
  - Difference in corneal astigmatism meridian between 2 devices was ≤15°.
- In eyes with previous RK, Canedo et al.[30] found that 73% and 88% of eyes had postoperative refractive astigmatism ≤0.5 D and ≤1.0 D after toric IOL implantation, respectively. Inclusion criteria are again those noted above for postablative corneas.
- In eyes with multifocal toric IOLs, studies showed that multifocal toric IOLs were noninferior to multifocal nontoric IOLs in uncorrected distance and near visual acuity and effectively corrected astigmatism.[15,31,32] Lehmann et al.[31] reported that 74.5% to 79.5% of eyes achieved a reduction in refractive astigmatism within 0.5 D of the target cylinder, and 94.1% to 97.6% of eyes achieved a reduction in refraction astigmatism within 1.0 D of the target cylinder. Blehm and Potvin[32] found that the residual refractive astigmatism was ≤ 0.50 D in 100% of eyes.
- In eyes with mild nonprogressive keratoconus and topographic central relatively regular astigmatism, studies showed that toric IOL implantation improved visual acuity and decreased astigmatism.[33–36] After toric IOL implantation, 38% to 87.5% of eyes had residual astigmatism ≤0.50 D, and 71% to 95% had residual astigmatism ≤1.0 D.
- Many studies compared the accuracy of various toric IOL calculators and the methodologies using estimated or measured values of total corneal astigmatism for toric IOL calculation. In general, toric calculators or formulas, such as the Barrett toric calculator and Abulafia-Koch formula, yielded lower astigmatic prediction errors, and directly evaluating total corneal power for toric IOL calculation was not superior to estimating it.[13,16]

Potential Complications

Aberrations

In theory, decentration or misalignment of a toric IOL can result in unwanted coma and aberrations, potentially impacting best corrected acuity. However, we have not encountered this clinically.

Asthenopia

Patients with high levels of astigmatism typically have spatial visual adaption to their refractive error, especially if corrected with glasses. Reducing this astigmatism with toric IOLs can result in spatial distortion (e.g., rectangles look like rhomboids), but this resolves typically within a few days as they neuroadapt.

As long as the residual astigmatism is minor, less than 0.5 D, changing the astigmatism and even reversing the axis is not problematic as noted above. Wearing spectacle correction with high levels of cylinder can be challenging in its own right. Reducing astigmatism therefore offers benefits to patients that outweighs any adaptions that may be required.

Residual Refractive Astigmatism

Residual astigmatism because of an error in prediction can occur, but, with the steps outlined in this chapter, one can expect that over 80% of eyes implanted with toric IOLs will be within 0.5 D of the targeted residual astigmatism. The remainder are typically within 0.75 D, and it is unusual to encounter 1.0 diopter "surprise" because of prediction

error. The latter is more likely caused by misalignment of the toric IOL and can be rectified with realignment.

It is preferred to wait for ~2 weeks to improve stability, although some surgeons report success with realignment on the slit lamp within the first week. One of us (DDK) has successfully realigned toric IOLs at the slit lamp 1 day postoperatively.

The meridian for repositioning can be determined by using either astigmatismfix.com developed by Berdhal and Hardten, Holladay Consultant, or the Barrett Rx Formulae accessible via the ASCRS or APACRS website. The Barrett Rx can also determine the toric IOL required for exchange or piggyback insertion if realignment of the toric IOL is not adequate to correct the astigmatism or there is an associated spherical error.

Alternatively, residual astigmatism or spherical error can be corrected with LASIK or surface ablation. The latter is often preferred in the older age group cataract population. Small amounts of residual astigmatism can be successfully addressed with corneal-relaxing incisions.

The use of the light-adjustable lens offers another alternative for managing residual astigmatism.

Other Complications

Although uncommon, a radial tear in the rhexis or capsular tear can occur in patients where a toric IOL is planned. If a radial tear is limited and does not extend, then a toric IOL can be contemplated. A toric IOL can also be considered in the presence of a small posterior capsular tear, especially if this has been converted into a circular rhexis. The use of a toric IOL in these circumstances is dependent on the orientation and extent of a capsular tear and in some circumstances may not be advised.

Complex Cataract Surgery

Subluxated cataracts either from congenital deficiencies such a Marfan's syndrome or trauma can be managed successfully, and often the capsular bag can be conserved to prostheses, such as Cionni rings or Ahmed segments. The use of toric IOLs in these circumstances can certainly be considered if required and indeed is the reward for the additional effort and expertise required in these complex cases.

POSTOPERATIVE MANAGEMENT

The postoperative management of patients with toric IOLs is not dissimilar to routine cataract patients. The unaided vision on day 1 or at 1 week will provide an indication whether the refractive target has been accomplished. If the unaided vision appeared to be less than expected, then refraction and dilated examination to ensure correct alignment would be warranted. The 1-month post-op visit is when final refraction is recorded. At that stage, the pupil is widely dilated, the position of the toric IOL is documented, and the biometry is repeated. This enables continued monitoring of outcomes and helps identify whether predictions can be refined and whether alignment methods are adequate. At this time one can of course also assess the spherical equivalent outcome and use this to assist in selecting the IOL for the fellow eye. For example, one of us (GDB) performs modest monovision as the primary method for providing a presbyopic solution, and the targeted outcome for the second eye is made at this visit.

The reward for using toric IOLs and reducing preexisting astigmatism is patient satisfaction.

- This is not unexpected with preexisting high levels of astigmatism but arguably not as widely appreciated in those patients with relatively low levels.
- A patient with 0.0 to 0.5 D measured anterior corneal astigmatism preop may have been spectacle independent prior to cataract surgery.
- If a toric calculation is not performed, and particularly if the preexisting astigmatism was against-the-rule in nature, then the patient could well end up with a refractive error of 1 or 1.25 D cylinder and require spectacle correction for distance and reading after surgery.
- Whereas a patient with ~3 diopters preexisting corneal astigmatism may well be satisfied with a residual astigmatism of 1.00 D, this is unlikely to be the case with the patient with low levels of preexisting astigmatism.
- In many countries, low dioptric cylinder toric IOLs with 1.0 D cylinder powers are readily available, but these are not yet approved in the United States.
- In countries where low dioptric IOLs are not available, astigmatic keratotomy or peripheral corneal-relaxing incisions are a reasonable option, but the latter strategy is not as predictable and can be associated with adverse impacts related to corneal incisions such as dry eye symptoms.

SUMMARY

- Toric IOLs can successfully reduce postoperative astigmatism to 0.5 D or less in the vast majority of patients. Key principles are as follows:
  - Use contemporary toric calculators that account for posterior corneal astigmatism.
  - Optimize the ocular surface to assure quality measurements.
  - Measure corneas with both a biometer and topographer or tomographer.
  - Meticulously align the IOL at the intended meridian.
  - Address residual astigmatism or ametropia as indicated.
- Toric IOLs are one of the great success stories in cataract surgery and should be a key part of the cataract surgeon's armamentarium.

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Managing Residual Postoperative Astigmatism

Cassandra C. Brooks, Nandini Venkateswaran, and Terry Kim

CONTENTS

KEY POINTS

- Numerous pre-, intra-, and postoperative variables can result in residual postoperative astigmatism.
- Several options for correcting residual astigmatism are available, including corrective spectacles or contact lenses, intraocular lens (IOL) rotation/repositioning/exchange, limbal relaxing incisions (LRI), light-adjustable lens adjustment, and corneal refractive surgery.
- A tailored approach aimed at each patients' unique expectations will help to achieve a high level of patient satisfaction.

INTRODUCTION

Residual postoperative astigmatism affects approximately 10% of patients with more than 1.00 D of residual cylinder, even with the meticulous application of advanced instrumentation and techniques.[1] With many patients expecting spectacle independence following cataract surgery, a thorough understanding of residual astigmatism management is critical to achieving high levels of patient satisfaction.[2]

CAUSES

A complex array of pre-, intra-, and postoperative factors can affect a patient's postoperative refractive outcome (Table 31.1).[3]

INITIAL ASSESSMENT

Once a thorough exam is performed, and it is determined that the residual astigmatism is not caused by a secondary pathology, additional steps to address the remaining refractive error can be pursued. An open discussion with the patient postoperatively is important to determine whether additional correction is required or whether the patient is happy with the current result. If the patient is interested in pursuing further correction, a discussion of the available options with recommendations tailored toward the exam and the patient's goals is important. Common methods for correcting residual astigmatism include the following:

- Corrective lenses (i.e., spectacles, contact lenses)
- IOL adjustments (i.e., rotation, repositioning, exchange)
- Limbal relaxing incisions (LRI)
- Corneal refractive surgery
- Light-adjustable IOL if implanted

MANAGEMENT OPTIONS

Corrective Lenses

Although the majority of patients undergoing refractive cataract surgery have the expectation of spectacle independence, some may prefer a mild glasses or contact lens prescription as opposed to an additional surgical or laser procedure. This conservative, noninvasive approach should always be offered. One study comparing the AcrySof Toric IOL to an AcrySof spherical IOL (n = 256 eyes) found that 39.1% still required some form of spectacle use at 6 months postoperatively, compared with 63.5% in the control group.[6] Therefore it is important to preoperatively discuss the potential need for corrective lenses or additional refractive procedures if the patient's goal is complete spectacle independence in order to appropriately align the patient's expectations.

! POTENTIAL COMPLICATIONS

- Contact lenses, particularly if poorly fitted, can induce new problems such as microbial keratitis, sterile infiltrates, corneal abrasions, allergic reactions, and corneal edema or neovascularization.
- Contact lenses, especially with extended wear durations, can exacerbate existing conditions, such as dry eye syndrome.
- Complications can be minimized with proper fitting lenses, good communication with the patient of return precautions, and appropriate follow-up to ensure continued fit, comfort, and patient satisfaction.

TABLE 31.1 Factors That Can Contribute to Residual Postoperative Astigmatism

Preoperative	Inaccurate/incomplete: • History (e.g., prior corneal refractive surgery) • Ocular exam (ex. dry eye syndrome or anterior basement membrane dystrophy) ▪ 54% of patients have symptoms suggestive of ocular surface dysfunction and 80% have evidence on exam of ocular surface dysfunction at the time of cataract surgery evaluation[4] • Measurements (e.g., axial length, keratometry, axis of astigmatism) ▪ Not accounting for posterior corneal astigmatism during toric lens calculations can also result in residual postoperative refractive astigmatism[5]
Intraoperative	Effect of eyelid speculum and draping Main incision length and position Monofocal/multifocal IOL tilt Toric IOL power and rotation/misalignment • Every 1 degree of off-axis rotation = about 3% loss of cylinder power
Postoperative	New or worsened secondary pathology • Corneal (e.g., dry eye syndrome, anterior basement membrane dystrophy, Salzmann's nodular degeneration) • Eyelid issues (e.g., ptosis, chalazion)

IOL ROTATION, REPOSITIONING, AND EXCHANGE

Rotation, repositioning, or exchange of the IOL is another reasonable approach for correcting postoperative astigmatism, particularly if a toric lens is not ideally aligned or if a standard or multifocal IOL is tilted. Ideally, IOL repositioning or rotation is undertaken between two to 4 weeks postoperatively. This provides time for the refraction to stabilize, but not too much time for fibrosis to form between the IOL and lens capsule, which can make rotation more challenging.

For correcting toric misalignment, ophthalmologists can either manually perform vector analysis or use an online calculator developed by Drs. John Berdahl and David Hardten (astigmatismfix.com) or the Barrett Rx Formula (available at www.ASCRS.org). After inputting the patient's postoperative uncorrected and corrected visual acuities, manifest refraction, model and power of the toric IOL used, current meridian of the toric IOL, and the originally calculated IOL meridian of the toric IOL, these online tools back-calculate the ideal toric position. They will also calculate a new IOL spherical power if there is excessive residual spherical equivalent refractive error.

Toric IOL Rotation

- Step 1: Mark the current and ideal meridian.
- Step 2: Instill viscoelastic to inflate and protect the capsular bag.
- Step 3: if necessary, instill viscoelastic under the IOL to free the implant.
- Step 4: Use a Sinskey hook to ensure the haptics are free from the posterior capsule.
- Step 5: Use the Sinskey hook to rotate the IOL to the ideal meridian.
- Step 6: Gently remove the viscoelastic.

SURGICAL PEARLS

- Consider placement of a capsular tension ring prior to IOL rotation, especially in eyes with capsular pathology (e.g., pseudoexfoliation syndrome) or long axial length.
- To determine the current meridian of a rotated toric IOL for the astigmatismfix.com calculator, the slit-lamp beam can be tilted to mirror the implant's meridian or a device such as the Pentacam wavefront can be used. This beam can then be transposed to a phoropter to determine the meridian. In addition, smart phone applications such as Axis Assistant can also be used to determine the location of the IOL axis. Some devices such as the Pentacam and iTrace can also be used to determine toric IOL alignment.

If posterior capsular rupture (PCR) has occurred in a case with an originally planned toric IOL, it is important to never place a one-piece toric IOL in the ciliary sulcus because this can lead to IOL tilt or malposition and more seriously to uveitis-hyphema-glaucoma (UGH) syndrome caused by contact of the IOL haptics with the posterior iris. One option that allows insertion of a toric IOL is reverse optic capture, in which the haptics remain posterior to the anterior capsulotomy and the optic is prolapsed forward anterior to the edge of the anterior capsular opening. This requires an intact anterior capsulotomy and precludes the need for a conversion to a monofocal sulcus IOL. In these scenarios, there is an inherently higher risk for inaccurate spherical power, toric IOL instability, tilt, rotation, and misalignment, all of which can contribute to residual astigmatism. In these cases, repositioning of the IOL can be attempted, but it is often preferable to perform an IOL exchange as discussed below.

IOL EXCHANGE

In cases of residual astigmatism with suspected toric IOL rotation, it is important to use the previously mentioned online calculators not only to determine the degree of IOL rotation but also to confirm that the correct power toric IOL was used. If the calculator calls for a different power and model toric IOL, measurements and calculations should be repeated, and an IOL exchange should be performed. In cases with inadequate posterior capsular support and a poorly positioned toric IOL, an IOL exchange should be performed for a monofocal sulcus IOL with optic capture if possible. If there is insufficient anterior or posterior capsular support, anterior chamber IOL, scleral-fixated IOLs or iris-fixated IOLs should be considered.

IOL EXCHANGE

- Step 1: Create multiple paracenteses and instill viscoelastic in the anterior chamber.
- Step 2: Use a keratome to create a main wound, or bluntly dissect open the original incision.
- Step 3: A 27g cannula should be used to carefully inject viscoelastic 360 degrees underneath the anterior capsular rim to separate the anterior capsule from the IOL optic. In cases where the cannula is difficult to insert between the anterior capsule edge and the IOL because of fibrosis, either a Sinskey hook, Atkinson needle, Palay cannula, or 30g needle bevel down on a viscoelastic syringe can be used to help dissect and lift the anterior capsular rim from the IOL optic.

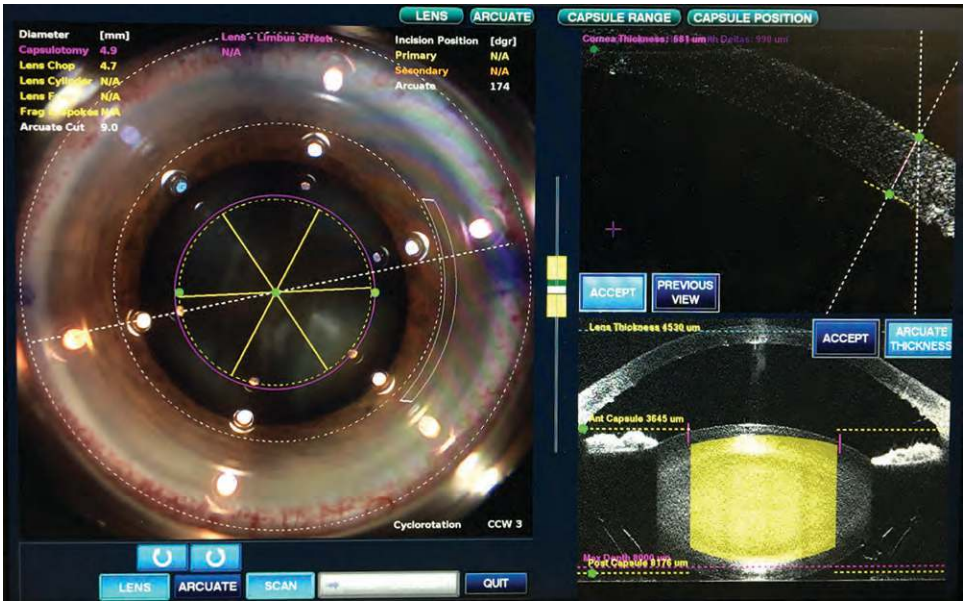

Fig. 31.1 View of the Alcon LenSx femtosecond laser planning screen for creation of a femtosecond arcuate incision at the time of cataract surgery. A 60-degree nasal arcuate incision within the 9 mm optical zone is planned to correct this patient's astigmatism (left hand panel). The yellow dashed lines (upper right panel) indicate the borders of the corneal epithelium and endothelium to ensure that the arcuate incision extends to only 80% depth of the peripheral corneal thickness to avoid full thickness corneal penetration.

- Step 4: Viscoelastic should be injected with a cannula underneath the IOL to inflate the capsular bag. Viscoelastic should also be injected along the equator of the bag to free the haptics.
- Step 5: A Sinskey hook should be used to carefully dial the IOL into the anterior chamber. Placing the Sinskey hook in the optic-haptic junction can serve as a good fulcrum to dial the lens.
- Step 6: If the haptics are fibrosed within the capsular bag, microsurgical forceps can be used to gently tease the haptics out. If the haptics cannot be freed without inducing zonular damage, microsurgical scissors can be used to amputate the haptics, and the optic can be brought into the anterior chamber. It is important to exert minimal force when removing a fibrosed IOL to avoid posterior capsular tears and vitreous loss.
- Step 7: Once the IOL is in the anterior chamber, it can be bisected with microsurgical scissors and removed through the main incision
- Step 8: At this point, if the posterior capsule is intact, a new toric IOL can be inserted into the capsular bag, positioned at the correct meridian, and held in position while meticulously removing viscoelastic
- Step 9: Ensure that all wounds are securely sealed and consider placing a 10-0 nylon suture in the main wound to avoid any postoperative anterior chamber shallowing that could lead to subsequent toric IOL rotation.
- Step 10: If there is any concern for breach of the posterior capsule, a monofocal 3-piece sulcus IOL can be inserted. Optic capture can be performed to secure the optic in the intact anterior capsule for increased IOL stability.

! POTENTIAL COMPLICATIONS

- IOL exchanges are less desirable in cases with a posterior capsular opening secondary to a Nd:YAG capsulotomy or intraoperative PCR because of an increased risk of vitreous prolapse, retinal tears or detachments, and inadequate capsular support.

LIMBAL RELAXING INCISIONS (LRI)

Patients with low amounts of residual astigmatism may benefit from an LRI because it is a safe, simple, and relatively reliable procedure.[7] An LRI can be performed manually with a guarded or adjustable diamond blade or with femtosecond laser-assisted arcuate incisions (Fig. 31.1).

If a new LRI is required, this can be performed either manually or with the femtosecond laser, either in the office or in the operating room. Manual LRIs are created just inside the limbus, while femtosecond arcuate incisions are typically created within the 9-mm optical zone (Video 31.1). There are multiple nomograms available online that can be used to plan LRIs, including www.laserarcs.com or www.lricalculator.com. Keratometry readings obtained from biometry readings should be inputted into these nomograms. If performed in the operating room, intraoperative aberrometry can be used to help determine whether LRIs need to be further opened or lengthened.

If a patient already had an LRI at the time of surgery and postoperatively undercorrection is identified, then the incision(s) should be inspected for length and positioning. The patient should have repeat pachymetry with subsequent opening of the LRI or further deepening or lengthening of the incision(s) using a guarded blade. If a patient already had an LRI at the time of surgery and postoperatively overcorrection is identified, then the incision(s) should again be inspected for length and positioning. If there are already 2 LRIs, additional LRIs should not be placed as this can destabilize the cornea. The overcorrection can be addressed by suturing a preexisting LRI closed with 10-0 nylon, or a secondary modality, such as photorefractive keratectomy (PRK) or laser-assisted in situ keratomileusis (LASIK), can be performed.

CORNEAL REFRACTIVE SURGERY

PRK and LASIK are both suitable options for residual astigmatism correction in patients with monofocal, multifocal, and toric IOLs.[8,9] These methods can also be favorable if IOL exchange is rendered more

SURGICAL PEARLS

- Always mark the surgical eye with the patient sitting up at the 3 o'clock, 9 o'clock, and/or 6 o'clock positions to account for cyclorotation of the eye once the patient is supine.
- Check that the LRI calculations are correct prior to surgery, and ensure that the accurate arcuate incision lengths and locations are inputted into the laser.
- Avoid creating LRIs that intersect your main wound or paracenteses.
- To avoid postoperative refractive instability and induction of irregular astigmatism, use caution when creating LRIs longer than 60 degrees along the vertical meridian and 45 degrees along the horizontal meridian.

! POTENTIAL COMPLICATIONS

- Infection, corneal perforation, decreased corneal sensation, and discomfort can all occur after LRIs.
- Using a guarded blade or femtosecond laser-assisted astigmatism correction helps significantly minimize the risk of perforation.
- Use a topical antibiotic for 1 week for infection prophylaxis.

challenging (e.g., open posterior capsule caused by a previous YAG capsulotomy or PCR). If a patient is a suitable candidate for LASIK, with a healthy ocular surface; no corneal ectasia, scars, or irregular astigmatism; and sufficient corneal thickness, this option is typically preferable given the combination of fast visual recovery with good visual outcomes. For patients with multifocal IOLs, there are mixed reviews on whether standard versus wave-front guided LASIK techniques provide the most optimal results; however, both result in excellent visual outcomes.[10,11] PRK can also be performed for enhancements, especially if the patient has slightly thinner corneas, a mild degree of dry eye disease or epithelial abnormalities, or previous LASIK many years prior to cataract surgery. Corneal refractive surgery is typically performed 3 to 6 months after initial cataract surgery to provide sufficient time for wound stabilization and refractive stability.

SURGICAL PLANNING PEARLS

- Typically, PRK is performed for patients will low degrees of residual refractive error; however, LASIK can be preferred if the patient is a suitable candidate and can allow for faster visual recovery.

! POTENTIAL COMPLICATIONS

- PRK and LASIK can both induce higher order aberrations (HOA).
- LASIK (more than PRK) can worsen dry eye syndrome, making appropriate patient selection for each procedure critical for long-term patient satisfaction.
- If LASIK is performed sooner than 3 months after cataract surgery, there is a risk for wound dehiscence and chamber instability during the procedure.

LIGHT ADJUSTABLE LENS (LAL)

The recent introduction of a Light Adjustable Lens (LAL, RxSight) appears to help mitigate many of the variables previously considered with cataract surgery and provide customized postoperative vision without the need for an additional invasive procedure. This premium IOL is a three-piece, foldable lens made of photoreactive silicone that can undergo selective exposure to ultraviolet (UV) light. While sitting at a slit lamp equipped with a Light Delivery Device, the lens curvature can be modified with UV light to provide a tailored spherocylinder power change while the IOL remains in the eye. In a patient that has been treated with a LAL, once the desired refraction is achieved, the Light Delivery Device is used to stabilize or "lock in" the final lens power. The lens can be adjusted by +/- 2 D of sphere in addition to up to 3 D of astigmatism in a single treatment. Up to 4.5 D of astigmatism can be treated with 2 treatments. This technology also allows patients to trial varying amounts of anisometropia without requiring an invasive procedure. Recent long-term studies have demonstrated stable refractions and visual acuities without long-term complications, making this potentially an excellent option for minimizing invasive methods for managing residual postoperative astigmatism.[12]

! POTENTIAL COMPLICATIONS

- Patients need to be able to dilate to 6 mm to treat the entire lens postoperatively, which makes appropriate preoperative patient selection critical.
- Patients need to decrease their risk for ambient UV exposure by wearing UV-blocking glasses, mostly when outdoors, until the final lens "locking" has been performed.
- Access to the Light Delivery Device is necessary for surgeons to perform postoperative adjustments.

SUMMARY

Residual postoperative astigmatism is not uncommon, but a thorough understanding of its management will lead to high levels of patient satisfaction.

- Consider each patient's unique expectations and goals.
- Complete a comprehensive exam to eliminate potentially confounding secondary pathology.
- Customize treatment modalities to individual expectations and characteristics.
- Ensure close follow-up after secondary correction to ensure patient satisfaction.
- Introduction of the Light Adjustable Lens may help mitigate many variables and provide optimal vision without the need for invasive secondary procedures.

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Video 31.1 Video of the Alcon LenSx femtosecond laser performing the capsulotomy, lens fragmentation and arcuate incision. The arcuate incision is created nasally within the 9 mm arcuate zone and is 60 degrees in length.

PART VI

Complex Cases

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Ultradense Cataract

Patrick W. Commiskey, Amar Bhat, and Deepinder K. Dhaliwal

CONTENTS

KEY POINTS

- The ultradense cataract poses pre- and intraoperative challenges.
- Managing expectations is important when posterior visualization is compromised.
- Axial length measurements require verification.
- Capsular visibility may be compromised.
- Maintain anterior chamber pressure to avoid run-out of capsulorrhexis, and use needle aspiration if Morgagnian.
- Techniques to divide lens to minimize zonular stress.
- Power and vacuum settings may be adjusted to avoid surge and protect the endothelium.
- Have a back-up surgical plan (MSICS, ECCE, scleral sutured lens, ACIOL).

INTRODUCTION

Cataract surgery on an ultradense lens can pose many challenges. Difficulties of ultradense lens cataract surgery can be encountered preoperatively, intraoperatively, or postoperatively. To minimize the chance of complications, a complete history should be taken, a thorough eye exam should be performed, and additional precautions should be taken during surgery. A cataract surgeon needs to properly prepare for surgery on an ultradense lens and address challenges as they arise (Fig. 32.1).

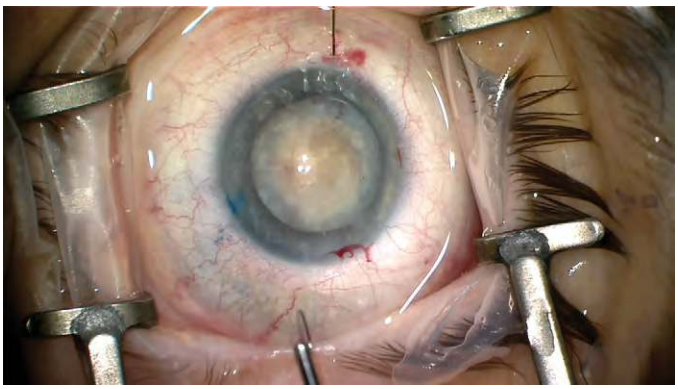

Fig. 32.1 Dense cataracts may appear white or brunescent and tend to have a yellow (as above) rather than bluish hue; rarely are they black.

RISK FACTORS

Age

The most common pathway toward lens density is time. Opaque cataracts secondary to trauma or in young people are unlikely to be ultradense. The incidence of dense cataracts will increase with age.[1]

Ultraviolet Exposure

Dense cataract development is higher in populations living near the equator, where exposure to ultraviolet light is greater. Additionally, high altitude is a risk for accelerated cataract development because the thinner atmosphere filters less ultraviolet light. Dense cataracts are also more likely in developing countries, where UV exposure in certain

socioeconomic situations may be increased. However, cataract development in these patients are likely multifactorial.[2]

Trauma

Both penetrating and blunt trauma can lead to acceleration of a cataract. Typically, this is a result of swelling inside the lens and disruption of the lens proteins. Trauma can also cause a star-shaped, or "stellate," cataract. Cataracts from old prior trauma can be extraordinarily ultradense, although traumatic cataracts in the acute setting are typically soft.

Previous Ocular Surgery

Cataract formation can be accelerated after many ocular surgeries but most prominently after pars plana vitrectomy. It is theorized that pars plana vitrectomy leads to increased oxygen tension inside the eye, resulting in faster cataract formation.

Uveitis

Inflammation alone may accelerate the formation of a cataract, although chronic use of corticosteroids, which may be used to treat uveitis, may also accelerate cataract formation.

PREOPERATIVE MANAGEMENT

The first challenge of the ultradense cataract begins with preoperative planning and managing patient expectations. Some of these dense lenses progress very quickly, leaving the patient and provider with some recent memory of visual potential. However, often the potential postoperative corrected visual acuity is unclear. Even with a plethora of preoperative testing, it is difficult to confidently counsel a patient that vision will return to normal when the examiner cannot directly visualize the fundus. Some useful modalities in these cases include the following:

- Pinhole acuity potential
- B-scan ultrasonography
- Optical coherence tomography (OCT) testing of the macula and optic nerve (the infrared light used with OCT can often penetrate the ultradense nuclear cataracts surprisingly well)[3]

Considerations in the eye with a history of uveitis

- In a dense, uveitic cataract, it is preferable that the eye is "quiet"
- No inflammation, even if on treatment, for at least 3 months prior to surgery
- B-scan ultrasonography may be necessary to assess for vitritis behind an opaque lens
- Posterior synechiae may require synechiolysis
- Band keratopathy from chronic uveitis may impede the view for cataract surgery and preoperative measurements, so removal of band keratopathy followed by repeat biometry may be helpful

POTENTIAL VISUAL ACUITY

The most common ways to elicit potential visual acuity in eyes with cataracts are the potential acuity meter (PAM) and the dilated near pinhole test. The utility of a PAM, which projects a Snellen chart through a clear portion of the cataract, decreases as the cataract density increases. Pinhole acuity potential is likewise limited but, in our experience, is a low-cost option: have the patient hold a near card in a dark room in front of the cataractous eye while the other hand holds the pinhole occluder. The patient should be wearing corrective lenses of choice, and the examiner should brightly illuminate the near card.

Gross evaluation of the patency of the visual system may be ascertained by visual evoked potentials or electroretinogram. The Purkinje vascular entoptic test may be conducted as a rough estimate of visual potential by transscleral illumination of the globe with a light. Absence of Purkinje visualization portends a poor visual potential. Presence of blue-field entoptic images (which are produced in dark-adapted eyes stimulated by transpupillary blue light) predicts positive postoperative visual potential.

LENS CALCULATIONS

Although keratometry values are unchanged by dense cataracts, it may be difficult to obtain axial length readings with optical biometry because of the opaque nature of these cataracts. Manual ultrasonic biometry is often required in order to verify axial length. In these circumstances, immersion (water bath) A-scan is preferred to applanation biometry if available.

Optical biometry relies on infrared light. Newer swept source optical coherence tomography (SS-OCT) instruments have better penetration through dense cataracts. Nevertheless, manual A-scan is an important tool if it is not possible to obtain reliable measurements. It is important to measure both eyes for comparison of axial length. Furthermore, parameters such as asymmetric aqueous depth may give clues about coexisting pathology, such as diffuse zonulopathy.

Intraoperative aberrometry is a newer development that allows for measurement of intraoperative refractive error after removal of the cataract; however, preoperative or intraoperative measurement axial length and keratometry is still required. Potential downsides to intraoperative aberrometry are cost, availability, extra time, and unreliable results if the eye is hypotonus or the cornea is hydrated.

DENSITY MEASUREMENT

Scheimpflug imaging provides lens densitometry measurements that can help predict phacoemulsification power. Adjusting phaco machine settings based on lens densitometry measurements may lead to improved surgical efficiency and more predictable outcomes.[4]

POSTERIOR EVALUATION

If there is no view of the fundus, B-scan is essential to evaluate for retinal detachment and posterior lesions such as retinal detachment, staphyloma, or intraocular mass. Ultrasound biomicroscopy (UBM) may be used to evaluate for posterior polar cataract and ciliary body lesions. Visual fields and slit lamp or fundus photos do not add additional benefit in routine evaluations.

SURGICAL PROCEDURE

Each step of cataract surgery may be modified to accommodate the challenges of an ultradense cataract (Box 32.1). We will walk through modifications of each step of phacoemulsification cataract surgery specifically. However, using manual small-incision cataract surgery

BOX 32.1 Surgical Pearls for Ultradense Cataracts

- Stain the anterior capsule with trypan blue.
- Flatten the anterior capsule with OVD to avoid run-outs.
- Perform gentle hydrodissection because visualization of any posterior capsular pathology is typically not possible.
- Refill the anterior chamber with dispersive OVD as needed to provide a continuous endothelial cushion.
- Use power modulation to minimize heating the phaco tip.
- Chop the nucleus into smaller fragments to reduce ultrasound energy demands.
- Always clear the handpiece/tubing if lens milk does not immediately clear.

(MSICS), which is covered elsewhere, is a very reasonable alternative to phacoemulsification in an experienced surgeons' hands, providing comparable outcomes.

PREOPERATIVE MODIFICATIONS

A surgeon should take steps preoperatively to prepare for a potentially difficult surgery on an ultradense lens.

- Mannitol: Intravenous mannitol can help dehydrate the vitreous and reduce posterior pressure. In standard cataract surgery, mannitol is primarily used for eyes with short axial lengths, but it may provide some additional stability during surgery on an ultradense lens. The intravenous mannitol should be infused at least 20 minutes prior to performing phacoemulsification. If infused too early, there is a possibility of the vitreous becoming rehydrated.
- Reverse Trendelenburg: Proper positioning of the patient and surgeon is also important. The surgeon can consider putting the patient in reverse Trendelenburg position, with the head higher than the feet. This serves a similar purpose as intravenous mannitol by attempting to decrease posterior pressure during surgery by reducing both choroidal and orbital venous pressure, and thus venous volume. This positioning is especially helpful in patients with sleep apnea, lung disease, or obesity, where posterior pressure during surgery will be a significant concern.
- Head taping: Even experienced surgeons can consider taping the patient's head to the surgical bed during surgery to assist in keeping the head immobile.

INSTRUMENT MODIFICATIONS

- A broader phaco needle may allow for easier emulsification of fragments during nuclear disassembly.
- Choppers with slightly longer length tips may facilitate chopping a large, dense lens, which may be thicker anterior-to-posterior than a standard cataract and may be more resistant to splitting the posterior layers.

WOUND CONSTRUCTION

Incisions are of paramount importance in standard cataract surgery, and even more so in surgery of an ultradense lens. A good main incision may help prevent anterior chamber instability that could provide undesired challenges during the rest of the surgery. The surgeon should take time to create a well-constructed triplanar or biplanar wound that will ideally be self-sealing at the end of the case. A limbal or scleral tunnel incision can be created if there is a high likelihood of conversion to a manual expression technique such as MSICS.

The surgeon should also avoid tight incisions. A slightly larger incision (2.8 mm vs 2.4 mm, for example) can be used with a larger phaco sleeve which might, at least minimally, promote cooling. A skilled surgeon will "float" the instrument in the incision, with minimal egress. Excessive egress can be seen when surgeons push on the posterior lip of the incision, which will result in anterior chamber shallowing.

CAPSULORRHEXIS

See Video 32.1: Trypan and Synechiolysis With Hydrodissection Cannula.

- Staining anterior capsule with trypan blue is helpful in the following:
  - Visualizing the propagation of the capsulorrhexis
  - Avoiding the capsular edge during phacoemulsification
  - Identifying whether a radial tear occurs
- It is important to flatten the anterior capsule of the bag to facilitate safe capsulorrhexis and avoid "run-outs." A soft-shell technique with a dispersive ophthalmic viscosurgical device (OVD) covering the endothelium and a more posterior pocket of cohesive OVD pressing down on the anterior capsule or completely filling the anterior chamber with a dispersive OVD can offer considerable control of the anterior chamber depth during this critical step.
  - Alternatively, if there is concern for significant posterior pressure during capsulorrhexis, a highly retentive OVD can be used (such as Healon 5).
- One technique to improve anterior chamber stability during capsulorrhexis is to create the main incision in a two-phase approach. First, the surgeon barely enters the anterior chamber to fill the chamber and perform the capsulorrhexis. Afterwards, the incision can be enlarged to its standard size for the purpose of inserting the phaco needle. Similarly, the capsulorrhexis can be created through paracentesis incisions using small gauge forceps.
- It can at times be difficult to tell if the cataract is dense with or without intumescence, that is, has a liquified component. A conservative strategy is to either use a 25-g needle to puncture the anterior capsule and begin aspirating, using the bobbing needle technique to make sure that any liquified cortex posterior to the rising nucleus is aspirated as well, or to use a mini capsulorrhexis for the purpose of decompressing the cortical material, which can later be enlarged. (See Chapter 33: Intumescent Cataract.)
- A fibrous anterior capsule that may be associated with ultradense cataract may require microscissors (i.e., 23-g or 25-g retinal scissors) to aid in creating the capsulorrhexis. (See Chapter 42: Traumatic Cataract.)

The final capsulorrhexis should be sufficiently large (5–6 mm) to provide adequate working distance, including having the ability to prolapse residual nucleus into the anterior chamber if necessary. Work to move in an efficient and controlled manner, recognizing, however, that a capsulorrhexis size greater than 5 mm may preclude optic capture into Berger's space if the posterior capsule becomes compromised.

- The Little Maneuver is an important technique to know to rescue a radializing rhexis. In this maneuver, when the rhexis begins radializing, additional OVD should be added into the anterior chamber to flatten the dome of the anterior capsule. Subsequently, the surgeon should pull the capsulorrhexis flap backward and then toward the center of the anterior lens, which allows the tear to be redirected away from the periphery.[5]

If there is poor red reflex, adjusting the microscope to "zero degree" illumination can be used to potentially improve the view, if your microscope has this feature.

HYDRODISSECTION

Gentle multiquadrant hydrodissection may be all that is necessary. There is often not much cortex or epinucleus in ultradense cataracts, so it is possible to rotate the nucleus often with no or minimal hydrodissection. The risk for hidden posterior polar cataract is another reason for minimal hydrodissection. If slit lamp examination reveals a posterior polar cataract or an opacity that could be a posterior polar cataract, then deferral of hydrodissection can be considered and, if executed, should be performed very cautiously to prevent posterior capsule rupture. It is usually not possible to see a fluid wave extend across the posterior capsule during hydrodissection because of the density of the nucleus; therefore one clue to achieving adequate dissection is to see the entire lens nucleus shift

slightly anteriorly. It is important to stop hydrodissection when this occurs, and then to push gently down on the nucleus to release any lenticular-capsular block.

PHACOMODULATION

Phacoemulsification with burst mode, high vacuum settings (400–500 mm Hg), moderately high infusion pressure (80 mm Hg), and high bottle height (100 cm H_2O) are helpful for chopping while maintaining anterior chamber stability. Many machines offer "dense cataract" settings that a surgeon can customize based on preferences. Newer machines also offer phacomodulation, where, rather than delivering continuous energy, the machine delivers energy in pulse mode, burst mode, or micropulse mode. These options are far more efficient than continuous mode and generate less heat.

NUCLEAR DISASSEMBLY TECHNIQUES

See the following videos:

- Video 32.2: Dense Morgagnian Cataract
- Video 32.3: Black Rock Cataract
- Video 32.4: Stop and Vertical Chop
- Video 32.5: MiLOOP for Nuclear Disassembly
- Video 32.6: Conversion to Extracapsular Cataract Extraction

There are innumerable modifications to standard cataract surgery technique that may be advantageous for the ultradense cataract.[6,7]

- **OVD Considerations:** Liberal use of dispersive OVD to protect the endothelium is helpful. A few bubbles in the anterior chamber against the cornea, under which one can place dispersive OVD, may be used as a marker for when the OVD has been aspirated out and more needs to be injected (see Video 32.3).

There are many techniques for nuclear disassembly of an ultradense cataract[8]:

- A divide-and-conquer technique is a standard technique that allows "debulking" of the nucleus within the capsular bag. Keeping the phaco energy as far away from the corneal endothelium is protective.
  - A useful teaching point is "the denser the lens, the wider the grooves."
- It is important to replenish dispersive OVD as needed to protect the corneal endothelium during nuclear disassembly. Again, some surgeons insert small air bubbles with their dispersive OVD in to know that the OVD is in place; once the bubbles are gone, the chamber should be refilled with dispersive OVD.
- **Lens Milk:** During phacoemulsification of a dense lens, a milky substance ("lens milk") may be seen and is a sign of an occluded phaco aspiration line. It is important to recognize this and allow for adequate aspiration to avoid wound burn. The aspirant entering the phaco tip is the most important component for cooling the phaco tip from the thermal energy created by the tip-nucleus contact during phacoemulsification. Whenever "lens milk" is identified, ultrasound energy should be halted, and irrigation and aspiration should be continued to ensure adequate flow. Gentle phacoemulsification can be attempted, but, if "lens milk" is again seen, the phaco handpiece should be removed and the instrument and line manually cleared with irrigation (Video 32.2). Adding additional ultrasound energy when no aspiration is occurring because of blockage is the most common mechanism of corneal wound burn.
- **Post-Occlusion Surge:** Additionally, the other danger of an occluded tip is post-occlusion surge subsequent to the blockage being abruptly relieved, resulting in sudden anterior chamber instability. Risk for rupturing the posterior capsule secondary to post-occlusion surge is highest during final quadrant removal, particularly so in the ultradense cataract because there is minimal cortical and epinuclear cushion protecting the posterior capsule. One can hold back the capsule with a blunt second instrument, or implant the intraocular lens underneath remaining nuclear pieces to protect the posterior capsule. The post-occlusion surge phenomenon has been mitigated by improved fluidics in newer phacoemulsification machines. Also, sometimes only a few very dense and small pieces of nucleus remain. If these pieces are suspended in OVD and are smaller in size than the main incision, they can be grasped by a microforceps and manually removed. There is no law that all nuclear pieces must leave the eye through a lumen (Fig. 32.2) (see Video 32.3).

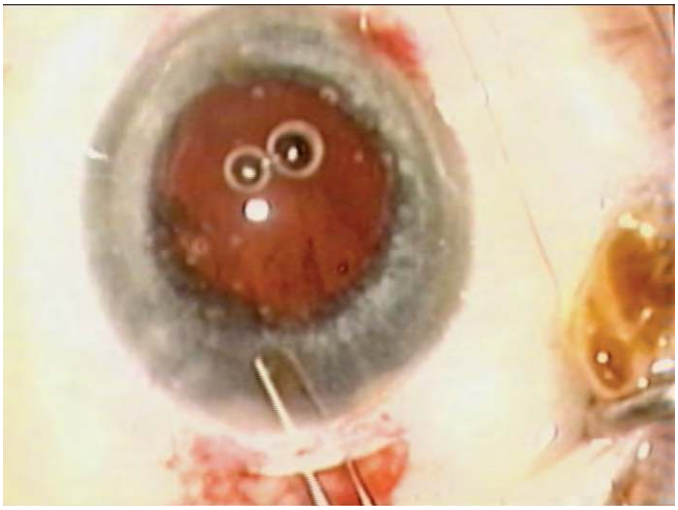

Fig. 32.2 Note dense fragment between jaws of forceps and prior manually removed fragment on the right edge of the image.

- **Nuclear Division:** For divide-and-conquer procedures, quadrants may be subdivided into smaller fragments and flipped to the iris plane or anterior chamber for emulsification. Because there is often minimal epinuclear and cortical material in ultradense cataracts, it is important to keep in mind that at the end of nuclear disassembly there is not much substance weighing down the posterior capsule. Risk for posterior capsule rupture here is the greatest, and judicious use of OVD (e.g., adding some OVD into the eye after three quadrants have been removed) may help prevent a posterior capsular rupture. A blunt second instrument can be maintained posterior to the phaco needle to protect the capsular bag during phacoemulsification of the final piece. Some surgeons may use OVD to express final small pieces through the main incision manually.
- **Chopping:** Judicious use of phacoemulsification energy is important to reduce corneal endothelial trauma. Many surgeons do this by relying on alternative lens disassembly techniques such as chopping. The more disassembly that is done manually (by chopping), the less ultrasound or machine energy is required. Vertical chop entails burying the phaco needle closer to the center of the lens deep within the nucleus and then applying anterior-posterior pressure with the chopping instrument to create the vertical chop. In an ultradense lens, this may not always be viable, as the chopper may not be effectively embedded into the hyperdense lens. Horizontal chop requires the chopping instrument to wrap around the lens equator and then travel through the segment and meet the phaco

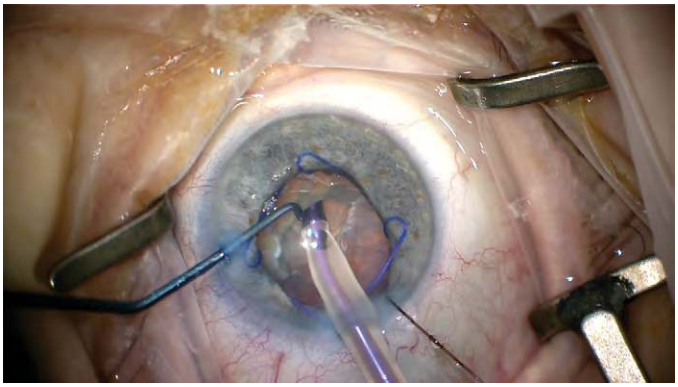

Fig. 32.3 A Malyugin ring used to provide exposure as the surgeon begins a vertical chop.

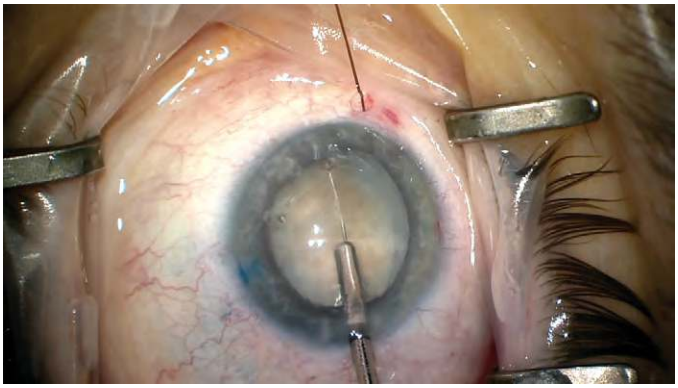

Fig. 32.4 The miLOOP may be used to divide an ultradense cataract.

tip in a horizontal direction (as opposed to the anterior-posterior or vertical direction in vertical chop). Many variations of chopping techniques have been described, such as stop-and-chop. Ultradense lenses are more easily segmented with vertical chop than horizontal chop (Fig. 32.3) (Video 32.4).

- **Posterior Plate:** The ultradense cataract often comes with a thick posterior plate that is challenging to crack. A thick plate can be elevated manually or with viscodissection under the plate, once there has been some debulking of the nucleus.
- **MiLoop:** Alternative strategies to manual chopping maneuvers include using a microinterventional endocapsular nuclear disassembly device (miLOOP Lens Fragmentation Device, Carl Zeiss Meditec Cataract Technology, Inc.) or fragmentation feature of femtosecond laser-assisted cataract surgery (FLACS) in order to fragment the nucleus. The primary benefit of miLOOP in ultradense cataract surgery is the ability to decrease phacoemulsification energy by cutting the lens with a looping microfilament. After standard capsulorrhexis and hydrodissection, the microfilament loop is wrapped around the nucleus and then retracted, cutting the lens in the process. This allows the surgeon to create multiple chops without using any phacoemulsification energy. Additionally, one study found a trend toward more predictable refractive outcomes using miLOOP compared with standard nuclear disassembly techniques during phacoemulsification.[9] Another benefit of miLOOP in ultradense cataract surgery is the relative ease of the procedure compared with the steeper learning curve of chopping techniques for a surgeon unfamiliar with such techniques[9] (Fig. 32.4) (Video 32.5).
- **FLACS:** Femtosecond laser-assisted cataract surgery (FLACS) has similar theoretical benefits to the miLOOP in that it may decrease phacoemulsification energy during surgery by fragmenting the nucleus prior to phacoemulsification. One benefit of FLACS is that, if one can visualize the posterior aspect of the cataract at the slit lamp, then FLACS can usually penetrate sufficiently to fragment the dense posterior plate, facilitating cleavage of this plate. In patients with Fuchs' dystrophy, eyes that underwent FLACS were found to have thinner central corneal thickness and less endothelial cell loss than the patients who underwent conventional phacoemulsification cataract surgery.[10] Some surgeons prefer to use FLACS in the setting of dense or white cataracts. One study of 58 eyes with white cataracts undergoing FLACS revealed that incomplete capsulotomy (17.2%) was the most common issue encountered, but no anterior or posterior capsule tears occurred.[11] Additionally, nuclear fragmentation was at least partially effective in 81.6% of cases, which may help to decrease phacoemulsification energy. Despite the theoretical benefits of FLACS, one meta-analysis failed to show that FLACS improved intra- or postoperative outcomes.[12] One limitation of studies involving FLACS is the very large sample size that would be required to demonstrate differences from conventional cataract surgery because of the relatively low complication rate of standard cataract surgery. With current technology, many surgeons anecdotally report that FLACS leads to more predictable and safer outcomes for them. It is unclear whether methods such as miLOOP and FLACS are superior to standard cataract surgery in the hands of a skilled surgeon.[10–12]

Even when using FLACS for an ultradense cataract, it is important to remember there is minimal epinucleus and cortex. Therefore when removing the final piece of nucleus, the posterior capsule is at risk for rupture if post-occlusion surge occurs. To prevent this, a blunt second instrument or OVD can be place in front of the posterior capsule prior to removal of the final nuclear chip.

- **SICS:** Small-incision cataract surgery (SICS), also known as *manual SICS* (MSICS) or *sutureless extracapsular cataract extraction* (SECCE), is an excellent technique that surgeons should learn. This is covered more extensively in Chapter 21. The technique involves using a scleral tunnel and removing the bulk of the lens with an irrigating vectis, similar to conventional ECCE. SICS is particularly helpful in eyes with ultradense cataracts where the cornea is at risk of decompensating. Many surgeons across the world use SICS as their primary method of cataract extraction with great success.
- **Conversion to ECCE:** If phacoemulsification is not making adequate headway, conversion to an extracapsular procedure is always a reasonable option (Video 32.6).

CORTICAL IRRIGATION AND ASPIRATION

Remaining epinuclear and cortical material is typically minimal in ultradense cataracts. The residual epinuclear cushion can be removed with a phaco-assisted vacuum technique. Zonular weakness may not be apparent until cortex removal. Using a "hurricane" technique for cortical removal may reduce zonular stress compared with the more conventional wedge-shaped cortex removal creating centripetal zonular stress. If needed, the bag can be filled with OVD and/or a capsular tension ring or segment may be placed. Poor suction of cortical material may be a sign of vitreous prolapse. Manual aspiration of cortical strands with a 27-gauge cannula attached to a 3-cc syringe half-filled with balanced salt solution may be helpful in some situations. This is performed in a stable, OVD-filled anterior chamber, offering exquisite control. If a posterior polar cataract was suspected preoperatively, then vacuuming the posterior capsule

should be deferred or considered only with great caution. Options are to perform a posterior capsulorrhexis or leave the opacity for postoperative Nd:YAG capsulotomy.

LENS PLACEMENT

As long as there is sufficient support, the preferred location for intraocular lens insertion is inside the capsular bag. In settings where there are only 1 to 2 clock hours of zonular weakness, a three-piece intraocular lens may be inserted into the bag with the haptics oriented toward the area of weakness. The surgeon should ensure lens centration by checking Purkinje light reflexes.

POTENTIAL COMPLICATIONS

Complexity of surgery of the ultradense cataract increases the risk for intraoperative complications (Box 32.2).

Zonulopathy

Increased age, pseudoexfoliation, and intraoperative trauma can result in zonular weakness at the end of the case. Capsule tension rings or segments should be used as needed.

Vitreous Loss

Because of comorbid zonulopathy and the additional surgical time, manipulation, and phaco power that may be expended during extraction of the ultradense cataract, these surgeries are at increased risk for vitreous loss.

- A cardinal intraoperative sign is poor flow of material to the aspiration or phacoemulsification tip.
- Early recognition of vitreous loss and appreciation of the mechanism for loss (i.e., zonular dialysis or posterior capsule rupture) is important to prevent further prolapse of vitreous into the anterior chamber and thereby minimize risk of inducing retinal pathology. Intraoperative management is with anterior vitrectomy.
- We recommend performing anterior vitrectomy through separate incisions with the infusion cannula anteriorly and the vitreous cutter through the pars plana, ideally through a trocar. This helps draw vitreous back out of the anterior chamber. Intraoperative vitreous loss results in higher risk of cystoid macular edema, retinal detachment, and endophthalmitis.[13]

Corneal Incision Contracture (Wound Burn)

A skilled cataract surgeon should take steps to decrease the possibility of corneal incision contracture, commonly known as *wound burn*. Although wound burn can be seen in more routine cataract surgery as well, surgery of an ultradense lens poses additional risk.

- Wound burn commonly occurs when phacoemulsification energy is applied without simultaneous aspiration flow through the needle tip, the most important mechanism for cooling of the tip. In especially dense lenses, fragments are more likely to occlude the tip, handpiece, or aspiration line, obstructing fluid movement in the phaco tip. Because heat generation will continue as ultrasound is applied, the temperature rises rapidly. This can result in denaturation of the collagen in the wound and can also even "melt" the underlying iris tissue.
- Another mechanism that reduces inflow of irrigant into the tip can be an OVD overfill in the anterior chamber. The type of OVD used may contribute to the risk. The surgeon should ensure that there is a space around the tip devoid of OVD so that fluid flow into the phacoemulsification needle is unimpeded.

After the capsulorrhexis but prior to starting phacoemulsification, the surgeon should ensure that adequate irrigation and aspiration are occurring. To do this, the surgeon can aspirate the anterior lens cortex and visualize rapid suctioning of the cortical material. Sluggish flow through the phacoemulsification handpiece may suggest that the phaco tip is working within OVD and BSS flow may be inadequate.

When performing phacoemulsification on an ultradense lens and as noted above, the surgeon should be cognizant of "lens milk" or "lens dust," which can be seen as cloudiness surrounding the tip. The presence of these dispersing lens particles should alert the surgeon that flow has slowed or halted through the phaco tip. If the tip is suspected to be clogged and does not clear readily by aspirating BSS, it is best to remove the phaco tip from the eye and attempt to clear the clogged tip.

Retinal Detachment

In patients with ultradense lenses, the risk for retinal detachment may be higher given the increased risk for other potential complications, such as vitreous loss. These patients should be counseled appropriately to be aware of potential symptoms of retinal detachment if capsular or vitreous complications are encountered. Peak incidence of retinal detachment varies from 3 to 31 months after surgery, although high myopia, young age, or posterior capsule rupture may lead to earlier retinal detachment.[14]

Corneal Decompensation

Corneal edema and decompensation can occur after routine cataract surgery, particularly in patients with preexisting endothelial dysfunction. Surgery of the ultradense lens typically will require more phacoemulsification energy, thereby putting the patient at increased risk for corneal decompensation. Preoperative examination should include a careful evaluation of the corneal endothelium to determine the patient's risk for corneal decompensation.

POSTOPERATIVE MANAGEMENT

Patients should as a general rule return for evaluation at day 1, week 1, and month 1 (Table 32.1).

BOX 32.2 Potential Complications

- Corneal edema often resolves with time, but use of steroids can speed the process. Sodium chloride drops or ointment may be palliative but do not change the final result.
- Zonulopathy with or without vitreous loss is important to recognize intraoperatively and address with capsule tension rings, capsule tension segments, sulcus placement of a three-piece IOL with or without optic capture, or anterior chamber IOL or scleral sutured IOL if there is no sulcus support.

TABLE 32.1 Tracking Patient Progress and Healing

Time Since Surgery	Positive Signs of Progress	Signs of Potential Complications
POD 1	AC formed, no wound leaks	Shallow AC, malpositioned lens
POW 1	Fewer cells, resolving corneal edema	More redness, pain, hypopyon
POM 1	Clear cornea, no AC reaction	Poor vision, CME

SUMMARY

The ultradense cataract poses unique challenges that are surmountable with preoperative planning and good technique.

- Set expectations with patients about unclear visual prognosis.
- Preop measurements may require manual A-scan to confirm axial length and B-scan to assess for posterior pathology.
- Perform careful capsulorrhexis after trypan blue staining of the anterior capsule.
- Use gentle hydrodissection.
- Use phacoemulsification with careful, staged nuclear disassembly to minimize endothelial and zonular trauma.
- Use periodic supplementation of additional dispersive OVD because it becomes depleted during nuclear removal.
- Be attentive to energy delivery and flow to minimize risk for wound burn.

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Video 32.1 Use of trypan blue with or without synechiolysis with hydrodissection canula may help improve visualization of the anterior capsule.
Video 32.2 Dr. Gregory Ogawa performs surgery on a dense morgagnian cataract, with excellent demonstration of lens milk aspiration and use of vertical chop.
Video 32.3 This very dense lens is emulsified with a chopping procedure, adding additional dispersive OVD throughout, using the bubbles in the OVD to determine depletion. The intraocular lens (IOL) is placed before emulsification of the final fragments to prevent a PC tear, should post-occlusion surge occur.
Video 32.4 Vertical chop can be an effective technique in beginning to disassemble a dense nucleus.
Video 32.5 The miLOOP device is used in this video to divide the nucleus and prolapse a fragment in to the anterior chamber for phacoemulsification.
Video 32.6 In this extremely dense lens in a colobomatous eye, phacoemulsification was aborted because of density and unsure capsular status and the procedure was converted to an extracapsular cataract extraction.

33

Intumescent Cataract

Gabriel B. Figueiredo

CONTENTS

KEY POINTS

- Creation of a CCC in an intumescent cataract is a challenge even for the experienced ophthalmic surgeon.
- Staining of the anterior capsule is mandatory.
- The surgeon must always be attentive to the anterior segment pressure gradient: capsular bag vs. anterior chamber.
- Glaucoma is often associated with the intumescent cataract.

INTRODUCTION

The intumescent cataract can be a challenge even for the experienced surgeon. Particularly, the creation of a continuous curvilinear capsulorrhexis (CCC) is tricky because of the increased endolenticular pressure. Further challenges the surgeon may face include absence of the red reflex, shallow anterior chamber, and zonular fragility. Secondary glaucoma can develop through multiple mechanisms, and adequate pre- and postoperative management is required.

CAUSES

This chapter approaches specifically the senile intumescent cataract. A white cataract can also rapidly develop after either ocular trauma (see Chapter 42) or iatrogenic puncture of the capsular bag.[1]

Senile Intumescent Cataract

The senile intumescent cataract is a type of mature cataract in which lens proteins denature and break down into smaller particles, increasing the number of osmotically active particles in the bag. This osmotic gradient draws fluid into the bag (which is a semipermeable membrane) until the hydrostatic pressure within the bag balances the osmotic pressure. This process of lens hydration leads to a significant increase of the volume within the capsular bag.[1]

COMORBIDITIES

Glaucoma

Two pathophysiological mechanisms can lead to high intraocular pressure (IOP) and consecutive secondary glaucoma in eyes with intumescent cataract.

Phacomorphic Glaucoma

Phacomorphic glaucoma is a consequence of the excessive increase in lens thickness, causing obstruction of the trabecular meshwork by (1) the mass effect of the thickened lens physically crowding the posterior chamber and pushing the iris anteriorly and/or (2) totally or partially obstructing the physiologic flow of the aqueous from the posterior chamber into the anterior chamber through the pupil caused by the pupil border touching the anterior capsule, inducing a relative trapping of the aqueous in the posterior chamber and consequently leading the peripheral iris to bow or billow forward, thereby blocking the trabecular meshwork.

Phacolytic Glaucoma

Tiny proteins arising from lens protein denaturation can leak through the capsular bag into the aqueous. These proteins then precipitate a secondary glaucoma as phagocytizing macrophages, inflammatory debris, and the proteins themselves obstruct the trabecular meshwork.

PREOPERATIVE MANAGEMENT

Before proceeding to dilated examination, a thorough investigation for angle closure must be performed. Initially, the patient should be asked about previous symptoms compatible with episodes of angle closure: acute or intermittent ocular pain, especially if directly over the brow, and blurred vision or rainbow colored haloes. Next, the surgeon should look for indirect signs of narrow angle on slit lamp examination: shallow anterior chamber and peripheral iris bowing, pupil atony/hypotony, iris atrophy, pigment deposition on the anterior capsule, or endothelium and anterior lens capsule opacities (glaukomflecken) are suggestive of previous acute angle closure. Finally, one should always proceed to gonioscopy. Although there are several

suggested clinical thresholds for an occludable angle, one rule of thumb for diagnosis is when the posterior trabecular meshwork is seen for less than 90 degrees of the angle circumference without indentation gonioscopy. The presence of peripheral anterior synechiae (PAS) is suggestive of previous episodes of angle closure. Once an occludable angle is diagnosed or in the suspicion of previous acute angle closure, a laser peripheral iridotomy should be performed promptly as a temporizing measure. The definitive treatment will be removal of the intumescent lens.

The mature, opaque lens makes fundus examination and axial length measurement through optical biometers impossible. Therefore, both A- and B-scan ultrasonography should be performed for axial length measurement and gross assessment for retinal detachment or other posterior segment pathology, respectively. Because posterior segment masses can induce a mature cataract, the B-scan will also be useful in ruling out this dreaded diagnosis. The mature cataract often slowly develops in an eye with previous impaired visual acuity, and the surgeon should ask the question, "Why did the patient wait so long before presenting?" History of previous low vision, whether amblyopic or acquired, should be investigated for proper counseling of realistic expectations. Although a potential acuity meter test can be attempted, it is unlikely to yield a probative result in an intumescent lens, and the results are often misleading. The true visual potential can only be assessed after surgery is performed.

SUBTYPE CLASSIFICATION

The intumescent cataract presents different features according to the stage[1] (Table 33.1) (Video 33.1). Correct subtype diagnosis is crucial for proper surgical management.

Pearly White Cataract

A large, hydrated nucleus is found in the pearly white cataract. Whiteish fluid can be either absent or present in a low to moderate amount. Several shades of white can be found on the anterior surface of the lens during slit lamp examination (Fig. 33.1). Increased convexity of the anterior capsule is an indirect sign of the presence of fluid within the capsular bag and consequent increase in endolenticular pressure.

Equatorial Block

Equatorial block occurs in the pearly white cataract with liquid. The fluid builds up within both the anterior and posterior subcapsular spaces and anteriorly and posteriorly to a huge nucleus, respectively. This liquid accumulation leads the anterior and posterior capsules to bow anteriorly and posteriorly, respectively. Consequently, the equatorial capsular bag is compressed against the nucleus, preventing the fluid from freely circulating between the two subcapsular spaces (Fig. 33.2). This process leads to the emergence of two independent hyperpressurized spaces within the capsular bag.

Morgagnian Cataract

Morgagnian cataract is the most advanced stage of the intumescent cataract, when most or all of the cortex is liquefied. The capsular bag is filled with a yellowish fluid, and the small nucleus floats freely in the bag. On slit lamp examination, the anterior surface of the lens presents a homogeneous yellowish aspect, and the brown nucleus can occasionally be seen inferiorly (Fig. 33.3).

SURGICAL PROCEDURE

Surgical Principles

The biggest challenge the anterior segment surgeon faces when approaching an intumescent lens is the creation of a CCC. Several techniques have been described, and we lack scientific consensus on the most appropriate one; different experienced surgeons have different techniques of choice to deal with the intumescent cataract. Given the description of all of those techniques in a single chapter is not feasible, the author presents his preferred technique based in his own personal surgical experience. Nevertheless, whichever technique one chooses, there are some fundamental surgical principles the surgeon should always keep in mind.

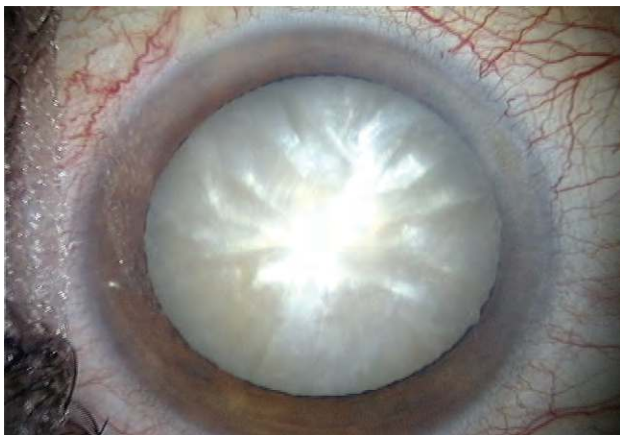
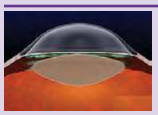
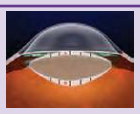
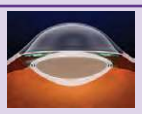


Fig. 33.1 Slitlamp picture of a pearly white cataract. Note the multiple shades of white throughout the anterior surface of the lens. This lens appears to be swollen, but, in all pearly white cataracts, one should assume that there is intralenticular fluid and pressure until proven otherwise intraoperatively.

TABLE 33.1 Feature Comparison Table of White Cataract Subtypes

	Pearly White		Morgagnian
	Without Fluid	With Fluid	
			
Nucleus	Big	Big	Small
Fluid	Absent	Low to moderate	Abundant
Endolenticular pressure	Normal to minimally elevated	High to extremely high	High
Equatorial block	Yes	Yes	No
Independent endocapsular spaces	No	Yes	No

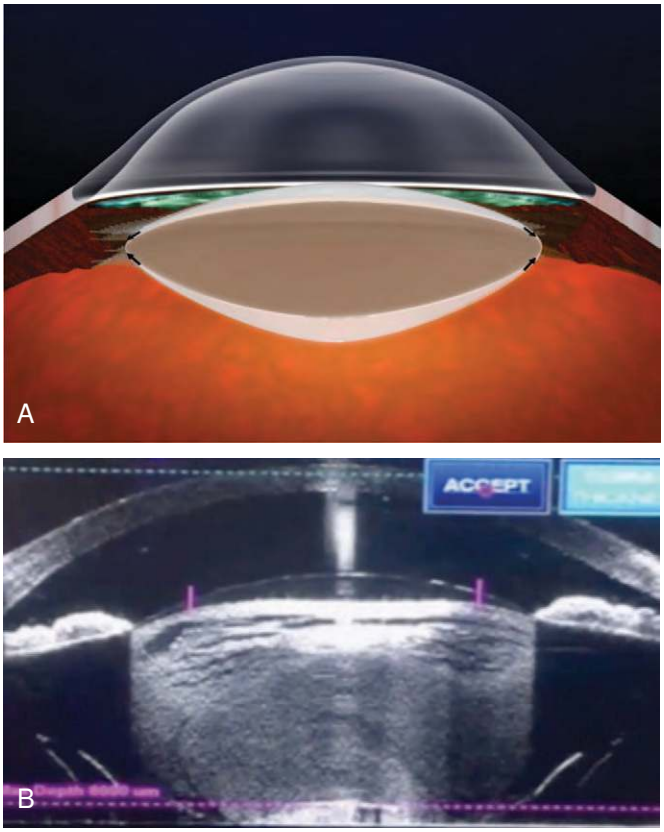


Fig. 33.2 (A) Illustration of a pearly white cataract demonstrating the equatorial block. Note the equatorial portion of the capsular bag compressed against the nucleus and the consequent accumulation of fluid in both the anterior and posterior subcapsular spaces. (B) Trapped fluid can be clearly identified in the anterior subcapsular space in an anterior segment optical coherence tomography image of a pearly white cataract. Although optical image capture of the posterior portion of the capsular bag is not possible, it is safe to assume a similar configuration is present.

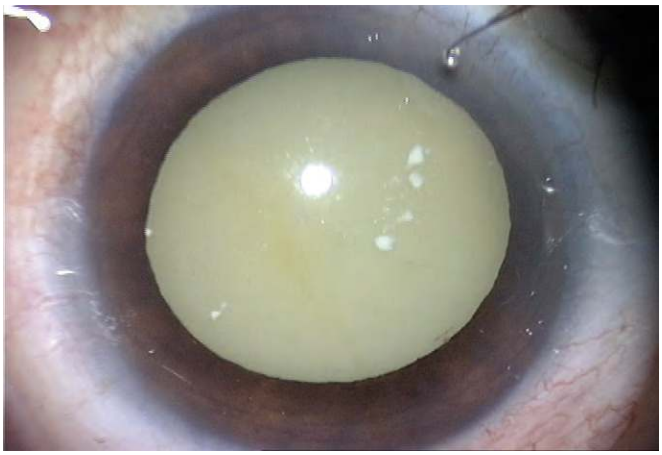


Fig. 33.3 Slitlamp picture of a morgagnian cataract. Note the homogeneously yellowish anterior surface of the lens.

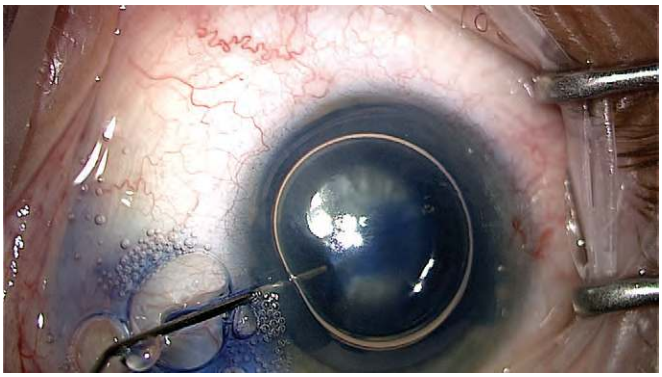


Fig. 33.4 Intraoperative picture demonstrating the injection of trypan blue under an air bubble in the anterior chamber of an eye with a white cataract to stain the anterior capsule. Trypan blue can also be injected directly into the anterior chamber without an air bubble.

Capsule Staining

The white, opacified lens blocks the intraoperative red reflex. Therefore the use of a capsular dye is mandatory to correctly identify the anterior capsule during creation of the capsulorrhexis. The most frequently used dye is trypan blue ophthalmic solution 0.06%.[2] The dye can be injected undiluted into the anterior chamber with or without an air bubble (Fig. 33.4). The anterior chamber is then irrigated after a few seconds with balanced salt solution (BSS), or directly with viscoelastic. Although staining of the anterior capsule is mandatory, trypan blue decreases elasticity of the capsule,[3] which could contribute to the increased risk of anterior capsule radial tear.

Pressure Gradient

The tendency for capsular tears to extend centrifugally toward the equator of the bag is caused by a hydrostatic/hydrodynamic principle: the anterior segment pressure gradient, or the difference between the anterior chamber and capsular bag pressures. The increased endolenticular volume leads to increased endolenticular pressure, causing the distension of the capsular bag and consequent increased convexity of the anterior capsule. The greater the convexity of the anterior capsule, the greater the tendency of the flap to run centrifugally. Simultaneously, as soon as the anterior capsule is pierced and a communication is created between the capsular bag and the anterior chamber, the content of both spaces will flow according to the pressure gradient—from the space of higher pressure to the space of lower pressure—until the pressure is equalized; that means that if the endolenticular pressure is greater than the intracameral pressure, the lenticular fluid will flow from the capsular bag into the anterior chamber, pushing the nucleus against the anterior capsule. Therefore the surgeon should always be attentive to the fundamental principle of keeping the anterior chamber highly pressurized up until the capsulorrhexis has been created and the endolenticular and intracameral pressures have been equalized. Techniques for decompression of the capsular bag for a variety of intumescent lens types will be described in the following paragraphs.

Shallow Anterior Chamber

In any intumescent cataract category, and even in some nonintumescent phacomorphic cataracts, the anterior chamber may be very shallow, limiting the amount of anterior chamber working space for surgical maneuvers. Several steps can be taken, either independently or in combination, to mitigate this challenge.

- Intravenous mannitol 30 minutes preoperatively: This can reduce vitreous volume and allow deepening of the anterior chamber, sometimes quite significantly.

- General anesthesia: Paralytics can reduce extraocular muscle tension and posterior pressure. Inhaled anesthetics cause systemic venous dilation with reduced central venous pressure, reducing orbital and choroidal congestion.
- Reverse Trendelenburg: This can can reduce central venous pressure similarly and additively to inhaled anesthetics.
- "Dry" vitrectomy: When the anterior chamber remains too shallow despite other measures, a pars plana cannula and trocar can be placed, and a few cuts of the vitrector in the central vitreous core can markedly improve anterior chamber depth. It is important to know from B-scan that there is no retinal or choroidal detachment or intraocular mass prior to trying this maneuver. Also, because the lens is thicker than usual, the surgeon must be careful to avoid contact with the lens during trocar placement or the limited core vitrectomy. An additional optical variable device should be added to the anterior chamber after each few cuts of the vitrector. Removing too much gel can make the anterior chamber overly deep and develop an unfavorably hyperdynamic chamber.

Hydrodissection

Hydrodissection should never be done in an intumescent lens. It is simply unnecessary in the morgagnian cataract, although it is a risk in the white pearly cataract. Because of the equatorial block present in the latter, the fluid injected under pressure reaches the posterior subcapsular space and gets trapped there (Fig. 33.5). The additional increase in pressure in the posterior subcapsular space can lead either to a radial tear of the anterior capsule or even the explosion of the posterior capsule.

Capsular Fibrosis

In mature and hypermature cataracts, the anterior capsule may undergo degeneration, with deposition of calcium or development of focal dense plaques. Ideally, when creating the capsulorrhexis, the surgeon should direct the tear around these abnormalities. If not possible, then the surgeon can cut across the plaque with small gauge scissors. Multiple cuts can be performed across the plaque; however, one single and continuous cut ought to be made when clear capsule is being cut both when entering and exiting the plaque to avoid the creation of zones of weakness.

Pearly White Cataract

The adequate surgical approach depends on the presence or absence of fluid within the capsular bag (Video 33.2). Even though one can look for signs of endolenticular liquid during slit lamp examination as discussed previously, this can only ultimately be confirmed intraoperatively once the anterior capsule has been pierced.

Fig. 33.5 Illustration of hydrodissection in a lens in which equatorial block is present. Note that the balanced salt solution, injected under pressure, accumulates in the posterior subcapsular space.

- Make two corneal paracenteses at the 12 o'clock and 6 o'clock positions.
- Inject trypan blue into the anterior chamber.
- Wash out the trypan blue, and overfill the anterior chamber with viscoelastic to keep it highly pressurized.
- Visualize a flattening of the anterior capsule. This denotes that the anterior chamber pressure is higher than the endolenticular pressure.
- Capsular entry and pressure equalization, either passive or active, should be performed through a paracentesis rather than through the main incision to prevent ophthalmic viscosurgical device (OVD) from leaking out, causing a loss of the anterior chamber pressurization.
- Puncture the anterior capsule with a cystotome (Fig. 33.6A).
- Attentively watch for white fluid leaking out of the bag, and proceed accordingly with subsequent steps determined by the presence or absence of excess fluid in the capsule (see Fig. 33.6B).

Pearly White Cataract Without Fluid

Endolenticular pressure is usually normal or just slightly elevated in this stage. The surgeon should keep the anterior chamber pressurized with viscoelastic and proceed to creation of the capsulorrhexis with routine technique. Attempted active decompression of the capsular bag by aspirating softer subcapsular cortex can be attempted in an abundance of caution if the degree of endolenticular pressurization is unclear.

Pearly White Cataract With Fluid

A pearly white cataract with fluid is the lens with the greatest risk for a radial capsular tear. Besides the elevated endolenticular pressure, there is also the presence of equatorial block and two independent and pressurized subcapsular spaces. Once the anterior caspule is open and the

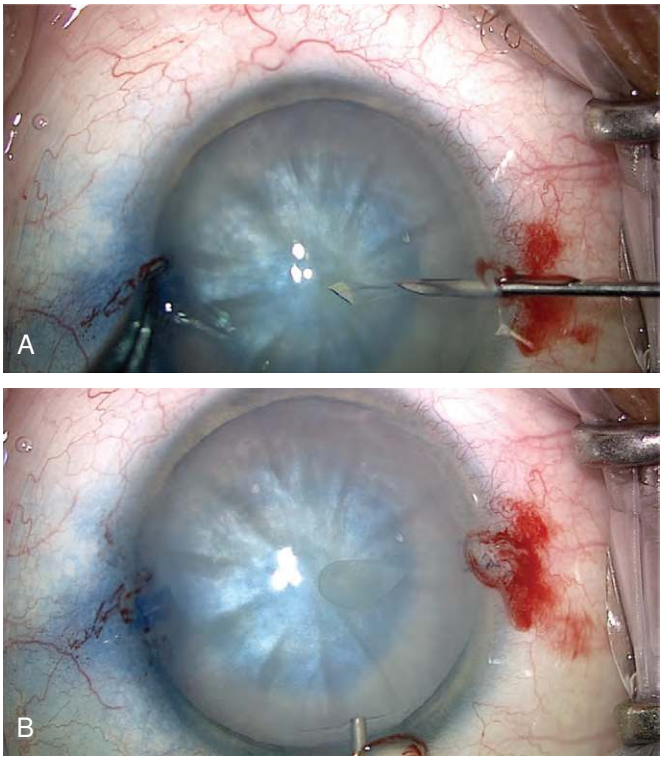


Fig. 33.6 Intraoperative pictures of the initial steps in a pearly white cataract. (A) The anterior capsule is pierced under a highly pressurized anterior chamber. (B) The surgeon must then attentively watch for any white fluid leakage from the capsular bag and proceed accordingly.

anterior subcapsular space pressure is equalized with the anterior chamber pressure, the fluid trapped in the posterior subcapsular space pushes the nucleus anteriorly against the anterior capsule (Fig. 33.7). The greater the gradient pressure between the posterior subcapsular space and the anterior chamber, the greater the force exerted by the nucleus onto the anterior capsule.

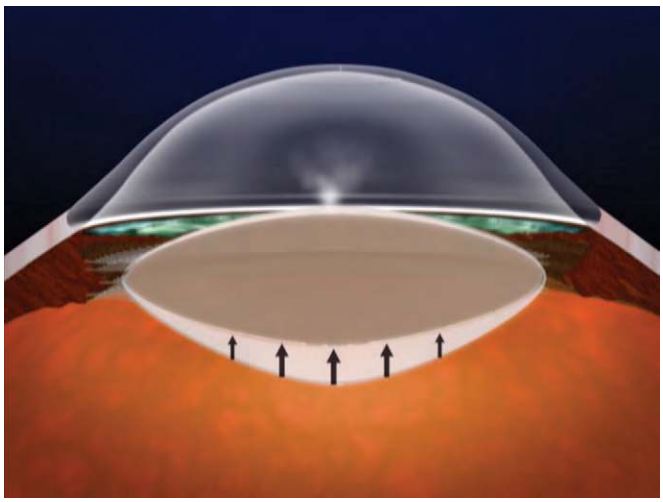


Fig. 33.7 Illustration of the anterior capsule piercing in a pearly white cataract with fluid. Note that the fluid in the anterior subcapsular space flows into the anterior chamber until the pressure in these two compartments are equalized. Meanwhile, the fluid trapped in the posterior subcapsular space pushes the nucleus anteriorly against the anterior capsule.

- After piercing the anterior capsule, one can wait for a slower, passive equalization of fluid, which is complete when no additional flow is seen.
- Alternatively, the capsular bag can be actively decompressed by aspiration using a partially BSS-filled syringe attached to a cannula or attached directly to the needle used for capsular puncture.
- Create a "mini-rhexis" (2.5–3.0 mm) with small-gauge forceps through one of the paracenteses (Fig. 33.8A). In case visualization of the flap gets clouded by the white fluid, clear the central area by injecting more viscoelastic.
- Use bimanual irrigation and aspiration to aspirate the fluid in the anterior subcapsular space. Next, use the aspiration handpiece to mobilize the nucleus, and break down the equatorial block, allowing the fluid in the posterior subcapsular space to flow anteriorly and be aspirated (see Fig. 33.8B).
- Make the temporal main incision.
- Create a new flap using small-gauge scissors (see Fig. 33.8C).
- Enlarge the capsulorrhexis to the desired diameter (see Fig. 33.8D).
- Proceed with surgery according to surgeon's routine (Video 33.3).

Morgagnian Cataract

Even though endolenticular pressure is usually elevated in theses lenses, equatorial block is not present, and pressure equalization can be achieved more easily.

- Create one paracentesis.
- Inject trypan blue into the anterior chamber.

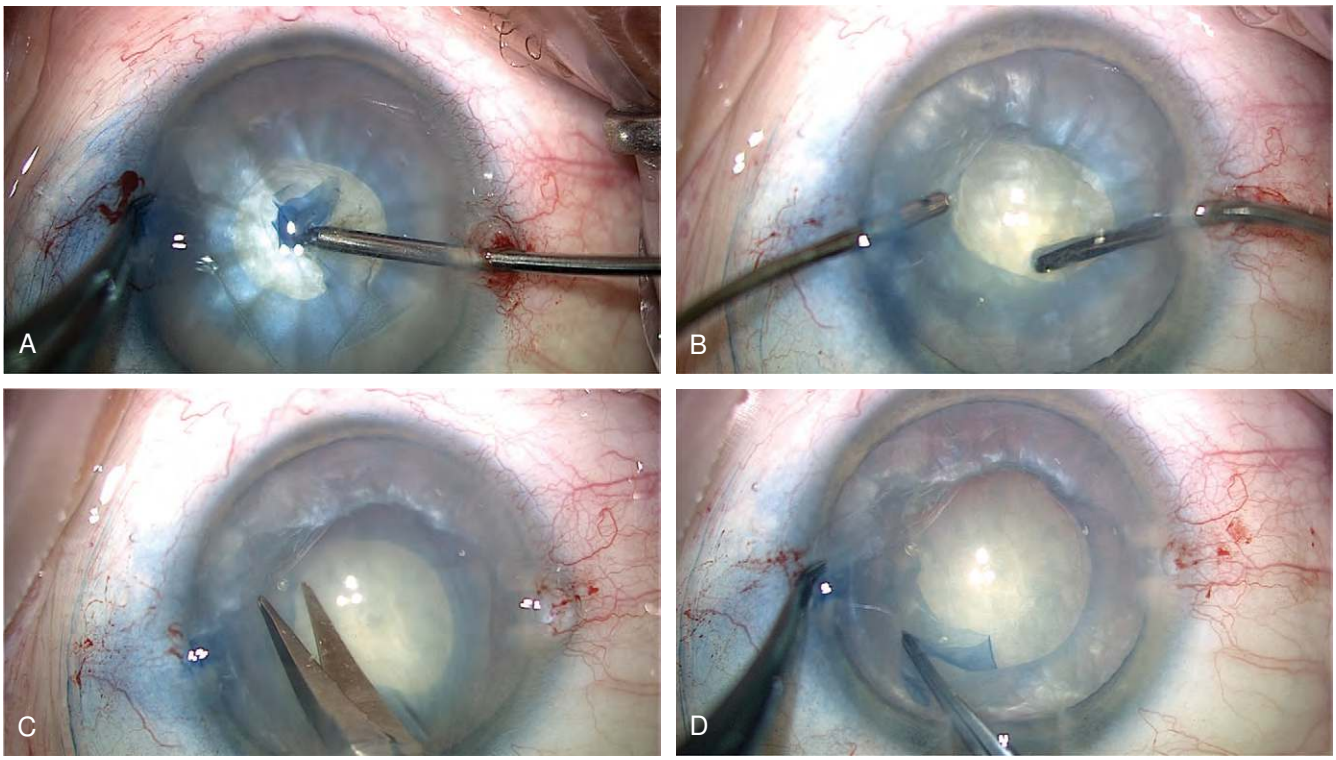


Fig. 33.8 Intraoperative pictures of key surgical steps in a pearly white cataract with fluid. (A) Creation of a "mini-rhexis" around 3 mm in diameter with a small-gauge forceps through the paracentesis to avoid viscoelastic burping out. (B) Decompression of the capsular bag by aspiration of the fluid both in the anterior and posterior subcapsular spaces with the assist of bimanual irrigation and aspiration. (C) Creation of a new anterior capsular flap. (D) Enlargement of the capsulorrhexis to the desired diameter.

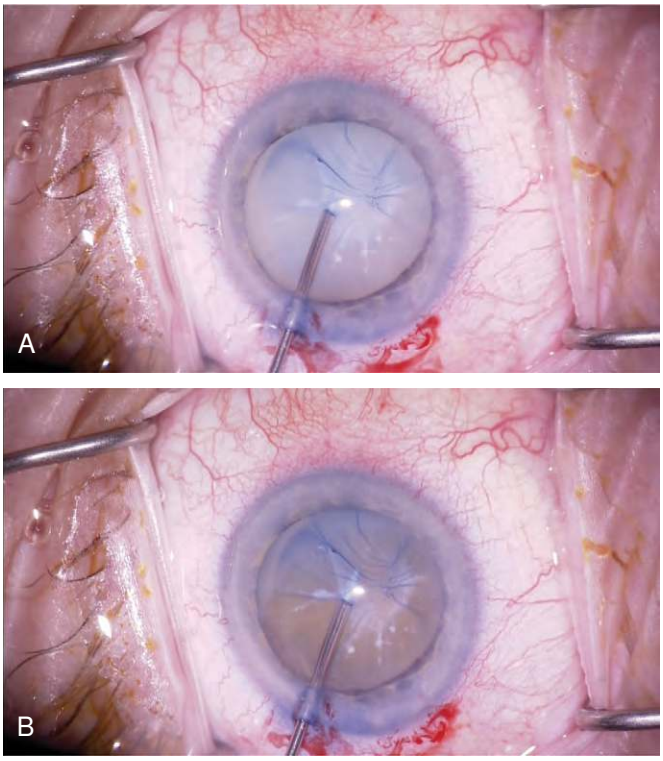


Fig. 33.9 Intraoperative picture (A) before and (B) after the aspiration of the fluid with a 27-g needle in a morgagnian cataract.

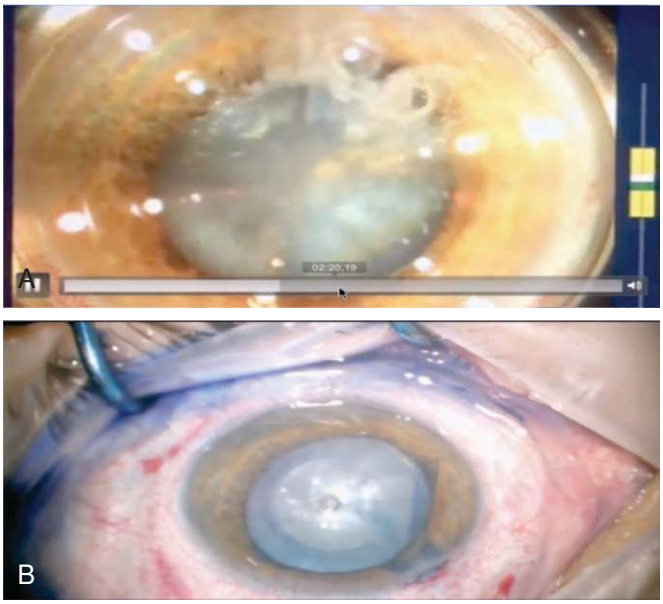


Fig. 33.10 Intraoperative picture of a case of femtosecond laser cataract surgery in an intumescent lens. (A)The substantial flow of whitish fluid from the capsular bag into the anterior chamber immediately after laser capsulotomy begins indicates that the endolenticular pressure is higher than the docking pressure. (B) The result is an incomplete capsulotomy with an inferonasal radial tear. (Courtesy Dr. Durval M. Carvalho Jr.)

SURGICAL PEARLS

- Stain the capsule.
- Keep the anterior chamber continuously overpressurized until the endolenticular pressure has been completely relieved and equalized with the anterior chamber pressure.
- Keep in mind the equatorial block.

- Wash out the trypan blue and overfill the anterior chamber with viscoelastic to keep it highly pressurized.
- Puncture the anterior capsule with a 27-g needle attached to a 3-cc syringe (Fig. 33.9A).
- Aspirate the endolenticular fluid (see Fig. 33.9B).
- Create the temporal main incision.
- Create the capsulorrhexis to the desired diameter.
- Proceed with surgery according to surgeon's routine.
- Because there is often no cortex in Morgagnian cataracts, some surgeons will fill the equatorial capsular bag with dispersive OVD to minimize mobility of the hard central nucleus during the phacoemulsification, mimicking the cortical cushion (Video 33.4).

Femtosecond Laser-Assisted Cataract Surgery in Intumescent Lenses

Some surgeons feel that the automated nature of FLACS is appealing in these cases. Delegation of these most important steps to the laser and its interface has potential hazards, as the FLACS surgeon cedes control of the relative anterior chamber pressure gradients. If the anterior chamber pressure increase that occurs during docking happens to increase the pressure higher than the endolenticular pressure, then the capsulotomy will probably proceed without incident. If, on the other hand, the endolenticular pressure is higher than the docking pressure, then the undesired sequelae of the Argentinian flag syndrome can occur (Fig. 33.10) (Video 33.5). Unlike the flattening of the anterior capsule seen when the anterior chamber pressure becomes higher than the lens pressure during OVD instillation, there are no visual cues of the relative pressure gradient based on the FLACS optimal coherence tomography.

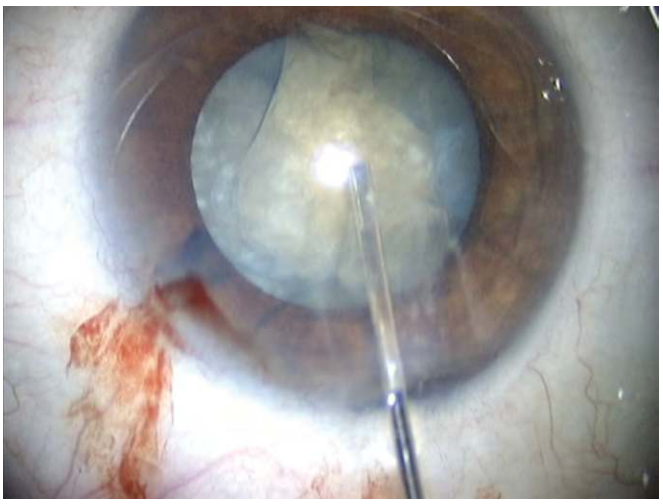


Fig. 33.11 Intraoperative picture of the Argentinian flag sign.

POTENTIAL COMPLICATIONS

Argentinean Flag Sign

The most common complication in intumescent cataracts is the radial tear of the anterior capsule known as the *Argentinean flag sign*

(Fig. 33.11). To manage this complication, the surgeon can either (1) create a new flap with small-gauge scissors in both "hemi-capsules" and create two "hemi-rhexis" or (2) resume opening the anterior capsule with the can-opener technique with a cystotome. Next, one should proceed with phacoemulsification carefully in a slow fashion with low parameters, so-called "slow phaco."[4] The radial tear might extend around the equator into the posterior capsule; therefore the surgeon must remain vigilant for signs of posterior capsule rupture (see Chapters 46 and 47). In the event of an Argentinian flag sign and the posterior capsule that remains intact after the phacoemulsification, one option is to implant a three-piece PCIOL ideally with a rounded anterior surface. Depending on surgeon comfort, a 4.5-mm primary posterior capsulorrhexis could be created, and the intraocular lens optic can be captured into Berger's space, ensuring long-term centration.

Posterior Capsule Rupture

There are three ways for the posterior capsule to rupture in these cases. As noted previously, an anterior capsulotomy extension around the equator may occur. Also, if the surgeon errantly adds hydrodissection fluid when an equatorial block is present, the posterior capsule may acutely blow out. Even if the posterior capsule is intact at the beginning of the phaco, if previously distended by the great endolenticular volume, it may be flaccid with a tendency of "trampolining" anteriorly during phacoemulsification, thereby increasing the risk of posterior capsule contact and tear. Dispersive viscoelastic should be used to keep the posterior capsule posteriorly and creating an additional cushion. Adequately tight incisions are mandatory to avoid BSS leakage during phacoemulsification.

! POTENTIAL PITFALLS

- Puncturing the anterior capsule with low-pressure anterior chamber.
- Viscoelastic burping out of the eye during creation of the capsulorrhexis.
- Not relieving the fluid trapped in the posterior subcapsular space.

Zonulopathy

Zonulopathy is frequently associated with these mature lenses. The surgeon should attentively look for signs of zonular fragility during preoperative evaluation. Further information on the management of weak zonules can be found in Chapter 34.

POSTOPERATIVE MANAGEMENT

The postoperative management differs only slightly from the cataract surgeon routine. Patients should return for evaluation within 1 day, 1 week, and 1 month. IOP usually normalizes once the cataract has been removed and the anterior chamber deepens. Persistence of intraocular hypertension suggests persistent anatomic changes to the angle such as PAS, trabecular meshwork pigmentation, etc., which must be further investigated. Detailed fundus examination should be performed as soon as the ocular media are sufficiently clear.

SUMMARY

- Creation of a CCC is a challenge in the intumescent cataract because of the elevated endolenticular pressure.
- During creation of the CCC, the surgeon should keep the anterior chamber highly pressurized to counterbalance the endolenticular pressure.
- The pearly white cataract with fluid is at the greatest risk for Argentinean flag sign caused by the presence of the equatorial block. The surgeon should keep in mind that the risk is only diminished once the posterior subcapsular space pressure has been alleviated.
- Angle closure and secondary glaucoma are often associated with the intumescent lens and should be managed accordingly.

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Video 33.1 Different stages of the white cataract and corresponding features.
Video 33.2 Surgical differences between the pearly white cataract with vs without fluid.
Video 33.3 Surgical technique for the pearly white cataract with fluid.
Video 33.4 Surgical technique for the Morgagnian cataract.
Video 33.5 Argentinean flag sign during femtosecond laser capsulotomy in a pearly white cataract with fluid.

34

Management of Weak Zonules

Ehud I. Assia, Guy Kleinmann, and Michael E. Snyder

CONTENTS

KEY POINTS

- Identifying ophthalmic conditions associated with zonulopathy will prepare the surgeon in advance of a case.
- Identifying systemic origins of zonulopathy can be lifesaving.
- The capsular bag can (and should) usually be preserved.
- Preservation of the capsular bag permits use of toric- or presbyopia-correcting intraocular lenses, both of which are of great value for many in the cohort of patients likely to have zonulopathy.
- Capsulorhexis creation is a critical step.
- The capsular bag can be stabilized intraoperatively by a variety of capsule hooks, iris hooks, microforceps, clips, and rings.
- The capsular bag can be stabilized in the long-term by implantable devices, some of which can be scleral fixated.
- Attentiveness to micropressure gradients and judicious use of step-dependent dispersive or cohesive optical variable device (OVD) can reduce the odds of capsule damage and/or vitreous prolapse.

INTRODUCTION

Weak zonules and phacodonesis are not uncommon and may complicate both lens removal and stable fixation of intraocular lenses (IOLs). Zonular weakness or dehiscence presents numerous surgical challenges:

- Intraoperative: removal of the lens material from the unstable capsular bag and safe implantation of an IOL in an eye with impaired capsular support
- Postoperative: maintaining the long-term stability of the implanted lens or management of the malpositioned IOL

CAUSES

The most common causes of loose zonules vary depending on demography. In elderly patients, one is most likely to see the following:

- Pseudoexfoliation (PXF) syndrome
- High axial myopia
- Advanced age

In the younger population, the leading causes include the following:

- Blunt ocular trauma
- Inherited disorders such as Marfan's syndrome, homocystinuria, retinitis pigmentosa, and Weill-Marchesani syndrome or primary pathology not associated with other ocular or systemic diseases (autosomal dominant primary ectopia lentis)

COMORBIDITIES

There are a wide array of common comorbidities in patients with zonulopathy.

Ocular Comorbidities

PXF eyes:

- Commonly associated glaucoma
- Often very poorly dilating pupils
  - Each surgeon has a threshold for using pupillary dilating mechanisms in cataract surgery. In patients with PXF, it would be wise to have a lower threshold because zonulopathy may not always be evident on the preoperative examination.
- Zonulopathy
  - Some surgeons like to place a capsular tension ring (CTR) in PXF eyes even in the absence of clinical zonulopathy.
    - Does not prevent late subluxation
    - May make the management of a later subluxation more facile

Traumatic zonulopathy may have the following concomitant:

- Vitreous in the anterior chamber
- Glaucoma
- Iris damage
- Reduced endothelial cell counts
- Retinal detachment
- Epiretinal membrane

In addition to the "routine" examination, obtaining endothelial cell counts and a careful retinal examination, along with optical coherence tomography of the retina and optic nerves, are helpful adjuncts in identifying problems before surgery and staging or combining procedures with other subspecialties as needed.

Systemic Comorbidities

Patients with known or suspected Marfan's syndrome should have echocardiograms with special attention to the aortic root because dissection is a potentially preventable and deadly consequence. When the origin of zonulopathy is unknown, we advise an echocardiogram and a serum homocysteine level. Homocystinuria may go undiagnosed through generations and is associated with early coronary artery disease. Seeking this possibility is another opportunity for early life-saving interventions. Although other diseases are also associated with zonulopathy, these two provide the greatest opportunity to identify treatable systemic disease.

Preoperative Management

Depending on the underlying pathology, preoperative management may require significant interventions, such as retinal detachment repair and management of intraocular pressure (IOP) either before the cataract is addressed or, sometimes, simultaneously with cataract surgery. In the presence of significant posterior segment pathology, combining the cataract surgery with vitreoretinal intervention can preserve the capsular bag anatomy and maximize the choices and accuracy of the IOL, even in profound zonulopathy.[1] Sometimes retinal specialists will otherwise perform a pars plana vitrectomy and lensectomy, which leads to less ideal IOL options. Preservation of the capsular bag maintains the ability to place toric- and presbyopia-correcting implants. Because many young patients with zonuoplathy from Marfans' syndrome, other progressive zonulopathies, or even trauma may have high corneal astigmatism if the zonulopathy is present during their early years while their eyes are growing, maintaining the option for toric IOL implantation has significant intrinsic value. Similarly, presbyopia is an unwelcome side effect, and monofocal pseudophakia, especially in the prepresbyopic age group, and multifocality may be desirable, provided there is a healthy posterior segment.

Likewise, if an elevated IOP cannot be controlled with drops preoperatively, then a combined procedure with a stent, goniotomy trabeculectomy or seton may be required.

SURGERY

Removal of the lens material and maintaining the capsular bag for IOL fixation in an eye with damaged zonules may potentially result in severe complications:

- Tearing of the remaining loose zonules
- Lens subluxation
- Breaking of the lens capsule followed by dropped lens material into the vitreous cavity
- Vitreous prolapse into the anterior segment

Accordingly, these cases require extreme attentiveness for each step. The degree of zonulopathy may be apparent at the outset of the case, but many times what appears to be mild zonular instability may be either masking severe damage or rapidly disclosing more prominent or even profound zonular damage. The surgeon must be willing to alter the surgical plan as the case evolves. The following paragraphs outline the tools and techniques required for these cases. When each technique may be implemented during a case can vary greatly depending on the preexisting anatomy, density of the lens, and the origin and extent of the zonular damage.

CAPSULORHEXIS

Creation of the continuous curvilinear capsulorhexis (CCC) is perhaps the most critical portion of a loose zonule case. Piercing the anterior capsule with a cystotome may be effectuated normally in most cases, but, in more prominent zonular damage and with softer lenses, there may not be enough countertraction to enter the capsule, and efforts may just result in a pincushion effect or lens displacement.

- Trypan blue to reduce capsular elasticity: In younger patients in particular, the capsule may be difficult to puncture, and it may be difficult propagate a tear because of inherent high elasticity. Painting the capsule with a drop of trypan blue and allowing it to sit for 30 to 40 seconds will reduce the elasticity and aid in both initiation and peeling of the CCC.[2]
- Capsule pinch: If the capsule is still difficult to enter, the initial capsule opening may be achieved by using two opposing 30-G needle tips to pinch the capsule centrally to begin the CCC[3] (Video 34.1).
- Propagation of CCC: The continuous tear can sometimes be performed as usual but may require stabilization to the capsule margin during this step. Some surgeons will hold the capsule margin with a separate microforceps for stabilization (Video 34.2). Others will use one or more iris hooks to the capsule margin (Video 34.3).
- Femtosecond laser capsulotomy: Some advocate the use of the femtosecond laser in the setting of zonulopathy. Although this may have some appeal, there are significant limitations as well. First, when zonulopathy is present, the lens is frequently tilted, and the anterior capsule plane may not be parallel to the plane of laser actuation. In such a case, the capsulotomy may be incomplete. Also current laser platforms can only perform a round capsulotomy. Because lenses with significant and/or long-standing zonulopathy may be misshapen, a circular best-fit capsulotomy may be impractical for execution of the case. For lenses that may be decentered under an iris leaflet, the laser may not have an acceptable "view" of enough exposed lens to create a reasonable capsulotomy without the prior placement of iris retraction hooks, which precludes laser docking. Lastly, the edge of a femtosecond capsulotomy is not as strong as a continuous tear and may have a greater chance of breaking during the manipulations required for these more complex cases.

CAPSULE STABILIZATION

In cases with a small degree of dialysis and otherwise normal remaining zonules, the phacoemulsification may be performed with zonular-friendly, gentle technique. In trauma cases, zonules are either broken or they are not, so remaining zonules are sound. Conversely, in progressive zonulopathies like Marfan's syndrome, areas where the zonules appear normal may be very weak as well.

Temporary Stabilization

Temporary stabilization during surgery can be achieved using conventional iris retractor hooked around the capsulorhexis margin or capsular hooks, which have a larger contact area, smooth edges, and support the lens capsule at the equator (Video 34.4).

Sometimes a 120-degree capsule segment with a fixation element (Ahmed segment, capsular tension segment [CTS], Morcher GMBH, Stuttgart, Germany) can be placed before or during phaco, supported by an inverted iris retractor to stabilize the bag for lens emulsification (Video 34.5). The Ahmed segment will also be described in more detail in the section on long-term fixation.

Flexible iris or capsule hooks are removed after IOL implantation, and the stability of the IOL is reevaluated. If a CTS segment is used, the hook

can be released and a suture threaded into the CTS eyelet (Video 34.6). Jacob reported using a temporary hook as a permanent capsular supporting element by transscleral fixation of the external edge under a glued scleral flap.

Long-Term Stabilization

In mild cases, a posterior-chamber intraocular lens (PC-IOL) can be positioned within the capsular bag, and the lens often maintains good centration and stability even in the presence of mild phacodonesis. However, in the more advanced cases, the surgeon may find, after removal of supporting hooks, that the remaining zonules are not sufficient to ensure a long-term stable IOL fixation and that an alternative technique is then required.

Mild Zonulolysis

One alternative IOL fixation technique includes positioning of the IOL in the sulcus and posterior capture of the lens optic through the ACCC. This way the IOL haptics may augment support to the capsule complex.

If a zonulolysis is modest in either extent or degree, a traditional CTR can be placed into the capsule fornix to redistribute the forces evenly to all of the remaining zonules. The relative size of the CTR can be selected to match the size of the capsular bag. Overlap of the terminal eyelets is required for maximum circumferential support. Which particular standard CTR is used is probably less important in most cases other than in either extremely small capsular bags (for example, in microspherophakic eyes) or very large megaloanterior segment eyes.

Moderate and Severe Zonulopathy and/or Zonulolysis

In moderate or severe cases, the weakened zonules are not sufficient to provide a stable long-term IOL fixation. This can be predicted by larger extent of zonular damage and/or significant decentration of the crystalline lens preoperatively. In such instances, the surgeon may choose one of the two options:

1. Remove the entire lens (including the capsule), and then deal with aphakia.
2. Maintain the capsular bag using artificial, scleral fixated, capsule-stabilizing devices.

Options for IOL implantation in an aphakic eye with no lens capsule include insertion of an anterior chamber lens (angle-supported or iris-supported), iris fixation of PC-IOL, or a variety of suture fixation or intrascleral haptic fixation techniques. Further details on IOL fixation in aphakic eyes is beyond the scope of this chapter. The following are some significant advantages to maintaining the lens capsule:

- The remaining weakened but still intact zonules help support the implanted IOL.
- The lens capsule maintains the barrier between the anterior and posterior segments of the eye.
- The vitreous body remains intact.
- The entire IOL is secured within the bag and is separated from the adjacent uveal tissue, thus avoiding iris chaffing, bleeding, and glaucoma (UGH syndrome).
- Furthermore, preservation of the capsular bag complex reduces the relative need for vitreous manipulation and thereby reduces posterior segment risk while preserving a wider variety of IOL options and greater accuracy of the ultimate refractive outcome. We have even gone to extremes in case of a dangling lens hanging into the vitreous cavity in which we have worked in tandem with our vitreoretinal colleagues to perform a core vitrectomy and then tilt the lens forward into the iris plane, after which a bag-preserving phaco can be performed (Video 34.7).

CAPSULE-STABILIZING DEVICES

Traditional Capsular Tension Rings

Hara et al.,[4] Legler et al., and Nagamoto et al. were the first to suggest the concept of an intracapsular ring. They separately suggested it for capsular bag stabilization and posterior capsule opacification (PCO) prevention. Hara's ring was made of silicon, whereas the ring presented by Legler was made of polymethyl methacrylate (PMMA). These rings expanded the capsular bag, stabilized it, and provided countertraction that may facilitate cortical aspiration in cases of moderate degrees of zonular weakness or dialysis.

Cionni and Osher[5] reported in 1995 successful surgery in four cases with extensive traumatic or congenital zonular dialysis using the endocapsular tension ring (known later as the CTR, or, more familiarly, the *CTR*) (Fig. 34.1). The IOLs remained well centered, and the patients have had excellent visual acuity with a follow up of 4 to 10 months. Jacob et al.[6] reported over 90% success rate while using the CTR in 21 eyes with less than 150 degrees zonular dialysis with a mean follow-up of 8 months. Extension of the dialysis occurred in 2 eyes, and 15 eyes had final visual acuity of 20/40 or better. The literature is now replete with studies demonstrating similarly favorable structural and visual results in eyes with a variety of pathophysiologies of their zonulopathies.[7–10]

Two manufacturers originally introduced rings to the market: Morcher in 2003 and Ophtec in 2004. Later many other manufacturers produced a variety of ring sizes ranging from 10.5 to 14.5 mm open diameter. A CTR can be implanted manually or with injectors. The Henderson CTR variation (Fig. 34.2) has an open C-shaped loop made

Fig. 34.1 Conventional, original CTRs (first described by Witschel and Legler).

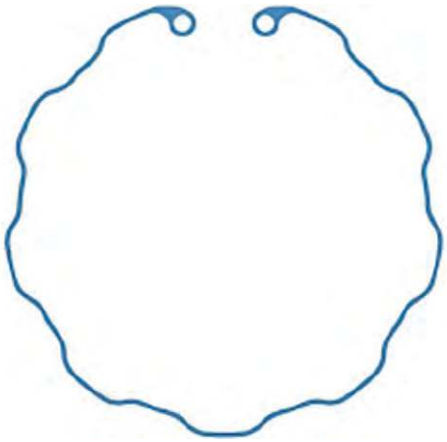

Fig. 34.2 Henderson CTR with periodic indentations, which are less likely to catch cortical fibers and, perhaps, may prevent toric IOL rotation.

of PMMA with eight equally spaced indentations of 0.15 mm that are intended to improve the surgeon's ability to remove equatorial cortical strands, which might otherwise become "trapped" by a traditional smooth CTR. Some have anecdotally suggested using this notched CTR to prevent rotation of toric IOLs in an oval capsular bag.

The standard endocapsular ring failed to stabilize the capsular bag in cases with extensive zonular loss in the long-term. In their first reported case, Cionni and Osher[11] implanted a CTR in a case with 240 degrees of zonular dialysis, and 5 months postoperatively the IOL was decentered. Later on, other reports of spontaneous total lens dislocation after CTR implantation were published. Many surgeons recommend the routine use of CTR in eyes with pseudoexfoliation (PXF) syndrome. One proposed advantage was that if the IOL will later subluxate or dislocate, it would be considerably easier to suture fixate lens capsule with a CTR within to the scleral wall. The point of fixation can be anywhere along the equatorial circumference and is not dictated by the position of the IOL haptic (Fig. 34.3). However, studies have shown that the insertion of the CTR by itself may be traumatic and may further cause unzipping of the weakened zonules and jeopardize IOL capsular fixation. Eyes with CTR subluxated more often and earlier (mean 6.8 years) than eyes without CTR (mean 8.5 years),[10,12] although there may be a selection bias in this data because cases with worse zonulopathy were more likely to have had a CTR placed.

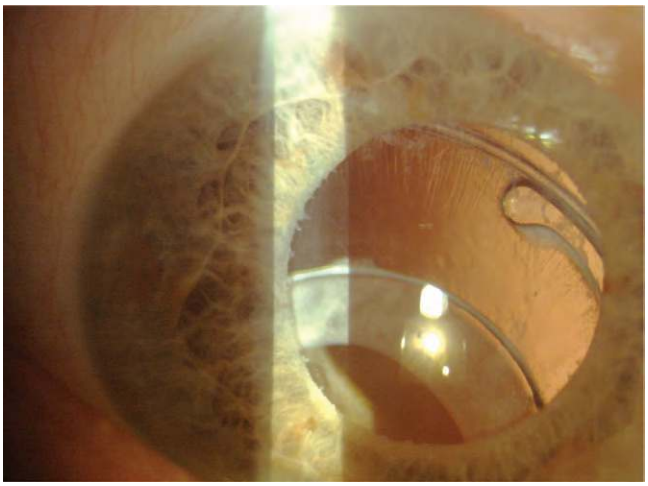

Fig. 34.3 Late subluxation of a PC-IOL-CTR-capsular bag complex in an eye with PXF syndrome. The CTR may facilitate scleral fixation of the bag-capsule complex by placing a suture loop around the ring.

In a large series of 295 patients with PXF, Shingleton et al. demonstrated that nonsutured CTR implantation does not prevent IOL and capsular complications postoperatively.[13]

Modified "Cionni" Capsular Tension Rings

In 1998 Cionni and Osher[14] published a modification of the ring (known later as the *Cionni CTR*), which enables scleral fixation of the ring without violating the integrity of the capsular bag. They added to the ring a hook element that extends perpendicular from the loop centrally and courses anteriorly (0.25 mm forward from the body of the CTR) in a way that it wraps around the capsulorhexis edge.

- An eyelet at the free end of the hook serves for manipulation and suture placement to secure the ring to the scleral wall to stabilize the capsular bag.
- The ring is available with single and double eyelet (Fig. 34.4).
- Before the implantation of the ring, a double-armed suture should be inserted through the eyelet. The two needles are then inserted through the incision and directed over the area of the zonular dialysis to exit through the ciliary sulcus and scleral wall, similar to the techniques for IOL scleral fixation. Next the ring is implanted into the capsular bag, the suture is tightened, and the knot is buried by rotation.
- Ahmed and Crandall presented a modified *ab externo* technique for the Cionni CTR, avoiding the blind needle passes under the iris at the exact scleral position for ciliary sulcus placement as identified externally.[15]
- An adequately sized capsulorhexis (about 5.0–5.5 mm) is important to avoid dragging a small capsulorhexis.

Cionni et al.[16] reported positive results with the implantation of the modified CTR in four cases with extreme zonular weakness with a follow-up time of 2 to 8 months. Later they reported results of 90 eyes with best corrected visual acuity at last follow up of 20/40 or better in 80 eyes (88.9%). Complications included six eyes (6.7%) with late PC-IOL decentration, PCO (20%), broken suture (10.0%), and persistent iritis (3.3%).[17] Buttanri et al.[18] reported results of 16 eyes of 16 patients with traumatic cataract and implantation of a foldable IOL and a 1- or 2-eyelet modified Cionni CTR. Although eight eyes (50%) had phacodonesis preoperatively, no eye had pseudophakodonesis postoperatively. Ten eyes had symptomatic decentration preoperatively, and only 2 eyes had asymptomatic nonprogressive decentration postoperatively. Vasavada et al.[19] reported results of 41 eyes with subluxated lenses that underwent capsular bag IOL fixation with the modified Cionni CTR. In a mean follow-up of 45.8 months, only 3 eyes demonstrated IOL decentration. Surgical repositioning was required in 2 of them. The Cionni rings must be implanted manually because the fixation elements along the course

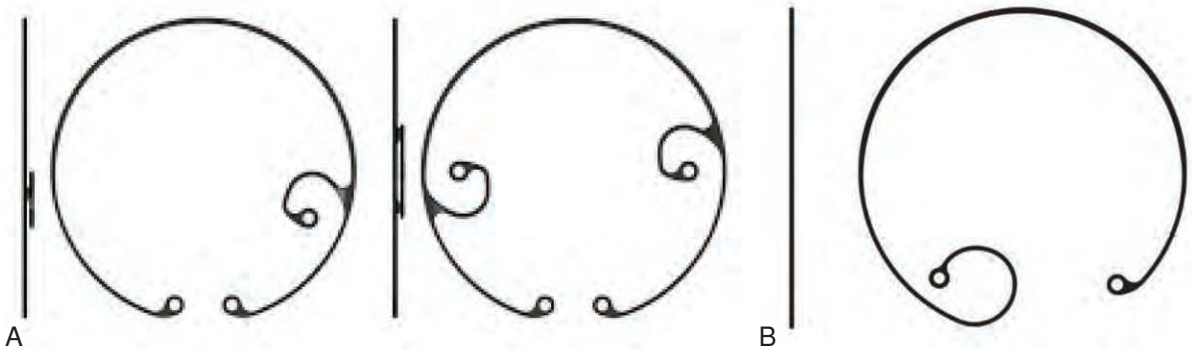

Fig. 34.4 Modified CTRs (M-CTRs). (A) Cionni ring demonstrating a fixation element that will course around the capsulorhexis in a plane slightly anterior to the plane of the ring. The version to the right has a double fixation element. (B) Malyugin modification of Cionni ring with the fixation element at the leading end.

of the ring backbone prevents its placement into an injector. Malyugin designed a variation in which the fixation element is at the leading edge of the ring and thus can be placed either by injector or manually.[20]

- Implantation of the modified Cionni CTR can be cumbersome and challenging in eyes with dense cataract and significant zonular weakness and phacodonesis. In 2002 Ahmed designed the capsular tension segment (known later as the *Ahmed segment*, or CTS) (Fig. 34.5).
- This is a partial 120-degree PMMA ring segment with three radii of curvature 4.5, 5.0, and 5.5 mm. The CTS is designed to slide atraumatically into the capsular bag over the area of zonular weakness with minimal efforts. Because it does not generate an expansile force, the CTS can theoretically be used also in cases of discontinuous capsulorhexis.
- In extensive zonular weakness cases, more than one CTS can be implanted.
- As mentioned earlier, the CTS can be used to stabilize the capsular bag during the surgery, temporarily using an iris hook inserted into the eyelet or permanently fixated to the sclera.
- Unlike the complete all-around equatorial rings, the suture tightening on an Ahmed segment generates a torque on the fixation element that is not opposed by counteracting forces on the opposite side, and the capsule may tilt. In cases of a very large or eccentric ACCC, the segment may even slip out of the capsular bag entirely.
- The Ambati CTS modification has two eyelets that distribute tension to two points, reducing excessive stress at a single point on the anterior capsulotomy (Fig. 34.6).

Timing of ring placement may also play a significant factor. Early ring placement maintains equatorial round contour during phacoemulsification or cortex aspiration. On the other hand, early placement of a CTR or its modifications require manipulation that may damage the zonules and makes cortex removal difficult. Ahmed et al.[21] investigated CTR implantation in the laboratory using the Miyake-Apple video analysis in cadaver eyes. They found that early CTR implantation, after the capsulorhexis and before lens extraction, resulted in significant increased capsular torque and displacement up to 4.00 mm and significant zonular elongation and tension compared with insertion it in an empty capsular bag.

ANTERIOR CAPSULAR SUPPORTING DEVICES

The capsular anchor (AssiAnchor, Hanita Lenses, Kibbutz Hanita, Israel) was developed in 2005 and was the first device designed to provide segmental support to the anterior lens capsule.[22] Its design is based on a concept different from the equatorial supporting devices.

- Whereas the rings or the segment contact the entire or part of the circumference of the capsular equator and, depending on ACCC diameter, may bypass the capsulorhexis rim, the anchor-shaped capsular supporting device creates a clip with a large surface area of contact with the anterior lens capsule, extending from the ACCC margin up to the lens equator.
- The first generation of the capsular anchor is a uniplanar, 2.5-mm wide PMMA device resembling in shape a marine anchor. The central rod is placed in front of the anterior capsule, and the two lateral prongs are positioned behind the anterior capsulorhexis edge, resulting in a firm grasp of the anterior capsular rim. The anchor is actually a capsular clip resembling a paper clip. The tips of the prongs extend to the capsular equator, thus also providing localized equatorial support (Fig. 34.7).
- The fixation element on the body of this device sits *peripheral* to the capsular equator and thereby prevents any meaningful torque of the bag, thereby reducing IOL tilt and the risk of the device popping out of the bag, as can be seen with the CTS.
- Securing the anchor to the scleral wall can be done using all varieties of scleral fixation techniques:
  - 10-0 or 9-10 polypropylene sutures
  - CV-8 extended polytetrafluoroethylene sutures (Gore-Tex, W. L. Gore & Associates, Newark, DE, USA, off-label for ophthalmic use)
  - Canabrava adjustable flange technique using 5-0 or 6-0 polypropylene sutures

The 10-0 or 9-10 polypropylene sutures (Prolene, Ethicon Inc., New Jersey, MANI Tochigi, Japan) are inserted using long straight or curved needles. A 27-G needle can be used as a guide to externalize the suture at the desired location. The Gore-Tex suture is usually manipulated without needles, using intraocular instruments, although is usually

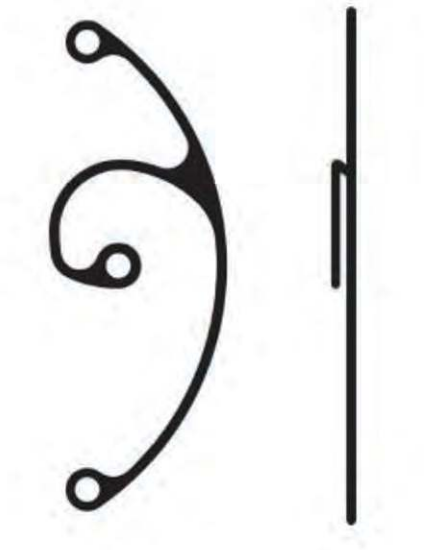

Fig. 34.5 Ahmed CTS showing a 120-degree arc with fixation element in a plane slightly anterior to the plane of the segment.

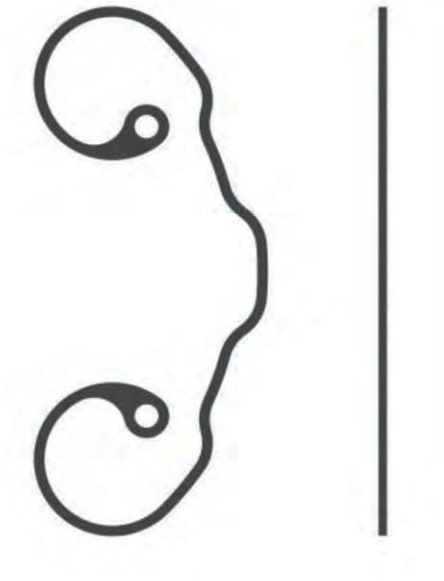

Fig. 34.6 Ambati CTS showing two fixation elements to distribute the tension over a wider area, presumably with lesser torque.

more difficult to bury the external knot compared with the polypropylene sutures. Both polypropylene 5-0 and 6-0 sutures (Ethicon Inc., New Jersey, USA) are suitable for the flange techniques. The suture is threaded through the opening at the base of the anchor, and an internal flange is created by localized heating using high or low temperature cautery (such as Accu-temp Beaver-Visitec International Inc., USA). The free edge of the polypropylene suture is externalized using a 27- or 30-G needle at about 2 mm from the limbus. An external flange is created in a similar manner, and the suture is shortened until the proper position of the anchor and the IOL is achieved (Fig. 34.8).[23,24]

In cases of a large zonular dialysis (6–9 clock hours) a plurality of anchors can be used, evenly distributed in the area of the missing zonules. Similarly, two to three anchors can be used in eyes with severe circumferential zonular weakness to prevent late lens subluxation. We have used the capsular anchor in dozens of eyes, including the entire spectrum of pathologies associated with zonular weakness or dialysis, and find it highly effective regardless the cause of zonular disease. In the younger age group, it is usually advantageous to position the capsular anchor right after ACCC is performed, thus using the anchor to stabilize the unstable capsule during lens removal. In elderly eyes with advanced hard cataracts, insertion of the anchor between the dense lens material and the taught capsule is more challenging.

A modification of anterior capsular clip was presented by Soosan Jacobs from India. Similar to the anchor, the fixation element has two supporting elements on either side and a central extension that, together, forms a "paper clip" that engages the rhexis. The haptic passes transsclerally through a sclerotomy made under a scleral flap and into an intrascleral Scharioth-type minitunnel (Fig. 34.9).

Recently a second-generation Assia anchor was developed. The main modifications include the following:

- Thinner elements of the device
- Spacing the planes of the central rod and the lateral prongs in a three-dimensional manner that significantly facilitates anchor manipulations and positioning
- The Anchor 2.0 is more flexible and can be inserted through a much smaller side-port incision, as small as a 19-G incision (Fig. 34.10)

The advantages of the modified anchor were demonstrated in a clinical study on 10 eyes of 10 patients. The second-generation anchor was used in 8 eyes with subluxated crystalline lenses with PXF and Marfan's syndrome and following blunt trauma. Two anchors were used in eyes with subluxated capsular-fixated PC-IOLs. In all cases, visual acuity improved significantly and the IOLs were central and stable (Video 34.8).[25]

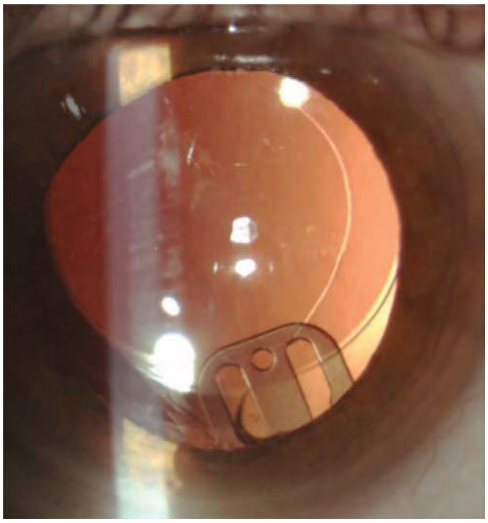

Fig. 34.7 The AssiAnchor in a clinical case showing two outer arms supporting the equator of the bag, the axillae of the anchor supporting the capsulorhexis, and the central body of the anchor (to which fixation is attached) anterior to the capsule.

TIPS AND TRICKS

Dry aspiration of cortex: After phacoemulsification of the nucleus, removal of the cortex in the area of greatest zonular damage can be challenging. Robert H. Osher, MD first introduced and has taught for decades the dry aspiration of cortex: a 27-G cannula on a 3-cc syringe half-filled with basal salt solution as an exquisitely controlled way to remove cortical strands in a bag filled with OVD. This process is easier in the presence of OVDs that are not highly dispersive because dispersive OVDs tend to clog the cannula.

- Manual wet aspiration of cortical fibers using anterior chamber maintainer (ACM) is an alternative technique for gentle and well controlled aspiration while maintaining a pressurized and fully formed anterior chamber.
- Centration of the bag complex: Once the capsule complex has been stabilized with its long-term device, the IOL can be placed into the bag.
  - Before finalizing the suture tension, suture length, or amount of material placed into a Sharioth tunnel, the globe should be pressurized with OVD.
  - The fixation element is pulled centripetally with a microforceps to take up any excess slack.

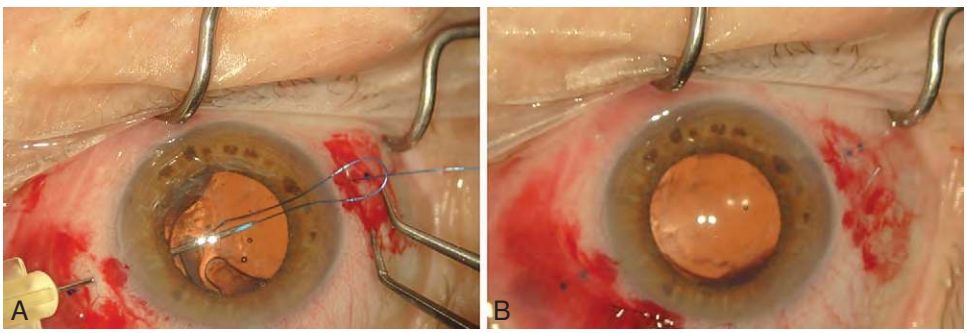

Fig. 34.8 Scleral fixation of subluxated scleral fixated PC-IOL with a closed haptic using the prolene 6-0 adjustable flanges technique. Subluxated capsular-fixated PC-IOL with a closed haptic is refixated using the adjustable flange technique. (A) The prolene 6-0 is threaded through a 30G needle encircling the IOL haptic. (B) At the end f surgery, the IOL is central and stable. The flanges are covered by the conjunctiva and tenon. Note that the flanges on each side are located radially, in the same meridian, to prevent IOL tilt.

- The device centration can then be fine-tuned based on the position of the IOL relative to the Purkinje 1, 3, and 4 reflexes.
- The suture can then be tied, trimmed, and rotated internally (or melted to the desired amount).
- In rare cases, excess slack will be identified after the suture knot has been tucked inside. If this occurs, the external run of the knot can be tacked to the episclera posteriorly to regain perfect centration.[26]

Complication Prevention and Management

Loss of CCC integrity during effectuation of the phaco: In some cases the capsule margin may break during phaco. If this occurs, placement of a CTR is no longer viable. If the break is small and the lens is fairly centrally positioned, the bag can potentially be fixated by either a CTS segment or an anchor. If nucleus is still present, the surgeon must decide whether to continue with phaco, or to convert to an extracapsular extraction.

Vitreous tamponade by dispersive OVD: Vitreous can potentially migrate into the anterior chamber any time there is a discontinuity within the zonules. The best treatment is, of course, prevention. If the anterior chamber pressure is always kept higher than the vitreous pressure, this is much less likely to occur. The anterior chamber should be filled with OVD, or an ACM is inserted before removing either the phaco or irrigation/aspiration handpieces any time during the procedure.

Vitreous prolapse during the case: In some instances, it is unavoidable. Once identified, any anterior chamber vitreous should be either sequestered backward by instillation of OVD, if possible, or removed with vitrectomy techniques, preferably using a pars plana cannula and trocar system for the vitrector and anterior irrigation. Once the offending gel has been removed, additional dispersive OVD can be placed in the anterior chamber and the phacoemulsification can be continued.

Loss of lens material around the equator: Just as vitreous can come anteriorly around the equator, lens material can follow the opposite path.

- A small amount of cortical material can likely be tolerated well and resorb on its own, provided that the postoperative inflammation and IOP remain controlled.
- Nuclear material in the posterior segment should be referred for vitreoretinal consultation for likely removal by three-port pars plana vitrectomy.
- It is important for the vitreoretinal surgeon to be aware of the location of device fixation so as to avoid inadvertently compromising the scleral fixation during trocar placement.
- Heroic efforts to mechanically bring descending pieces of nucleus forward should be avoided, as this is more likely to created vitreoretinal traction, tears, and/or retinal detachment. Furthermore, such maneuvers are rarely successful. Any time vitrectomy is required, a good dilated fundus exam should be performed at sequential postop visits.

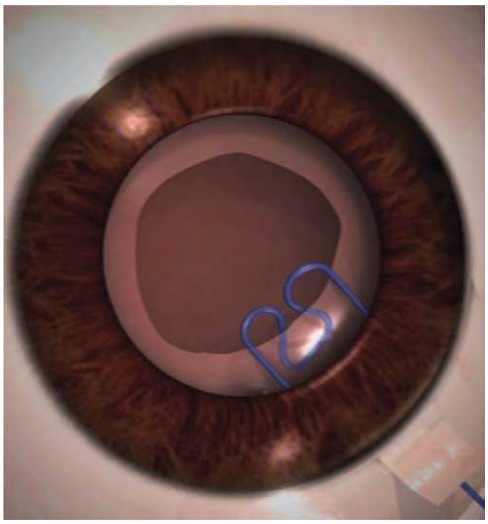

Fig. 34.9 Jacob's capsular "paper clip" along the capsule margin with intrascleral fixation element to be placed into a Scharioth tunnel.

SPECIAL CONSIDERATIONS

Capsule-Stabilizing Devices in Children

Konradsen et al.[27] used the CTR (4 eyes) and the modified Cionni CTR (33 eyes) successfully in 37 eyes of 22 children (mean age 52 months) with lens dislocation using 10-0 polypropylene (Prolene) suture. Two eyes had IOL decentration that required secondary suturing. Vasavada et al.[28] reported results of implantation of the single- and double-eyelet Cionni CTR in 35 eyes of 22 children (mean age 8.2 years) of which 3 eyes required resuturing for IOL decentration. Kim et al.[29] reported results of 19 eyes of 13 consecutive pediatric patients

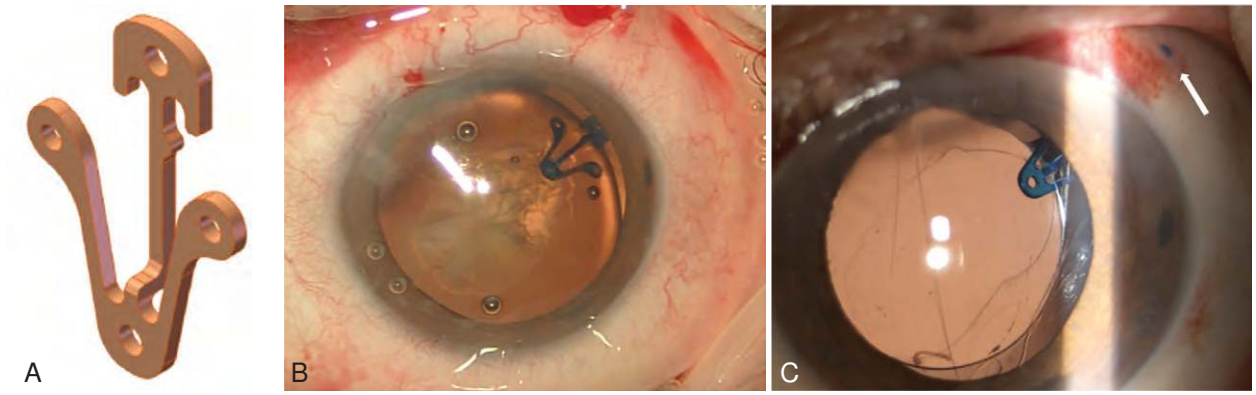

Fig. 34.10 Second generation of the AssiAnchor. (A) Illustration of the new anchor with thinner prongs and three-dimensional configuration to facilitate device positioning. (B) Intraoperative photograph of the anchor inserted after ACCC to stabilize the lens capsule during phacoemulsification. (C) At 1 week postoperative the IOL is central and stable. Note the single flange of the Polypropylene 6-0 suture (Canabrava rivet) covered by the conjunctiva *(white arrow)*.

with Ectopia Lentis (mean age 10.2 years) who underwent implantation of in-the-bag IOL with either a modified Cionni CTR (5 eyes) or a combination of CTS and conventional CTR (12 eyes) using 9-0 polypropylene in 16 eyes and CV-8 Gore-Tex in 3 eyes. In 2 eyes, CTR alone was used. Median follow-up time was 23.4 months. All the IOLs were well centered. PCO developed in 11 eyes (57.9%), 9 eyes (47.4%) required ND: YAG capsulotomy, and 3 eyes (15.8%) required surgical posterior capsulotomy. Suture broke in one eye. Other studies by Thapa et al., Das et al., and others further reported successful management of pediatric lens subluxation often associated with PCO and occasionally recurrent subluxation.

In young patients the lens is very soft and can often be viscoexpressed completely out of the capsular bag. The soft lens material can then be aspirated without needing ultrasound energy (Video 34.9).

Subluxated Intraocular Lens/Capsular Bag Complexes

The incidence of malpositioned PC-IOLs is increasing as patients today elect cataract surgery earlier in life and tend to have longer lifespan. With this increasing lifespan, many of these cases are ones in which the entire IOL/capsular bag complex becomes subluxed because of progressive zonulopathy. Although a plethora of IOL reposition and exchange techniques exist, most of these techniques are beyond the scope of this chapter. One technique is shown in Fig. 34.11 and in Video 34.10 demonstrating a loop suture placed either around a haptic or a CTR if one is in situ. We would be remiss, however, not to point out that some of the same techniques designed for primary capsular bag fixation with some of the same devices described herein can be equally applied to the subluxated IOL/bag complex depending on the degree of fusion of the anterior and posterior capsule leaflets and the amount of Soemmering ring material present.

Fixation of the capsular bag using an equatorial capsular stabilizing device is possible; however, the capsular equator needs to be surgically opened 360 degrees in case of a ring, 120 degrees in case of a segment, or 2.5 mm in case of an AssiAnchor.

- Bag complex reposition with an Ahmed Segment (CTS): Releasing the strong adhesions and fibrosis after several years is not always viable, especially in the presence of weak or missing zonules. Visualization through poorly dilating pupils is suboptimal, and blind manipulations at the lens equator obscured by the iris are risky and not practical. This may often cause more damage to the remaining zonules and jeopardize the integrity of the lens capsule. Nevertheless, there are some cases in which the bag can be fully reopened. One example is in the presence of an in-the-bag iris prosthesis. In these cases the capsulorhexis does not fuse, and a traditional CTR is already in situ. The segments can be slide into the fornix of the bag and tethered to the scleral wall as one would plan primarily (Video 34.11).
- Bag complex reposition with an anchor: Because the anchor requires only a 1.5-clock hour, 2.5-mm, relatively small pocket to be opening in the capsular bag, in most cases this pocket can be created within the pupil under direct visualization.[30] In cases of very severe pseudophakodonesis, only one arm of the anchor can be positioned behind the anterior capsule, acting as a capsular hook. In a series of 6 cases in 2 eyes, only one arm of the anchor was positioned under

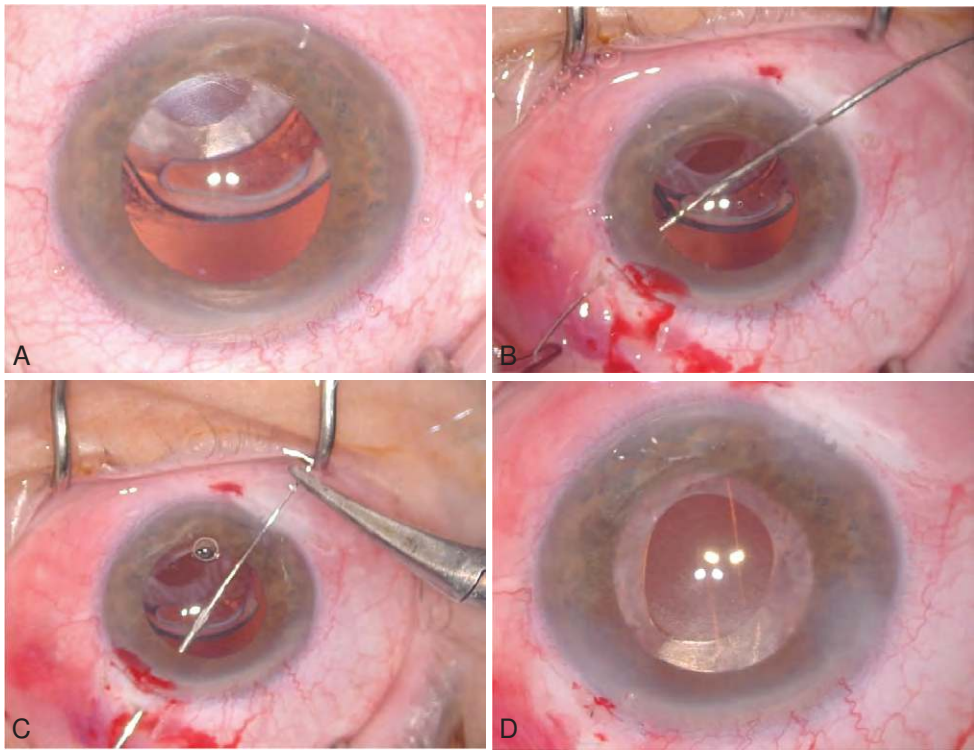

Fig. 34.11 Surgical repositioning of a capsule-fixated PC-IOL with a loop suture. (A) In-the-bag PC-IOL inferior subluxation (surgeon's view). (B) The long straight needle of a 9-0 polypropylene suture is inserted 1 mm posterior to the limbus and passed underneath the IOL haptic. A 27-G needle is used as a guide to externalize the suture through a paracentesis on the opposite side. (C) The suture is reinserted through the same side-port incision passing in front of the haptic and externalized by the 27-G needle. (D) Final position of the PC-IOL after repeating the same procedure on the opposite side. The IOL is well centered and, stable and lies parallel to the iris plane.

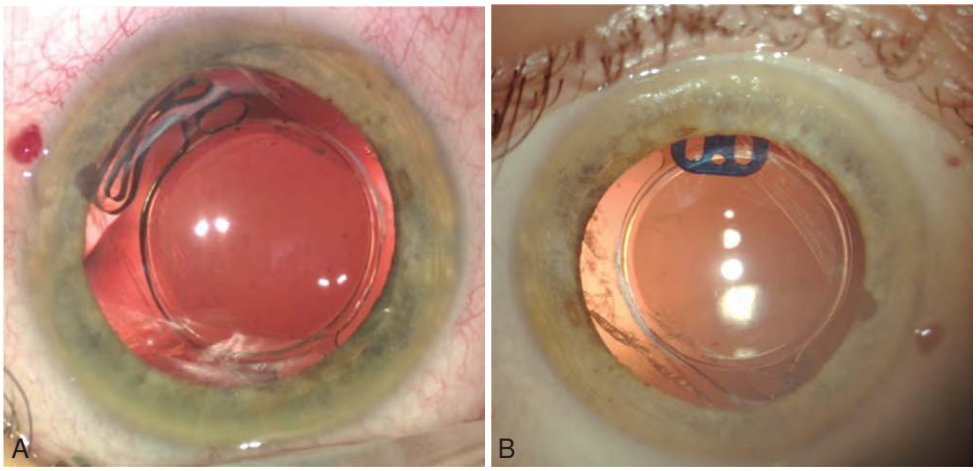

Fig. 34.12 Reposition of subluxated capsular fixated PC-IOL using a capsule-stabilizing device. (A) Surgeon's view, dehiscence of the inferior zonules. The lower haptic lies partially anterior to the iris. The superior zonules are also loose but not evident in this image. (B) Slit-lamp view, the inferior haptic was directly sutured to the sclera, whereas a capsular anchor was used to secure the inferior capsule to the sclera. The superior capsule was secured with an anchor, seen here supporting the superior capsular bag. The large contact area (approximately 1.5 clock hours) provides effective capsular grip, and the planar configuration prevents tilt.

the anterior capsule. Central and stable fixation was achieved in all 6 eyes.[31] Li et al.[32] reported clinical experience with capsular fixation using the capsular anchor in which some eyes required only one anchor placement, although others with larger degrees of zonulopathy received two anchors. The desired fixation was achieved in all cases with both arms of each anchor placed within the capsular bag. Opening of the small pocket in the capsule can be achieved by either viscodissection or gently blunt dissection with a Sinskey or similar small hook (Video 34.12).

- Fixation of the subluxated IOL can be done using a combination of capsular stabilizing device and direct suturing of the lens haptic (Fig. 34.12 and Video 34.13).
- The Anchor 2 was found to be especially effective also for scleral fixation of subluxated PC-IOL (Video 34.14).

Placement of an In-the-Bag Iris Prosthesis with a Fixated Capsular Bag

Coexisting zonular and iris damage is common. If an iris prosthesis is to be placed within a capsular bag harboring either an MCTR, CTS, or anchor, it is prudent to tuck the edge of the iris device under the fixation element before the iris device fully unfolds. It is difficult to tuck it underneath once the iris device is planar (Video 34.15).

SUMMARY

In most cases of zonulopathy, the capsular bag can be spared.

Capsulorhexis can be facilitated by the following:

- "Crossed swords" piercing of the capsule
- Trypan blue to reduce capsule elasticity
- Microforceps
- Hooks for countertraction

Temporary capsule support devices (hooks, segments, and anchors) can aid with completion of the phacoemulsification.

Dispersive OVD can also be used to "stent" the equatorial capsular bag.

Permanent capsule fixation devices (segments, anchors, clips, CTRs, and MCTRs) can provide long-term stability of the capsular complex.

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Video 34.1 Theanterior capsule is pinched between the tips of two 30-G needles to pierce the elastic, lax anterior capsule.

Video 34.2 The anterior capsular rim is stabilized with a 25-G MaxGrip (Alcon, Fort Worth, TX, USA) forceps so that a capsulorhexis forceps has adequate countertraction to peel a complete capsulorhexis.

Video 34.3 An iris retractor is placed to the initiated capsulorhexis margin so that a capsulorhexis forceps has adequate countertraction to peel a complete capsulorhexis.

Video 34.4 Capsule hooks used to stabilize the capsular bag during phaco in a case requiring a modified "Cionni" CTR. Coincidentally, a small pterygium was present requiring removal and a free conjunctival graft to cover the fixation suture.

Video 34.5 A CTS segment is supported by a flexible iris retractor to stabilize the bag during phaco.

Video 34.6 The flexible iris retractor is removed from the CTS segment, and an extended polytetrafluoroethylene suture (Gore-Tex) is threaded through the eyelet *in situ*.

Video 34.7 A dangling lens is elevated after pars plana vitrectomy, and the capsular bag is stabilized first temporarily with iris hooks and then permanently with capsule segments.

Video 34.8 Anchor-generation 2 in traumatic cataract (2 cases) demonstrating the facile use of this device through small incisions.

Video 34.9 A young, subluxated lens is viscodissected out of the bag and evacuated. A modified Cionni CTR is placed to stabilize the complex.

Video 34.10 Scleral fixation of a PC-IOL using prolene 9-0 loop sutures.

Video 34.11 Two CTS segments are used to reposition a subluxed IOL-CTR-custom iris prosthesis-capsular bag complex.

Video 34.12 An Assia anchor is placed by dissecting open 2.5-mm pockets in a fused capsular bag in two opposing areas.

Video 34.13 Fixation of a subluxated PC-IOL using Anchor 1 on one side and direct fixation on the other haptic.

Video 34.14 Anchor 2 is used for fixation of a subluxated PC-IOL/capsular bag complex.

Video 34.15 An iris prosthesis is tucked under a modified Cionni CTR fixation element into the capsular bag during the unfolding process.

35

Cataract Surgery in the Small Pupil

Seng-Ei Ti and Soon-Phaik Chee

CONTENTS

KEY POINTS

- The small pupil makes access to the cataract difficult.
- It is important to establish the cause of the small pupil and to have a perioperative strategy for patient management to ensure a good outcome.
- The principles involved in managing the small pupil include release of adhesions that bind the pupil, widening the pupil, and retaining the pupil expansion.
- Pupil enlargement strategies include the following:
- Pharmacologic and ophthalmic viscoelastic device (OVD) dilation
- Removal of pupillary membranes and release of synechiae
- Appropriate use of pupil-expander devices
- Postoperative management goal is to avoid excessive and prolonged intraocular inflammation, recurrence of synechiae, or occurrence of cystoid macula edema (CME).

INTRODUCTION

Cataract surgery in the small pupil poses a technical challenge because it obscures visualization during all stages of phacoemulsification and therefore surgical access to the cataract is limited. Not infrequently, this small surgical field is further exacerbated by the presence of a shallow anterior chamber (AC). The target pupil diameter should exceed 5 mm to facilitate the formation of an adequately sized continuous curvilinear capsulorrhexis (CCC) for safe cataract surgery. An adequately sized CCC is important to prevent anterior capsular phimosis, especially in uveitic eyes.

To overcome the small pupil challenge, the strategy for good surgical outcome includes evaluating the systemic and local factors leading to poor pupil dilation. Careful surgical planning should include the need for pupil expansion, having the necessary instruments and devices at hand, and the technique of phacoemulsification.

This chapter focuses on optimal preoperative evaluation, options for minimally invasive pupil management, phacoemulsification techniques in small pupils, and preemptive management of possible intraoperative and postoperative complications.

CAUSES

A variety of systemic and ocular conditions may predispose individuals to a small pupil. Advancing age and additional associated comorbidities such as diabetes mellitus are commonly associated with poorer dilating pupils. Other important conditions are discussed below.

UVEITIS

Uveitic cataracts (e.g. Fuchs' heterochromic uveitis syndrome, sarcoidosis, Behcet's disease, Vogt-Koyanagi- Harada disease, juvenile idiopathic arthritis-associated uveitis etc.) account for about 1.2% of all cataract surgeries[1] and may be associated with a poorly dilated pupil. In recurrent fibrinous or chronic uveitis, posterior synechiae (PS) may be present at the pupil or broadly across the posterior surface of the iris. Often, a partial membrane is found at the edge of the pupil. In more severe cases, the membrane may be more extensive, causing seclusio or occlusio pupillae. When dealing with these pupils, one would anticipate microbleeding and increased risk for postoperative fibrin formation. In addition, these eyes are at increased risk for CME and exacerbation of uveitis.

PSEUDOEXFOLIATION SYNDROME (PXE)

PXE is a systemic condition in which there is deposition of white, flaky, elastic fibrillin and basement membrane material within the eye and in other organs, such as the heart, lung, liver, and kidneys. In ocular PXE, fine, white fibrillar deposits on the lens capsule, ciliary body, zonules, corneal endothelium, iris and pupillary margin, and anterior lens capsule occur and are often associated with a poorly dilating pupil, reduced endothelial cell count, glaucoma with or without zonular dialysis, and phacodonesis.

Stabilization of the glaucoma before cataract surgery is important. Consideration should be given whether lens removal alone or a

combined lens-glaucoma procedure is preferred. Before cataract surgery, avoiding topical prostaglandin analogs may reduce the risk for postoperative CME.

Even when the zonules can be imaged and appear intact, they are weak and may give way during surgery, and it is important to be prepared for this.

TRAUMA

Blunt ocular trauma or focal penetrating corneal trauma may be the underlying cause of an irregular pupil; the pupil may dilate poorly at the area of posterior synechiae and may also be associated with focal or partial zonular weakness.

USE OF MEDICATIONS: IFIS

Intraoperative floppy iris syndrome (IFIS)[2,3] was first described in 2005[2] in relation to the systemic administration of an alpha-1a antagonist, tamsulosin. In recent years, IFIS has also been documented with other systemic alpha-1-antagonists, such as doxazosin and terazosin. The condition arises because of atrophy of the iris dilator muscle and reduced iris tissue tone, causing irregular iris behavior during surgery. In addition to a poorly dilating pupil, severe IFIS cases exhibit increased risk of iris billowing, risk of prolapse at incisions, and progressive intraoperative miosis. This may develop as soon as 1 day after consuming a single dose of tamsulosin. Discontinuing the medication before surgery does not reverse the risk for IFIS.

Other causes of small pupil include chronic use of miotics (e.g. pilocarpine) for glaucoma and ingestion of narcotics (e.g. codeine, oxycodone) and of phenothiazines for psychiatric conditions.

NARROW-ANGLE GLAUCOMA

Eyes with short axial lengths (<22.0 mm), shallow ACs, and narrow angles are often associated with small pupils. Pupil size is progressively smaller from normal to glaucoma suspect to glaucoma patients.[4,5] The reduced pupil size in glaucoma is caused by the disease itself and the influence of IOP-lowering eye drops such as brimonidine.

PREOPERATIVE MANAGEMENT

Performing an optical coherence tomography of the macula (OCT macula) and optic disc aids in assessing coexisting macula and optic nerve pathology. In addition, where indicated, an ultrasound biomicroscopy (UBM) is helpful in assessing zonular integrity.

For patients with uveitis, preoperative assessment and planning is highly important.[6] Consider comanaging with a uveitis specialist who can help evaluate the cause of uveitis, assist in management of the inflammation and getting the eye quiescent.

- Establish that the cataract is the cause of poor vision.
- Determine whether preoperative steroid prophylaxis (eye should be already quiescent for 3 months or more) is required. Alternatively, intraoperative intravitreal triamcinolone acetonide or steroid implant (e.g., OZURDEX® 0.7 mg dexamethasone) may be considered.
- The presence of peripheral anterior synechiae (PAS), band keratopathy, glaucoma, and so forth should be noted. Determine whether these should be addressed at the time of cataract surgery or as a separate procedure before cataract extraction.
- Patients on antiplatelet medications and anticoagulants should be advised to discontinue these medications before surgery, balancing the risk analysis with systemic health, because iris manipulation may result in uncontrolled bleeding.
- Decide on the instruments and devices needed to manage the pupil.
- Phacoemulsification is preferred to small-incision manual cataract surgery because the smaller phacoincision techniques incur a less inflammatory response.
- It may be better to defer implantation of an intraocular lens (IOL) if the uveitis is not well controlled.
- The IOL should preferably be a hydrophobic acrylic IOL, implanted in the bag and not in the sulcus. Diffractive multifocal IOLs can be considered, provided that visual potential is normal and if the uveitis is unlikely to affect this visual potential in the foreseeable future.

PHARMACOLOGIC PUPIL EXPANSION

The usual combination of drugs for perioperative pupil dilation is a cycloplegic mydriatic (tropicamide 1%) and adrenergic receptor agonist (phenylephrine 2.5%).[7] However, these may have little effect on the small pupils because of chronic drug therapy or synechiae. Use of topical nonsteroidal antiinflammatory drugs (NSAIDs) just before cataract surgery is useful to minimize intraoperative miosis.[8]

SURGICAL PROCEDURE

This surgery may ideally be done under regional or intracameral anesthesia (preservative–free lignocaine 2%) as manipulation of the iris can be painful in spite of topical anesthesia. For patients who are anxious and are likely to squeeze during the procedure, a regional block is preferred to avoid iris prolapse. When planning which approach to undertake, consideration should be given to whether the iris is stretchable or atrophic and scarred.

OVERVIEW OF INTRAOPERATIVE SMALL PUPIL ENLARGEMENT TECHNIQUES

1. Ophthalmic viscoelastic device (OVD) mydriasis using visco-adaptive OVD with sweeping movements of the cannula can help enlarge the pupil, separate away adherent tissue, and maintain dilation.
2. Surgical manipulation of iris
   - Pupillary membrane removal from the pupil edge (Videos 35.1 and 35.2)
   - Bimanual iris stretching with 2 Kuglen hooks
   - Multiple partial sphincterotomies
3. Mechanical pupil dilatation[9–15]
   - Iris retractor hooks
   - Mechanical dilator devices, e.g. Beehler pupil dilator[9,10]
   - Pupil expansion devices (e.g., Malyugin ring,[9–15] Visitec I-Ring[9,14])

SPECIFIC SMALL PUPIL SCENARIOS

1. Minimal Focal or No Posterior Synechiae
   a. Pharmacologic and OVD Dilation
      - Add 0.5 mL of 1:1000 adrenaline to 500 mL balanced salt solution (BSS®) irrigation fluid.
      - Use a small aliquot of this mixture through the paracentesis site for pharmacologic pupil dilation.
      - The adrenaline in the BSS® subsequently helps maintain of pupil dilation during surgery. Adrenaline is also helpful especially when bleeding occurs during pupil manipulation.
      - The use of visco-adaptive OVD helps to deepen a shallow AC and widen the pupil. Visco-adaptive OVD creates space and

is retained to keep the pupil dilated during phaco when the flow rates are high.

b. Unbinding and Opening the Pupil Without Devices
   - A blunt OVD cannula may be all that is required to sweep the pupil to release focal PS.
   - A Kuglen hook is an efficient instrument to release posterior synechiae all around and can be used to gently push and pull at the pupil edge to release the iris adhesions to the lens capsule.
   - Injecting some OVD under the iris helps to avoid engaging and tearing the anterior capsule.
   - Pupil size may be further enhanced by controlled bimanual stretching of pupil using 2 Kuglen hooks, set 180° apart and repeated at 90° to the original meridian (Fig. 35.1A–D). After stretching, additional OVD is injected to maintain the pupil size, and this may be adequate for milder cases. There may be small sphincter ruptures at the sites of stretch, with focal areas of bleeding. Stretching should immediately be stopped if tearing of the iris tissue occurs.
   - Avoid stretching if the iris is stiff and not stretchable because the sphincter can tear, leading to a permanently dilated pupil. In such a situation, multiple 0.5 to 1 mm long sphincterotomies using an intraocular scissors produces a less traumatic, controlled opening of the pupil.

c. Pupil Dilating and Retaining Devices
   - The choice of pupil dilation technique depends on the following:
     - The surgeon's familiarity with the device(s)
     - Whether the iris is stretchable
     - The size of the eye and the AC depth in relation to the device's dimensions
   - Inserting a pupil retainer device should be as atraumatic to the iris as possible.
   - Understanding the features of each device is important.

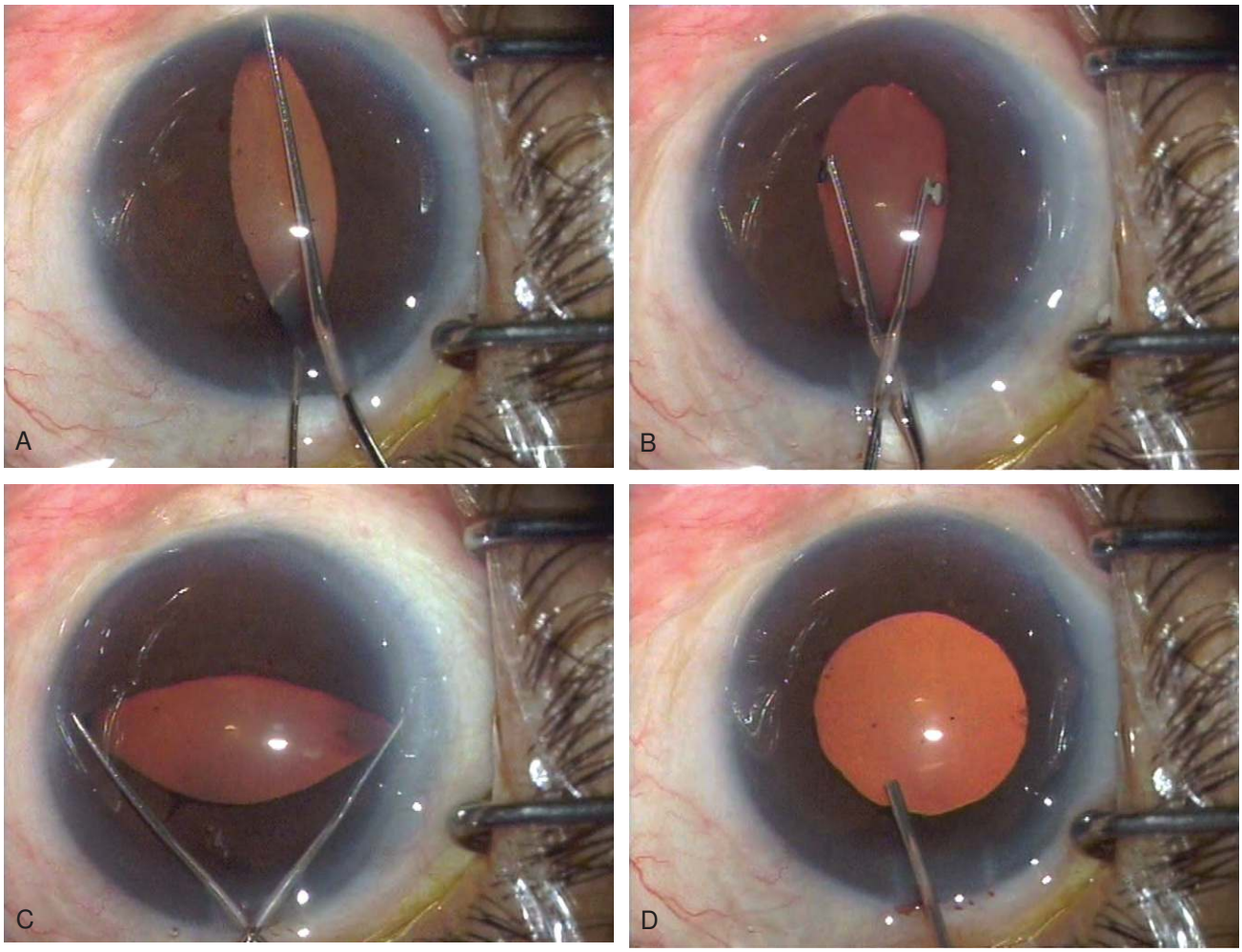

Fig. 35.1 Composite operative microscope views demonstrating pupil expansion by stretching in an eye with a small pupil and normal iris. (A) Two angled Kuglen hooks are used to engage the edge of the pupil and simultaneously applying diametrically opposing forces kept in maximal dilating position for several seconds. (B) This is followed by positioning the hooks in the opposite meridian, taking care not to breach the anterior capsule. Injecting some ophthalmic viscoelastic device (OVD) to lift the iris off the anterior capsule facilitates this process. (C) The stretching procedure is then repeated. (D) Dispersive OVD is injected to refill the anterior chamber and the size of the expanded pupil is examined for adequacy to proceed with capsulorrhexis and phacoemulsification.

- I-Ring pupil expander[8, 13] (Beaver -Visitec Inc, USA) of polyurethane material is softer to manipulate, can be more protective of the pupil margin compared with Malyugin ring, though has a thicker profile and is therefore more space-occupying.

- In addition to pupil expansion, ring pupil retainers also partially inhibit iris billowing.[15]

(i) Beehler Pupil Dilator

- The Beehler pupil dilator (Moria, USA) is an instrument that dilates the pupil but is not a pupil retainer.
- It can be reused and is thus cost saving.
- It consists of a fixed subincisional hook together with either two or three hooks on prongs that can be deployed to engage the pupil margin to expand the pupil evenly.
- It can be used after pupil membrane removal (Fig. 35.2A–C). It is easier to use in a deep AC and with a pupil that is not excessively small and the iris should be stretchable.

(ii) Iris Hooks (Video 35.3)

- Self-retaining iris hooks are a good alternative to Kuglen hook pupil stretching.
- They come in a set of four or five devices in each package.
- Advantage: each hook is flexible and slim and can easily and safely be placed in a small eye or shallow AC.
- The technique is recommended for the infrequent user and also for challenging cases.
- The position of each hook can be appropriately chosen and variable tension applied to each hook to adjust the pupil size.
- A useful technique is to place one of the iris hooks in or adjacent to the subincisional location (i.e., under the main clear corneal incision) (Fig. 35.3A–D) to help keep the iris away from the phaco probe or prolapsing into the incision.[16]
- If the iris is slightly stiff, a combination of iris hooks with multiple sphincterotomies (Fig. 35.3C,D) can help provide a wider opening of the pupil.

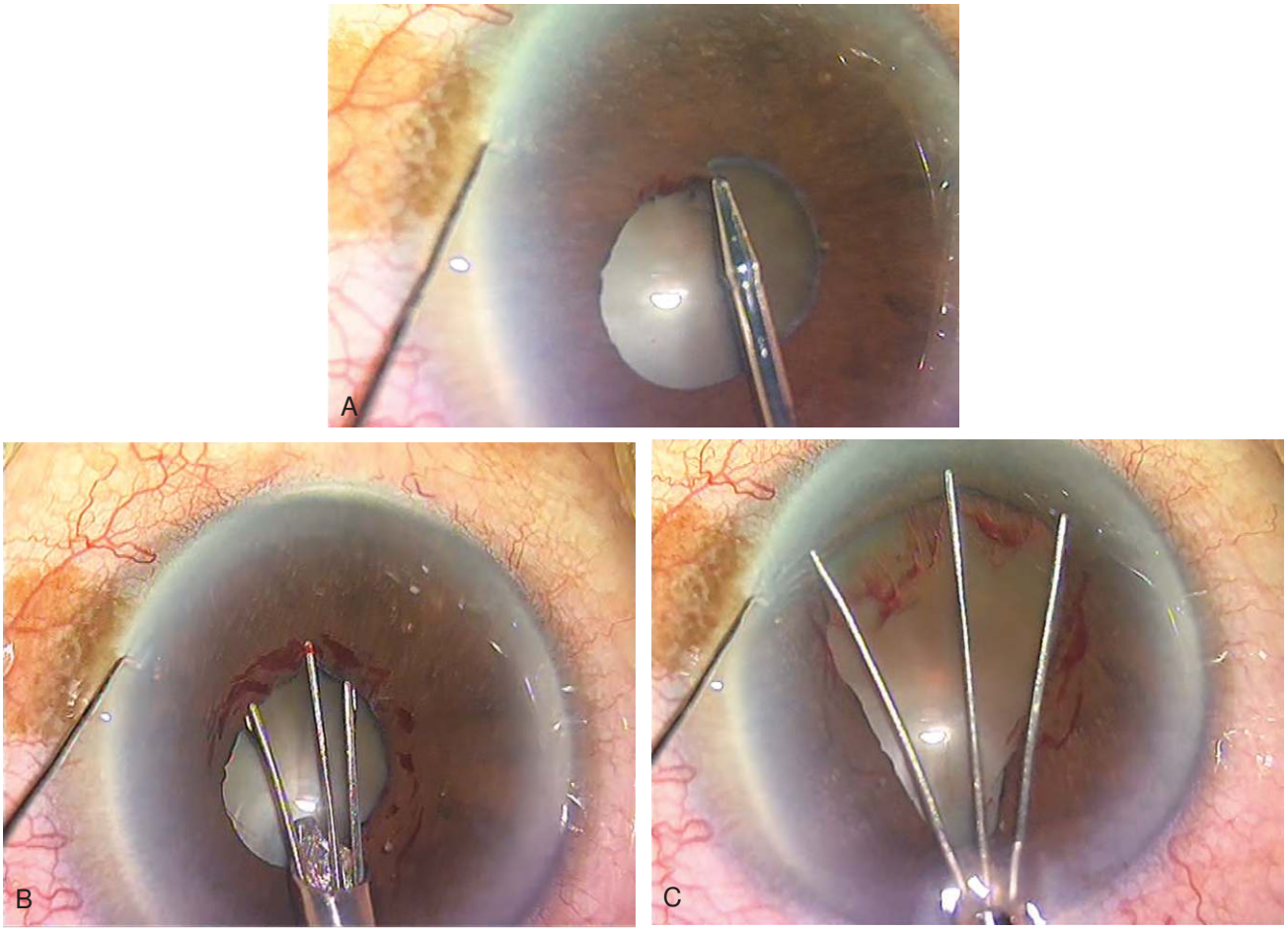

Fig. 35.2 Composite operative microscope views demonstrating pupil expansion by Beehler pupil dilator in a uveitic eye with a stretchable iris and partial pupillary membrane. (A) The edge of the narrow ribbon of pupillary membrane is carefully picked off the anterior capsule and grasped with capsulorrhexis microforceps and stripped off the iris gently. (B) The three engaging arms of pupil dilator and the larger proximal hook are carefully latched on to the pupil margin which has been elevated from the anterior capsule by injecting some ophthalmic viscoelastic device. (C) The device is then deployed by pushing on the plunger resulting in stretching of the pupil. This is kept in maximum dilated position for a couple of seconds before release, achieving a well-dilated round pupil.

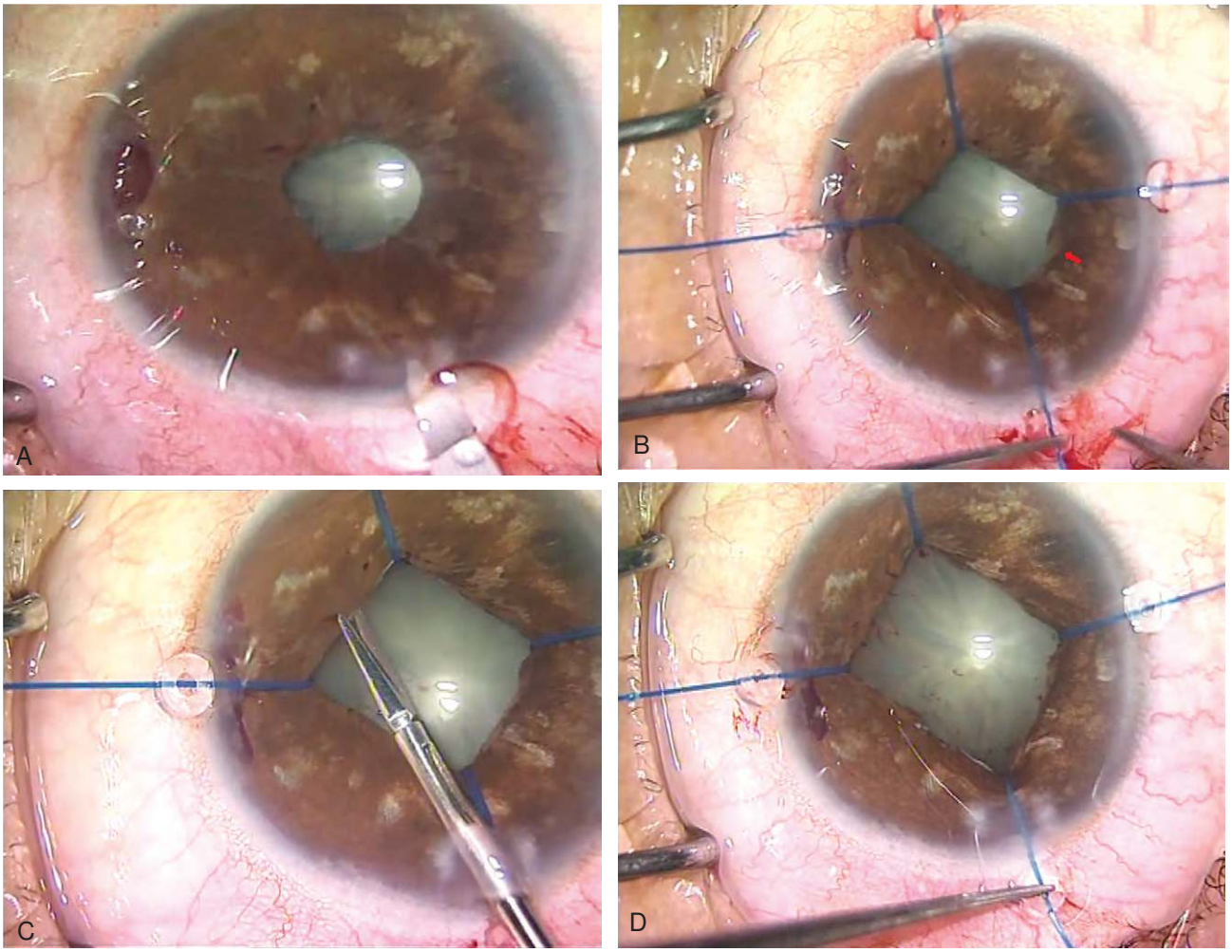

Fig. 35.3 Composite operative microscope views demonstrating pupil expansion by iris hooks and multiple sphincterotomies in this eye with chronic uveitis and a scarred, nonstretchable iris. (A) Four snug paracenteses are created in an ophthalmic viscoelastic device-filled eye in a diamond configuration, ensuring that the blade is pointing in the direction of the pupil. This photograph shows the subincisional paracentesis being created in a position that is more limbal and posteriorly directed than the clear corneal incision. (B) The iris hooks are inserted one by one and retracted gradually to open pupil. A tear in the iris is noted as indicated by the red arrow and further iris hook retraction is immediately ceased. (C) Pupil expansion is completed using intraocular scissors to create multiple small snips of the sphincter pupillae between the iris hooks. (D) At this stage, the iris hooks are gradually further retracted, providing adequate widening of the pupil for safe surgery.

- When making the limbal openings through which to place the iris hooks, making the external entry as posterior as practical with the blade angled posteriorly while creating the opening will make the internal entry site closer to the iris surface and will reduce anterior tenting or billowing of the now taut iris plane.

(iii) Pupil Expansion Rings

- Currently, the most widely used pupil expander device is the Malyugin ring[9–15] (MST, Redmond, WA, USA; Figs. 35.4 and 35.5), and provides eight points of fixation.
- Malyugin Ring (Video 35.1) comes in two versions.
  - Classic version: thicker 4/0 polypropylene, is stiffer; introduced via inserter through a 2.2 mm or larger, clear corneal incision (CCI).
  - Version 2.0 (2016): thinner (5/0 polypropylene), more flexible; the inserter fits a 2.0 mm CCI.
  - It is available in two sizes: 6.25 mm or 7.0 mm.
  - In eyes with moderately sized pupils and normal iris, Malyugin rings are easy to insert and remove, and save the surgeon creating additional paracenteses.

Method of Inserting Malyugin Ring (Fig. 35.4A–D; Video 35.1)

- A small amount of OVD is injected under the iris to create some space to accommodate the ring.
- The device is withdrawn into the inserter.
- The leading scroll is inserted to engage the distal pupil margin.

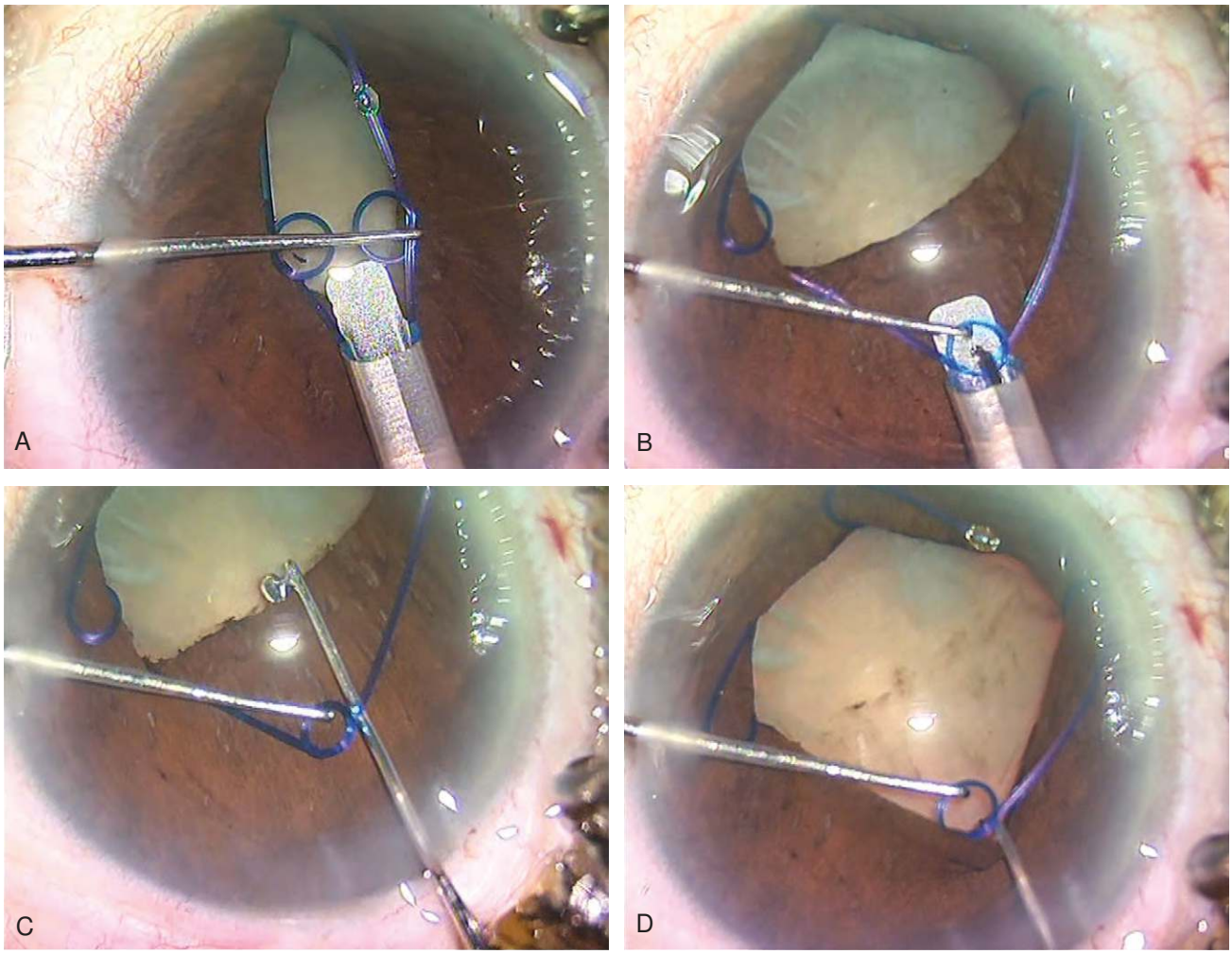

Fig. 35.4 Composite operative microscope views demonstrating pupil expansion by insertion of a pupil expansion device, the Malyugin ring. (A) After filling the eye with ophthalmic viscoelastic device and injecting some under the pupil to just lift the iris off the anterior capsule, the Malyugin ring loaded on the inserted is introduced into the anterior chamber and the leading scroll carefully deployed to latch onto the distal iris margin. Next, the two side scrolls are manipulated to engage the iris margins. (B) The Sinskey hook or ring manipulator is introduced from side port to engage the last scroll as the inserter is removed from the eye. (C) Simultaneously, an angled Kuglen hook inserted through the main incision is used to retract the subincisional iris. (D) The final scroll then engages the iris margin readily using bimanual manipulation. This avoids the inadvertent ramming of the proximal scroll into the anterior chamber angle when trying to engage the distal scroll in a small pupil.

- The two side scrolls are manipulated to engage the pupil margins lateral to the incision, with the help of a Sinskey hook or ring manipulator from the side port.
- For the proximal scroll at sub incisional area, a Kuglen hook inserted through the main incision is used to retract the iris to enable the last scroll to easily engage the iris as (or after) the ring is released from the inserter.

Removal of Malyugin Ring (Fig. 35.5A–C; Video 35.1)

- There are several techniques of removal.
- The authors' preference (Fig. 35.5):
  - Use a Sinskey hook through the side port to disengage the proximal, subincisional scroll.
  - Latch this proximal, subincisional scroll into the retractor rod of the inserter and pull back on the actuator to slowly withdraw the ring into the inserter.
  - As the lateral scrolls come together, the Sinskey (or similar) hook is used to compress them against the inserter so that they slip easily into the inserter.
  - Before the last scroll is fully disengaged from the iris, sometimes it may be necessary to use the Sinskey hook to widen the scroll which sometimes does not readily release in a thick pigmented iris and may cause bleeding at the root of the iris (less common with version 2 of the rings).

2. Partial Posterior Synechiae With Peripheral Anterior Synechiae (PAS)

- When PAS (Fig. 35.6A–C) are present (i.e., peripheral iris is adherent to the cornea endothelium), the PAS should be released first, before tackling the posterior synechiae.
- Direct the blunt dispersive OVD cannula into the angle space (Fig. 35.6A).
- Gently nudge the iris from the endothelium toward the angle *without* injecting more OVD (Fig. 35.6B). This avoids using an excessive amount of OVD, which is ineffective in releasing PAS, which are often chronic. Repeat this manoeuvre until the PAS are completely released and the iris is no longer tented forward.

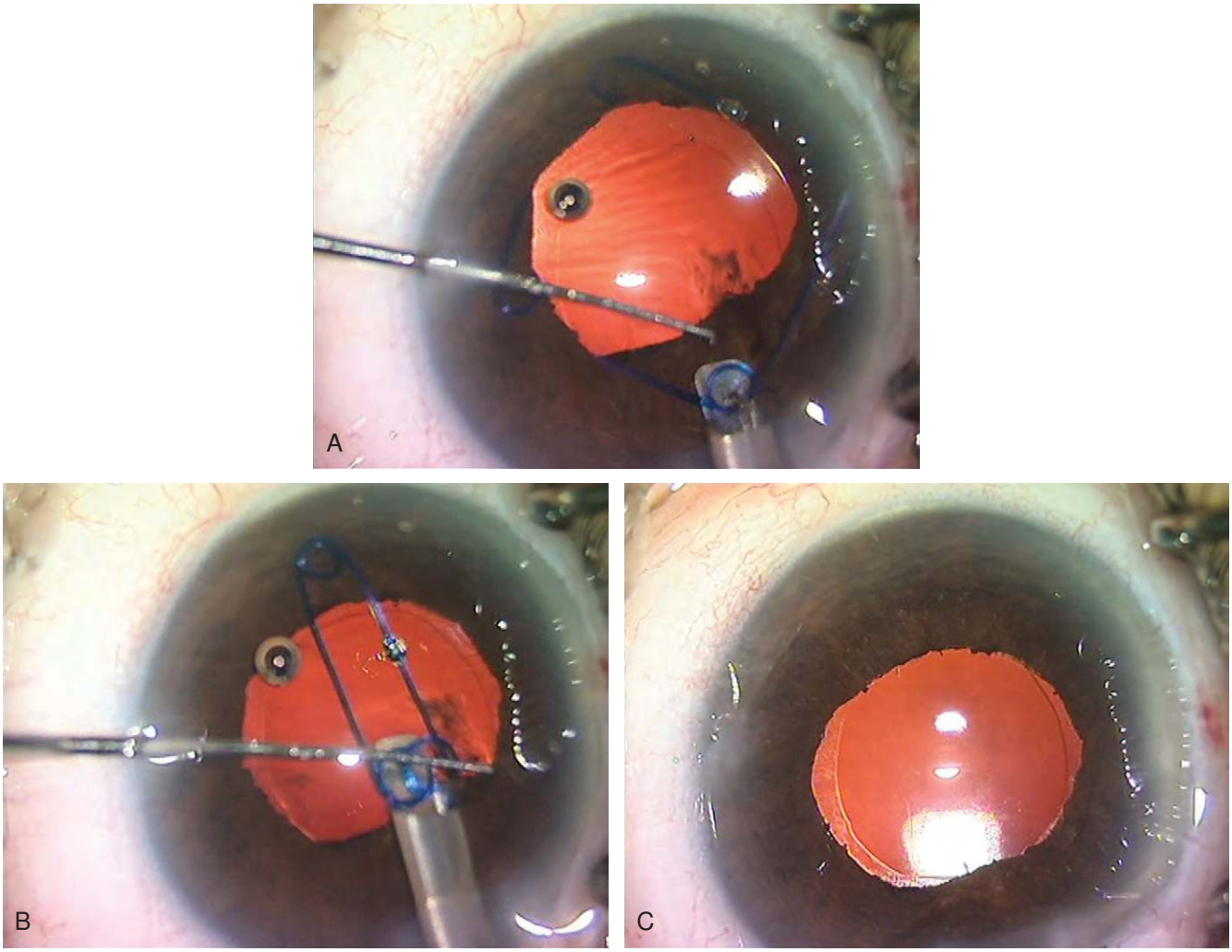

Fig. 35.5 Composite operative microscope views demonstrating removal of the pupil expansion device (Malyugin Ring) under ophthalmic viscoelastic device. (A) The subincisional scroll is carefully released using a Sinskey hook and positioned on the inserter, allowing the inserter retraction hook to engage the scroll while the inserter plunger is in the fully actuated position. (B) The ring is then withdrawn into the inserter. As the two side scrolls come together, a Sinskey hook inserted from the side port is used to compress them against the platform of the inserter to ensure they enter the inserter channel smoothly as the rest of the device is retracted and removed from the eye. (C) This photograph shows the final appearance of the pupil at the end of surgery.

- For synechiae which do not open with gentle viscodissection, the midpreipheral iris stroma can be grasped with a microforceps and gently pulled centripetally, often releasing PAS.
- If the iris cannot be gently separated from the cornea, do not persist and avoid sweeping the cannula circumferentially as this may cause a descemet's membrane detachment.
- Dispersive OVD is injected to provide a tamponade when bleeding occurs. If there is excessive bleeding, injecting cohesive OVD can help clear the bleeding to allow the procedure to continue.
- It is helpful to identify any areas in which a pupillary membrane is present or absent and where the membrane edge is well defined and clearly visible at the pupil margin. The narrow strip of pupillary membrane should be peeled off by using a 23 g capsulorrhexis microforceps (Fig. 35.2A)-(e.g., Kawai capsulorrhexis forceps, ASICO, LLC) to restore the pupil to a regular round shape. This will also reduce contractile forces of the membrane, which may be limiting dilation. Pupil expanding and retaining devices can then be applied as needed. Failure to release these membranes may cause decentration of a ring device because of uneven pupil dilation.
- In cases of trauma accompanied by iridodialysis, the iris will first need to be dissected free to open the pupil and then kept retracted by an iris hook during phaco. After IOL implantation, the iris hook is removed, and then iridodialysis can then be repaired.

When there are PAS that extend centrally, it may be possible to use nontoothed micro graspers to gently separate the iris from the cornea (Fig. 35.6C). Sometimes using microscissors to incise the broad bands of iris adherent to scarred Descemet's membrane followed by repair of iris defect using pupilloplasty sutures is preferable because this is less traumatic to the cornea and iris. In addition, these pupilloplasty sutures also may sometimes prevent reoccurrence of the PAS. However, such manoeuvres are best left to *after* IOL implantation to prevent a floppy iris getting caught in the phaco probe.

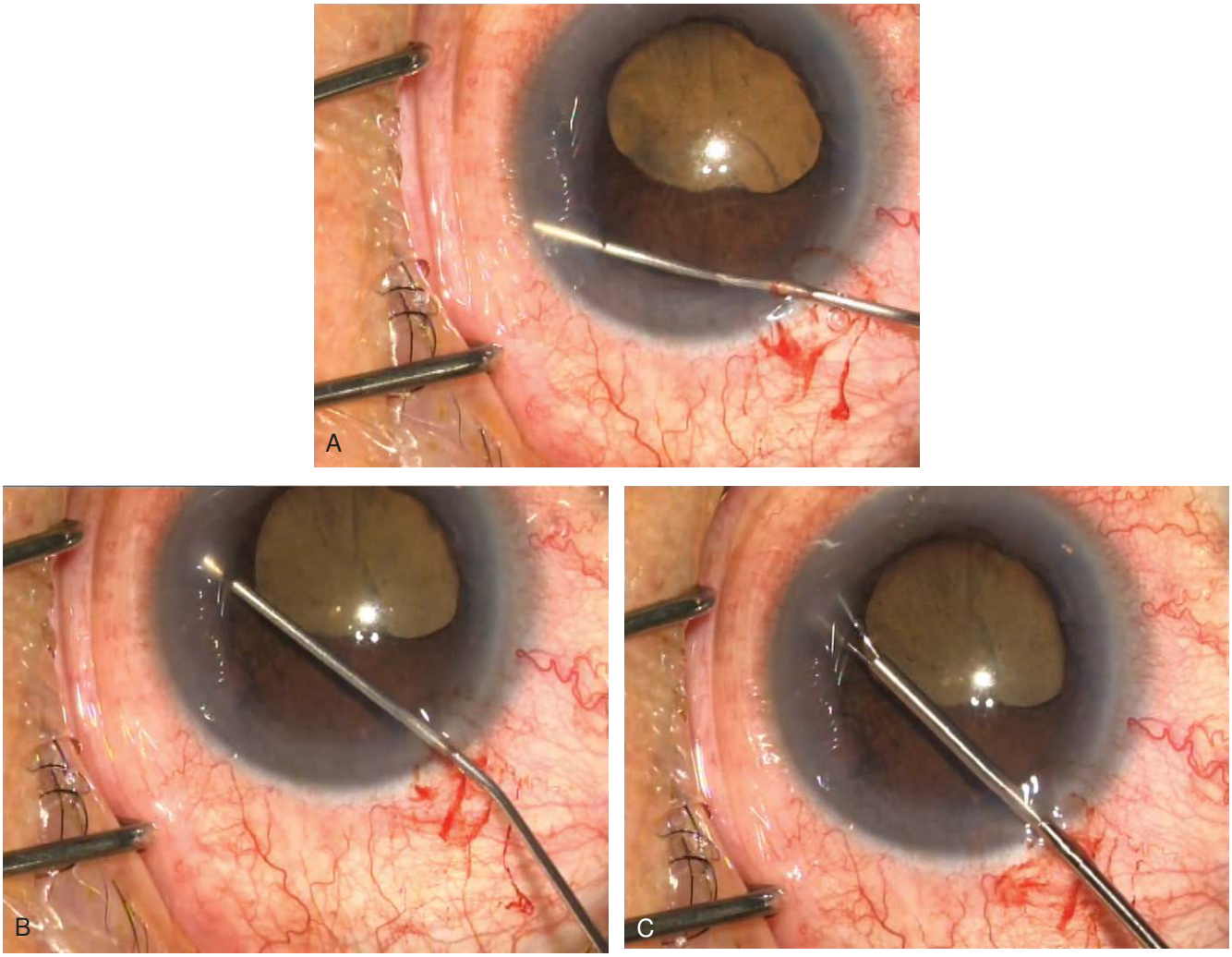

Fig. 35.6 Composite operative microscope views demonstrating the release of peripheral anterior synechiae (PAS), which may be present in a uveitic eye with an adherent pupil. (A) Some dispersive ophthalmic viscoelastic device (OVD) is injected into the anterior chamber without pressurizing the eye before directing the cannula into the angles, injecting a little more to check if the PAS will release. (B) For PAS that are adherent, the OVD cannula is use to gently nudge the iris from the area of adhesion toward the angle *without* injecting more OVD. Once the PAS have been released, some OVD is injected to widen the angle. The manoeuvre is repeated until the entire area of PAS is completely released. (C) In areas where PAS are particularly adherent and resistant to release, bridges of iris that adherent iris may be released by using micrograsper forceps to help distract iris from cornea, taking care to direct the force peripherally to avoid stripping of Descemet's membrane.

3. Seclusio or Occlusio Pupillae

- As above, identify the strip of pupillary membrane that is binding the pupil edge and causing adhesion to the anterior capsule. It is important to choose the site to initiate the peeling carefully. Use a 23 gauge (G) capsulorrhexis microforceps to pick up the membrane edge and tear using a capsulorrhexis maneuver (Fig. 35.7A,B; Video 35.1). Repeated regrasping may be necessary.
- One should stop pulling if the membrane does not come easily to avoid bleeding at the root of the iris. Some mild oozing at the pupil margin is not uncommon, though. It is appropriate here to switch to a bimanual membrane peeling, introducing a micrograsper (23 G Ahmed Micro-graspers, MST, Redmond, WA) to grasp the iris stroma and provide counter traction on the pupil margin, so that the iris insertion is not bearing the forces of the peeling. Care should be taken to only grasp the membrane and not the iris itself.
- Examine the membrane under high magnification to identify a membrane edge that can be cleanly lifted. Care must be taken not to breach the anterior capsule during these maneuvers.
- If the pupil remains small and immobile, the entire iris may be plastered to the anterior lens capsule. Use a Kuglen hook or blunt cannula to release mild adhesions
- In the presence of stubborn adhesions, caused by fibrosis of the posterior leaf of the iris to the anterior capsule by tough fibrotic tissue, the pupil should be opened only to the extent where it is adequate for the cataract to be safely removed without excessive trauma to the iris. Intraocular scissors (Fig. 35.7C) coupled with micrograspers are required to excise this fibrous membrane before the capsule can be accessed.

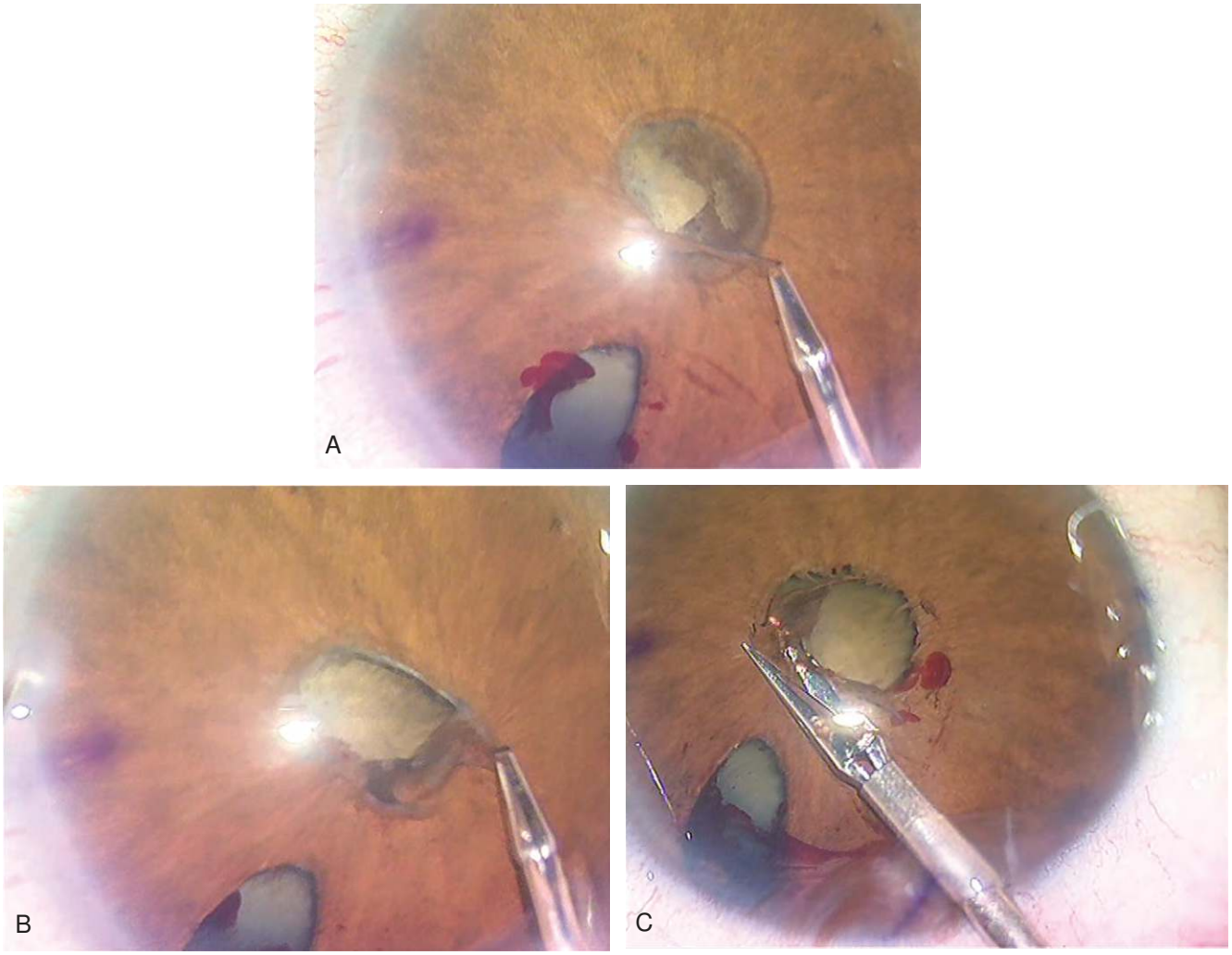

Fig. 35.7 Composite operative microscope views demonstrating the removal of a complete pupillary membrane (occlusio pupillae). (A) Using a 23 G capsulorrhexis microforceps, the pupillary membrane edge is picked up and torn from the iris using a capsulorrhexis maneuver. (B) When resistance is encountered, the membrane is picked up from a new edge and the membrane is stripped from the opposite direction. (C) In areas where is adherence fibrotic membrane to the iris is particularly resistant to removal, intraocular microscissors are used to excise part of the pupillary membrane as atraumatically as possible. Complete removal of the membrane is essential for even expansion of the pupil.

SURGICAL PEARLS ON PUPIL MANAGEMENT

- Visco-adaptive OVD can be used to widen a nonadherent pupil and keep it dilated during phacoemulsification.
- Avoid overfilling the AC with OVD to prevent iris prolapse.
- Use a blunt OVD cannula or Kuglen hook to release mild posterior synechaie.
- When using iris hooks, aim the paracentesis toward the pupil edge to prevent it lifting the iris when retracted.
- An iris hook positioned in the subincisional location retracts the iris and keeps it out of the way of the phaco probe.
- Iris hooks are preferred when the iris is not stretchable, the AC is shallow, and the eye is small.
- Release PAS before lysing posterior synechiae.
- For pupils bound by membrane, strip the fibrotic band picking the clean edge of the fibrous tissue using a capsulorrhexis microforceps.

PHACOEMULSIFICATION SURGERY

- Pay attention to wound construction.
- The main clear corneal incision entry should be radial, symmetric, and adequately long (tunnel length symmetry across the width of the incision). An incision length to width ratio is preferably between 3/5 to 3/4.
- A short incision increases the risk for iris prolapse.
- Iris retractor and sideport paracenteses need to be snug.
- Phacoemulsification technique (Video 35.2): A vertical phaco-chop technique is a safe technique to use as the instruments and all maneuvers are kept in the center of the pupil, minimizing risk for inadvertent iris damage.
- Cortex removal (Video 35.2): In a small pupil and to avoid catching iris, the key is to sweep the irrigation/aspiration tip circumferentially under the anterior capsule to gather the cortex, stripping it from the equator and aspirating the cortex only when the IA tip is in the center of the bag and pupil.

- After IOL insertion: Complete removal of OVD is difficult with small capsulorrhexis, but it is necessary to avoid postoperative capsular block syndrome. If the capsulorrhexis is too small, it should be enlarged at this stage, using the optic as a guide both for size and centration of the capsulotomy enlargement. This may be done by initiating a tearing edge using intraocular scissors or the Vannas scissors under OVD. The tear is then propagated around or just in the area needing expansion, ensuring complete CCC overlap of the optic.
- Prevention of fibrin formation: Consider injection of preservative free dexamethasone intracamerally (0.4 mg/0.1 mL) in predisposed eyes with noninfectious uveitis.

POTENTIAL COMPLICATIONS

1. Intraoperative Complications
   - A small pupil, if left unexpanded, inadvertently results in an inadequately sized capsulotomy (less than 4.5 mm); this, in turn, increases the difficulty of surgical maneuvering in the eye and predisposes to capsular phimosis.
   - Intraoperative Complications that may develop include:
     - Iris trauma: iris prolapse, shredding, and bleeding from aspiration and phaco of the iris.
     - Hydrorupture, or posterior capsular rupture during hydrodissection, is predisposed by a small CCC.
     - Anterior capsule tears from a runaway capsulorrhexis or from the chopper or phaco needle hitting the capsular rim during phaco.
     - IOL malposition: resulting from a CCC that is too small and difficult to visualize. The iris should be retracted at the end of the case to confirm that the haptics are both within the capsular bag.
     - Posterior capsule rupture and vitreous loss resulting from extension of an anterior capsule rip.
     - Difficult visualization of the posterior capsule because of the limited red reflex from a reduced pupil aperture.
     - Zonular dialysis: aspiration of the anterior capsule during cortex removal because of the small capsulorrhexis and limited visualization of the cortex as a result of reduced pupil aperture. It is important to ensure that the capsule is not engaged before centripetal movement of the I/A handpiece.
     - Postoperative capsular block syndrome may result from inadequate removal of OVD from behind the IOL.
       - Mechanical pupil expansion itself can cause iris bleeding, permanent loss of iris sphincter function, or a distorted pupil postoperatively. Tearing of the iris into the area beyond the sphincter pupillae should be repaired using a modified Siepser sliding knot[17] or its modification, the single pass four throw pupilloplasty.
       - Risk for iris damage is related to the state of the iris tissue and the forces applied during surgery (e.g., if there is there is excessive traction on the iris retractor); this can lead to iris sphincter tears and bleeding. These risks should be explained to patients with light- colored irises before surgery and this may affect their appearance postoperatively.
       - In PXE, there is a risk for progressive zonular dehiscence, therefore insertion of a capsular tension ring (CTR) is advised. The CTR does not prevent zonulysis but may make fixation of the dislocated IOL easier.
2. Postoperative Complications

   Postoperatively, from early to late, the following complications may be seen:
   - Fibrin in the AC, especially if there is background of uveitis ± exacerbation of uveitis.
   - Formation of fresh posterior synechiae to the CCC rim and a resultant nondilating or nonconstriction of the pupil.
   - Cystoid macula edema.

HOW TO AVOID INTRAOPERATIVE SURGICAL COMPLICATIONS

- If the pupil remains too small to perform phacoemulsification safely (<4.0 mm diameter), it requires mechanical pupil dilatation for creation of an adequately sized capsulotomy
- Patients at greatest risk for iris damage and atonic pupils after mechanical dilation are those with iris tissue that cannot be stretched. Therefore use mechanical dilators with caution.
- In eyes with floppy iris, practice careful attention to wound construction (avoid short tunnels), timely use of iris retractors or pupil ring expanders, so as to reduce risk for iris billowing and facilitate safe phaco surgery.
- Enlarge the capsulorrhexis after IOL insertion to reduce the risk for capsular phimosis.

   - Linear lines of iris atrophy and irregular atonic pupils after forceful extension of the pupil.[18] The use of symmetric pupil ring expander devices may help distribute the stress forces of the iris more uniformly, to reduce postoperative iris damage.
   - Capsular phimosis, zonular dehiscence, and IOL dislocation.

POSTOPERATIVE MANAGEMENT

- There is a greater risk for developing postoperative inflammation and CME with iris manipulation.
- For uncomplicated cataract surgery with small pupil associated with PXE, narrow-angle glaucoma or IFIS, topical steroids (e.g., Prednisolone acetate 1%), and NSAIDs together with prophylactic antibiotics should be commenced immediately after surgery and continued for 4 to 6 weeks postoperatively depending on clinical response.
- In patients with history of uveitis, there is a risk for severe inflammatory response and the severity or duration of inflammation may lead to reformation of posterior synechiae, CME, glaucoma, pupillary membrane reformation, or even hypotony.[19]
  - Consider oral steroids for prophylaxis in the preoperative or early postoperative period to supplement the maintenance immunosuppression.
  - The addition of antiglaucoma medication may be necessary in cases of anticipated ocular hypertension.
  - Conversely, eyes with chronic inflammation with a compromised ciliary body function may become hypotonus with the increased inflammation. Salvage measures such as intravenous methyl prednisolone or intravitreal injection of a steroid drug delivery system may be necessary to save the eye.

SUMMARY

- Pay attention to meticulous wound construction. A corneal tunnel that is too short increases the risk for iris prolapse.
- Use of intracameral diluted adrenaline in BSS and inject viscoadaptive OVD to dilate the pupil and deepen the chamber before introducing pupil dilating devices.
- Fashion snug paracenteses pointing toward the pupil margin for iris hooks that should include one placed in the subincisional location.
- Iris hooks are preferred to pupillary ring expanders in small eyes, shallow AC and when the iris is not stretchable and scarred, and especially, when the surgeon is an infrequent user of pupil expander devices.

- Enlarge a small CCC after IOL insertion to prevent capsular phimosis.
- Postoperative management with adequate and rapid control of the anterior chamber inflammation to prevent reformation of posterior synechiae and other complications.

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Video 35.1 Video demonstrates removal of membranes causing occlusio pupillae followed by pupil expansion with Malyugin ring.

Video 35.2 Video demonstrates pupillary membrane stripping followed by horizontal and vertical phacochop technique, keeping phacotip within center of the pupil.

Video 35.3 Video demonstrates the insertion and removal of iris hooks, using a hook near the incision to prevent prolapse.

Phacoemulsification in the Glaucoma Patient

Nathan M. Radcliffe and Nicholas E. Tan

CONTENTS

KEY POINTS

- Standalone cataract extraction lowers IOP in the long-term.
- Early postoperative IOP spikes after phacoemulsification can be prevented and managed with intracameral, topical, and oral hypotensives.
- Multiple options exist for combining cataract surgery with minimally invasive, angle-targeting procedures that provide good IOP control.
- Excellent gonioscopic visualization begets successful, efficient angle procedures.
- Phaco-tube and phaco-trab can treat severe glaucoma patients, but postoperative management can be complex, and both refractive and IOP outcomes may be less optimal than sequential surgeries.
- Diligent follow-up examination is instrumental in identifying and controlling the most common complications that follow combined procedures.

INTRODUCTION

Cataract and glaucoma are two of the most common vision-threatening pathologies that ophthalmologists encounter. Glaucomatous optic nerve damage can often copresent with an existing cataract, given that numerous risk factors overlap between the two conditions. Consequently, it is becoming more common for cataract surgeons to encounter eyes with prior glaucoma surgery, or to even combine glaucoma surgery with cataract surgery. This chapter outlines pertinent considerations and beneficial interventions for cataract-glaucoma patients.

THE EFFECT OF CATARACT EXTRACTION ON IOP

There is some evidence to suggest that standalone cataract extraction can be protective against glaucoma. Historical rhetoric states that cataract removal reduces intraocular pressure (IOP) by 2 to 4 mm Hg on average.[1] More recent research suggests that the reduction may be even more ample, with greater effects on glaucomatous eyes with higher preoperative IOPs.[2]

- Previous studies on angle-closure patients indicate that cataract extraction can accomplish greater IOP control with fewer long-term medications than laser peripheral iridotomy.[3,4]
- The multicenter prospective EAGLE study revealed that *clear lens removal* showed greater quality of life, better IOP reduction, and enhanced cost-effectiveness versus peripheral iridotomy and medical therapy for angle-closure glaucoma cases.[5]

However, cataract extraction can also cause IOP to spike up to 25 mm Hg or more in the hours or days after the procedure.[2] A few options exist for limiting pressure elevations:

- Intracameral carbachol injected after IOL placement:
  - One study found the 8- and 24-hour IOP spikes to be 29% less and 13% less, respectively, compared with placebo.[6]
  - Transient decreases in macular thickness and macular volume may occur during the first 24 hours postoperatively.
  - Pupillary miosis on the first postoperative day is the main downside of therapy.
- Topical glaucoma agents:
  - A systematic review identified the most evidence in favor of using single-dose timolol or prostaglandin analogs to control early postop IOP.[7]
  - Brinzolamide drops were more effective than beta-blockers or prostaglandin analogs at preventing 24 hours postphaco spikes in a recent randomized controlled trial.[8]
- Oral acetazolamide.[9]

Intraoperatively, attentiveness to complete viscoelastic removal prevents obstruction of the anterior meshwork. Extra care should be taken if concomitant angle surgery is performed.

Other risk factors for postextraction spikes in glaucomatous eyes include:

- Longer axial length
- More preoperative glaucoma drops
- Previous laser treatment[10]

Such risk factors may coincide with more severe glaucomas. These are the same cases that warrant most concern regarding nerve damage. The authors thus recommend spike prophylaxis when these risk factors are present or when glaucomatous visual field loss is already significant. Widespread prophylactic use for all glaucoma patients undergoing phacoemulsification is more contentious.

ANGLE SURGERY CONCOMITANT WITH CATARACT EXTRACTION

Ophthalmologists now have a wealth of options for combined phacoemulsification with glaucoma surgery:

- The Trabectome (Microsurgical Technology) introduced a simplified approach to goniotomy in 2005.
- The Kahook Dual Blade (New World Medical) came soon after.
- The first trabecular bypass stent (iStent, Glaukos) received FDA approval in 2012, followed by the second and third generation iStents in 2018 and 2020.
- Allergan's XEN 45 implant received FDA approval in 2016 for refractory glaucoma.
- The Hydrus trabecular scaffold (Ivantis) was approved by the FDA in 2018.
- The OMNI Surgical System (Sight Sciences) obtained FDA indication for primary open-angle glaucoma in 2021.
- Numerous other tools exist, including ab interno canaloplasty from Ellex, gonioscopy-assisted transluminal trabeculotomy, and various goniotomy approaches.[11, 12]

These innovations reduce medication use and intraocular pressure as an adjunct to cataract surgery, with safety profiles generally similar to cataract surgery.[13] Although each technique has its own nuances, we will begin with a general overview of how to optimize angle surgery at the time of cataract extraction.

Angle Surgery Preoperative Evaluation

Preoperatively, one should perform gonioscopy on all glaucoma patients, noting angle and relative trabecular meshwork pigmentation (or its absence). Trabecular microbypass stent placement generally requires an angle that will be open after cataract extraction, whereas procedures such as goniotomy can be performed in angle closure. Noting peripheral anterior synechiae is crucial because angle scarring will influence options for angle procedures.

Angle surgeries are indicated when the benefits of lowering the intraocular pressure or reducing the number of medications used offer a greater value than the risk of postoperative complications. FDA-approved trabecular stents are indicated for mild to moderate glaucoma in combination with cataract surgery, whereas procedures such as goniotomy and canaloplasty can be performed on cases ranging from ocular hypertension to severe glaucoma and even angle closure, with or without concomitant cataract extraction.[11] Although significant efficacy has been observed with trabecular microbypass stent combined with phacoemulsification, as reported by Samuelson et al., the outcomes of angle procedures can be modest for some patients.[14] Though this does not mean that such procedures cannot be performed on severe glaucoma, it is necessary to have subsequent procedures in mind should meshwork-targeting interventions prove to be insufficient.

Anticoagulation and Blood Reflux

Although angle surgery may be safely performed on anticoagulated patients, the risk for intraoperative and even postoperative bleeding is believed to be lower if the anticoagulation can be safely halted. With ab interno trabeculotomy techniques such as the Trabectome, reflux bleeding is a common occurrence.[15] In a few patients, hyphema may occur months or even years after ab interno goniotomy with Trabectome and possibly with other techniques.[15]

Interestingly, healthy eyes do not bleed because pressure in the anterior chamber (AC) is greater than the episcleral venous pressure.[16] Coagulation plays a comparatively minor role. Limiting anterior chamber blood reflux during angle surgery can thus be best achieved by maintaining a pressurized anterior chamber. Use of a small amount of dispersive viscoelastic against the trabecular meshwork may also repel blood from the canal. Reflux is problematic primarily because it limits gonioscopic visualization and less because of delayed clearing or recurrence.

Combined Angle Surgery or Phacoemulsification: Which Goes First?

Advantages of angle surgery first:

- Vitreous would not be encountered.
- No corneal edema from phacoemulsification to impede the view of the angle.
- Avoids difficulties with device manipulation near the angle in the case of complicated intraocular lens (IOL) placement.

Advantages of cataract surgery first:

- Creates a deep anterior chamber and a wider, open angle.
- No blood reflux from angle surgery to impede cataract extraction.
- Allows for an approach in which the cataract surgery is performed with the head taped, then the tape is released for the angle surgery's head rotation.

Ultimately, the decision of operative order can be made on a case-by-case basis. Surgeon preference, experience level, and anticipated difficulty of either the cataract or angle procedure each warrant consideration.

Gonioscopic Visualization

Trabecular meshwork surgery requires impeccable visualization of the angle structures. Although many gonioscopic lenses can give an excellent view, the Swan-Jacob style lens is popular and suitable for beginning angle surgeons. The following are the basic steps to achieving excellent gonioscopic visualization:

- Practice gonioscopic visualization under the operating microscope during other nonangle surgeries first.
- Tilt your microscope roughly 45 degrees *toward* you so that the microscope eyepiece moves toward you while the microscope optic moves away.
- Tilt your patient's head 30° to 45° *away* from you, such that the eye to be visualized is further away from you.
- Use the gross microscope movement to focus on the distal limbus. This will ensure that the plane of the trabecular meshwork will be in focus once the gonioscopic lens is placed.
- Viscoelastic of any type may be placed on the cornea and/or on the undersurface of the gonioscopic lens, which will then be rested gently on top of the eye.
- Ensure appropriate magnification to see the trabecular meshwork (TM).
- Fine focus to bring the TM into view.

Four main issues will interrupt excellent gonioscopic view:

- Too much or too little tilting
  - The meshwork simply will not be visualized, and your scope should be tilted more or less until the tissue comes into view.
- Blood on the surface of the eye mixing with viscoelastic
  - If this occurs, the surface of the eye must be irrigated and the blood removed.
  - Some advocate placing corneal incisions that are more anterior than those in routine cataract extractions to avoid limbal capillaries.
  - Rarely, gentle cautery may be used to arrest bleeding at the limbus. This will not be necessary if the surgery can be performed swiftly.

- Corneal striae
  - Striae are most commonly caused by an underfilled anterior chamber.
  - The solution is to repressurize and reform the anterior chamber with additional viscoelastic. A higher viscosity cohesive viscoelastic may be helpful in maintaining chamber depth and eliminating striae.
  - A less common cause of corneal striae is excessive pressure on the cornea from the gonioscopic lens itself.
- Bubbles or debris in the anterior chamber from the viscosurgical device
  - Aspiration and refilling of the chamber with fresh, clear viscoelastic should improve visualization.

SUBCONJUNCTIVAL STENT METHOD

This section describes the ab externo placement of a subconjunctival gel stent (Allergan's XEN 45) as an example of targeting the subconjunctival outflow pathway. The XEN stent is a 6-mm-long gel implant with an internal lumen of 45 μm. Grover et al.'s prospective trial of the standalone procedure showed a reduction in glaucoma medications from 3.5 to 1.7 and a reduction in intraocular pressure from 25 mm Hg to 15 mm Hg by 12 months postoperatively.[17] Grover's standalone bleb revision rate of 35% was similar to the 37.5% in another trial for combined XEN-phacoemulsification at 2 years of follow-up.[18] Schlenker et al found noninferiority in safety and success rate for standalone ab interno XEN implantation compared with standalone trabeculectomy.[19]

An ab externo technique with peritomy for placing the gel stent is as follows:

1. Complete the phacoemulsification and leave the cohesive viscoelastic in the eye.
2. Use a 7-0 corneal traction suture to rotate the eye inferiorly.
3. Perform a 3-mm conjunctival peritomy with cautery superotemporally or superonasally, depending on preference (Fig. 36.1).
4. Bluntly dissect Tenon's fascia from the sclera in the area of the peritomy until a pocket is created between the bordering recti.
5. Apply sponges soaked in 0.4 mg/mL of MMC to the sclera underneath the peritomy for 2 minutes, followed by copious irrigation (Fig. 36.2).
6. Enter the sclera with the XEN gel inserter bevel-up 3 mm posterior to the limbus (Fig. 36.3).
7. As the inserter passes the limbus, angle your hand downward and rotate the eye upward so that the inserter is in parallel with the iris. Enter the anterior chamber.
8. Advance the slider gradually to release the stent and simultaneously retract the inserter.
9. After the XEN is in place, use forceps to ensure that 1 mm of the stent is present in the anterior chamber. Confirm with gonioscopic visualization (Fig. 36.4).
10. Close the conjunctiva at the limbus with two 10-0 nylon wing sutures (Fig. 36.5).

A simplified ab externo approach can be performed without conjunctival peritomy (also known as transconjunctival). This option is

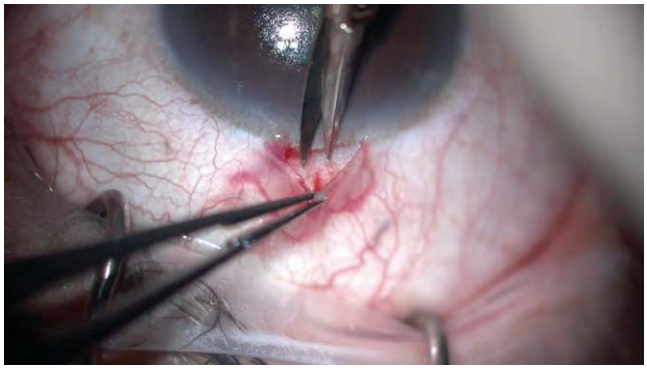

Fig. 36.1 XEN conjunctival flap. A 3-mm conjunctival peritomy is performed in preparation for XEN placement.

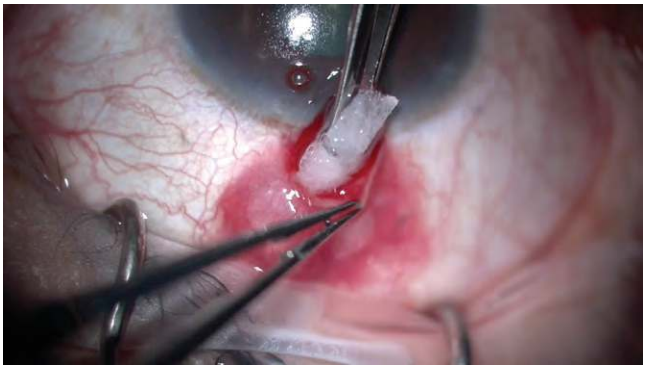

Fig. 36.2 XEN MMC. MMC sponges can be placed within the conjunctival peritomy to aid in antifibrotic chemotherapy. Subconjunctival mitomycin may be injected as an alternative or a supplement to MMC sponges.

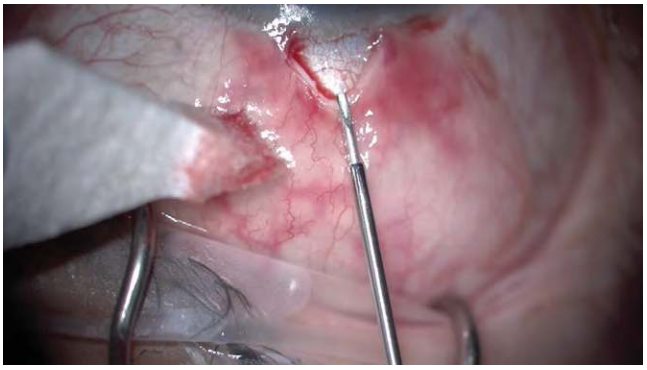

Fig. 36.3 XEN ab externo placement. With conjunctival peritomy in place, the gel inserter enters the sclera 3 mm posterior to the limbus so that the XEN may deploy from an ab externo approach.

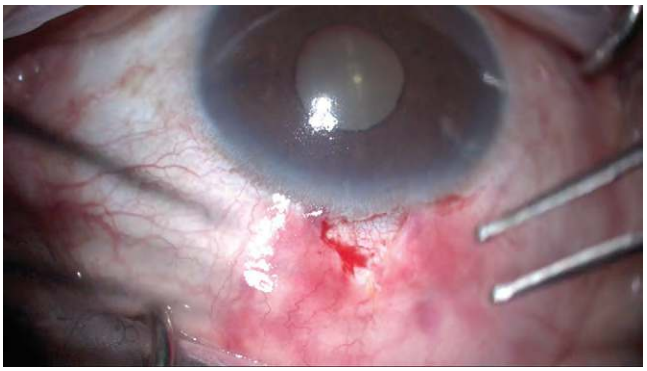

Fig. 36.4 XEN positioning. In this image, the straw-colored XEN is seen both in the anterior chamber for approximately 1 mm and exiting the sclera 3 mm posterior to the limbus where it rests above the conjunctiva before conjunctival closure.

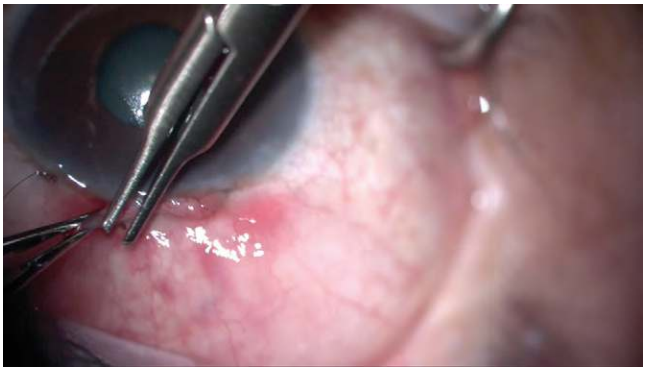

Fig. 36.5 XEN ab externo closure. After the XEN has been placed, two 10-0 nylon wing sutures are used to reapproximate the conjunctiva.

BOX 36.1 XEN 45 Pearls

- Preoperatively, try to limit medications that cause conjunctival inflammation.
- Treat any ocular surface disease such as blepharitis.
- Consider preoperative steroids in inflamed eyes.
- During surgery, titrate MMC dosage to the patient's disease severity and likelihood of failure.
- Postoperatively, keep the IOP low with topical steroids, adjuvant antifibrotics, and needling.

advantageous in eyes with thin conjunctivas but offers less opportunity for revising erroneous placement. In brief:

1. Enter the conjunctiva directly with the XEN inserter 8 mm posterior to the limbus.
2. Tunnel toward the anterior chamber until the inserter is 2 to 3 mm from the limbus.
3. At this point, advance the slider gradually to release the stent into the chamber and simultaneously retract the inserter.

Please see Video 36.1 for instructions on both the ab interno approach and the ab externo technique with peritomy. Box 36.1 describes strategies for optimizing XEN outcomes.

TRABECULAR MESHWORK UNROOFING METHOD

One device that excises the trabecular meshwork is New World Medical's Kahook Dual Blade (KDB). The KDB uses a 230-micron wide, J-shaped footplate reminiscent of a hockey stick. A sharp-tipped, angled ramp on the footplate is paired with dual blades to allow for circumferential trabecular meshwork excision. Prospective 12-month analyses have found that combined KDB-phacoemulsification can lead to over a 25% IOP reduction and the removal of close to one glaucoma medication, with few side effects besides mild reflux bleeding.[20, 21] A modified version of the KDB, known as the KDB GLIDE, was recently released for commercial purchase. The KDB GLIDE uses a thinner, tapered footplate with a rounded heel to improve usability, particularly in eyes with narrower canals.

The procedure for using the KDB is as follows (Video 36.2):

1. Complete the phacoemulsification and leave the cohesive viscoelastic in the eye after IOL placement.
2. Under direct visualization, insert the KDB through the temporal wound. Rest the footplate on the trabecular meshwork at the center of your view.
3. Apply pressure to allow the sharp tip to incise the meshwork. Excise several clock hours of trabecular meshwork, proceeding either in a clockwise or counterclockwise direction. Adjust the gonioscope field as needed.
4. Return to the point on the trabecular meshwork where you began the cut. Extract several more clock hours of meshwork in the direction opposite the initial excision arc.
5. Do not be alarmed by blood reflux, as that is a positive indication that patent collector channels have been exposed. If the view becomes compromised with reflux, deploy more viscoelastic (dispersive preferred).
6. You may leave the excised trabecular meshwork within the eye; it is benign.

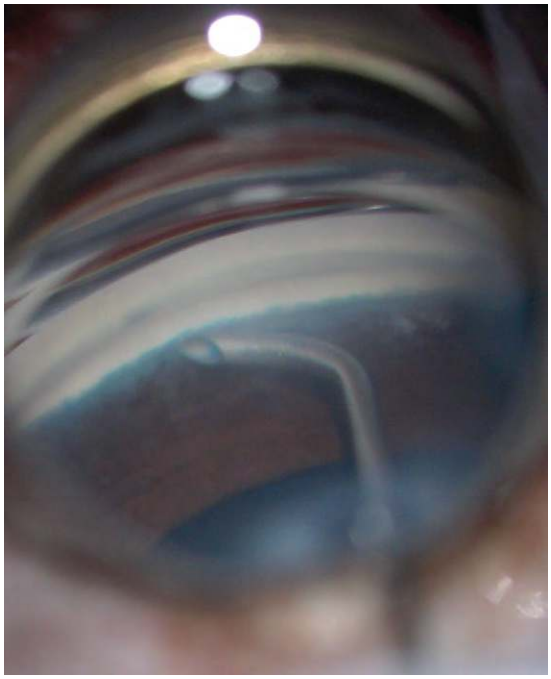

Fig. 36.6 OMNI placement with trypan blue. In this eye where the TM was stained with trypan blue, the OMNI inserter is placed against the TM with sufficient pressure to allow the catheter to enter the canal. *TM*, trabecular meshwork.

Sight Science's OMNI Surgical System provides another option for trabeculotomy, also incorporating dilation of Schlemm's canal and collector channels. The OMNI cannula uses a flexible microcatheter to perform the incisional goniotomy. An internal reservoir contains viscoelastic that exits through the microcatheter to achieve canaloplasty. Preliminary findings suggest that the OMNI system can achieve good IOP control.[22]

The OMNI procedure is as follows:

1. Complete the phacoemulsification and leave the cohesive viscoelastic in the eye after IOL placement.
2. Prime the OMNI by injecting cohesive viscoelastic into the port at the end of the device opposite the cannula. A viscoelastic bubble at the cannula tip indicates sufficient priming.
3. Insert the cannula through the main wound used for the cataract extraction.
4. Locate the trabecular meshwork and use the sharp tip of the cannula to penetrate (Fig. 36.6).
5. Keep the cannula in the canal and roll the OMNI gear wheel forwards to extend the microcatheter (Fig. 36.7) until 180° of Schlemm's canal has been traversed or the wheel stops movement. Retract the microcatheter by rolling the gear backward. Viscoelastic is automatically released during the retraction process.

6. Keeping the cannula in the same place, reextend the microcatheter 180° in the same clock direction.
7. Gently pull the cannula off the meshwork and toward the direction of the entry incision, displacing the microcatheter from the canal and opening the trabecular meshwork in the process.
8. Repeat steps 4 and 5, proceeding in the opposite clock direction to dilate the remaining 180° of Schlemm's canal (Fig. 36.8).
9. The surgeon may consider repeating steps 6 and 7 if it is desired to incise the remaining hemisphere of trabecular meshwork.

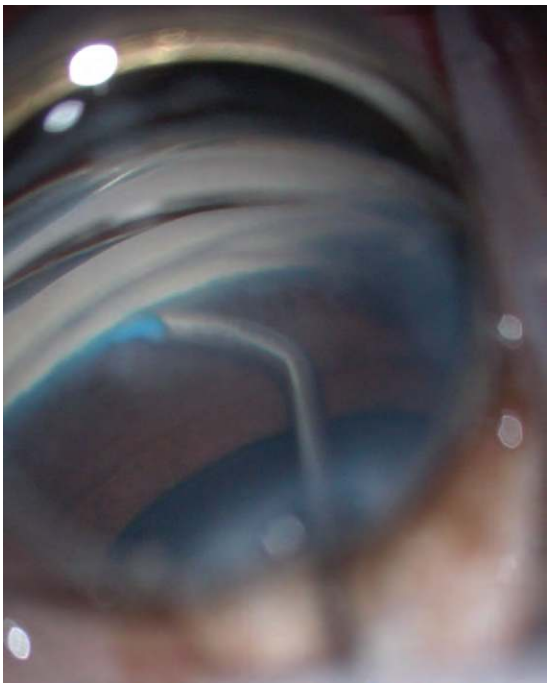

Fig. 36.7 OMNI with catheter in canal. The OMNI catheter is advanced counterclockwise into the canal of Schlemm, stained with trypan blue.

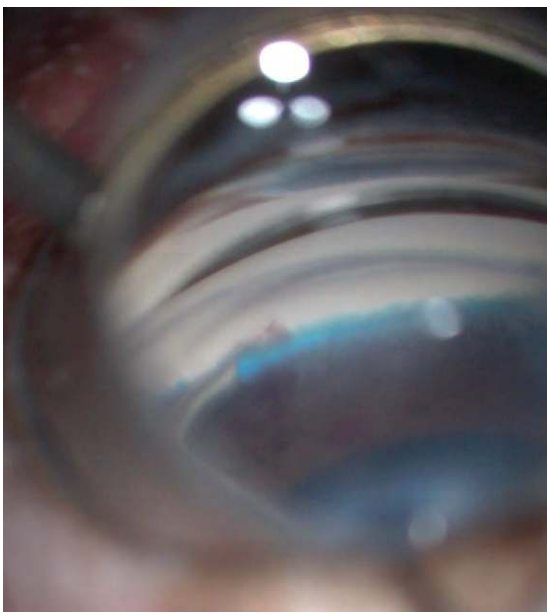

Fig. 36.8 OMNI second pass. After counterclockwise delivery of the OMNI, the catheter now has been placed in Schlemm's canal in the clockwise direction to target the remaining hemisphere.

TRABECULAR MESHWORK STENT METHOD

The Glaukos iStent is a 1-mm long titanium lampshade-shaped device that inserts at the trabecular meshwork to decrease outflow resistance into Schlemm's canal. The second generation iStent inserter, known as the iStent *inject*, enables the surgeon to place two of these stents in the same eye consecutively. The third generation iStent *inject* W has a wider flange to improve intraoperative visibility. One-year follow-up data indicated greater IOP control and similar safety profile for cataract surgery combined with iStent versus cataract surgery alone.[14]

The procedure for inserting the second or third generation iStent is as follows:

1. Complete the phacoemulsification and leave the cohesive viscoelastic in the eye after IOL insertion.
2. Place the inserter through the main wound used for the cataract extraction.
3. Locate the trabecular meshwork and position the inserter by applying mild pressure against the meshwork. Ensure that the inserter is not bent and that the stent guide needle is visible and centered in the inserter as the stent is injected (Fig. 36.9). Deploy the first stent.
4. Place the second iStent inject 2.5 to 3 clock hours apart from the first injection.
5. Ensure that both stents are placed with sufficient depth. Only the wide, hockey-puck-shaped end of each stent should be visible outside the trabecular meshwork (Fig. 36.10).

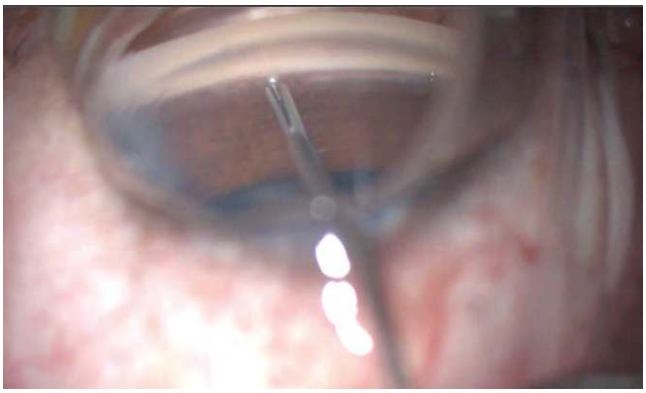

Fig. 36.9 Inject pin visible. Note excellent stent alignment with the pin centered in the middle of the iStent inserter. This ensures that the stent is deployed without being stuck.

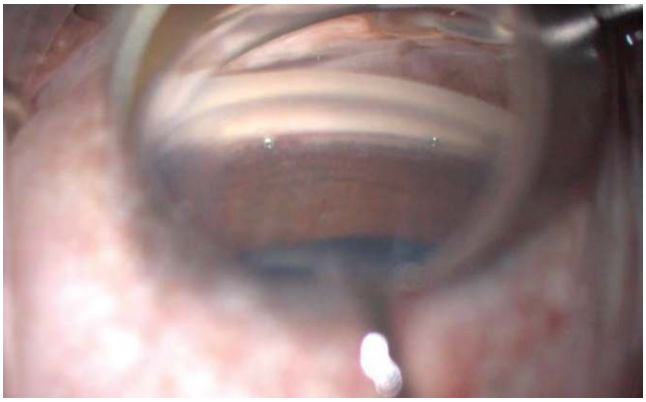

Fig. 36.10 Two well-positioned injects. Although these two stents are not the full 3 clock hours apart, the stents are perpendicular to the TM and only the hockey-puck ends are visible. Good placement of each stent is more important than separation. *TM*, trabecular meshwork.

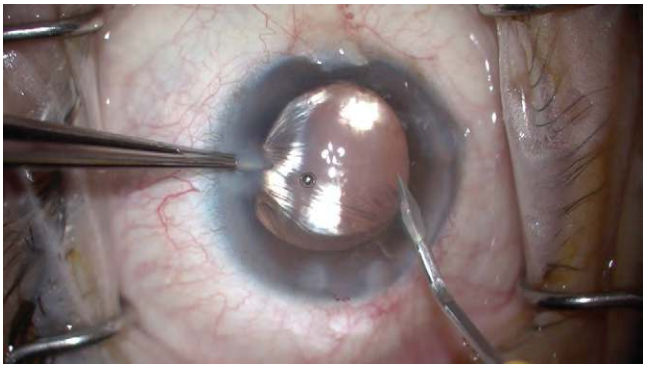

Fig. 36.11 Hydrus incision placement. A 1 mm MVR blade is used to create the Hydrus incision inferior to the temporal phaco wound while nontoothed forceps stabilize the eye through a paracentesis incision.

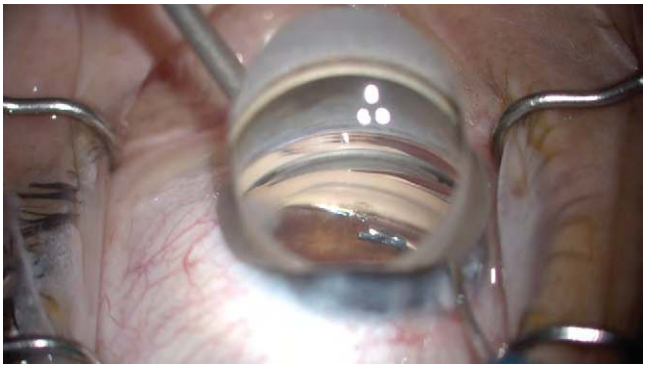

Fig. 36.13 Hydrus placement before final advancement. This eye with 2+ trabecular meshwork pigmentation has a Hydrus placed in the canal. The Hydrus needs to be advanced 1 to 2 mm to its final position in the canal.

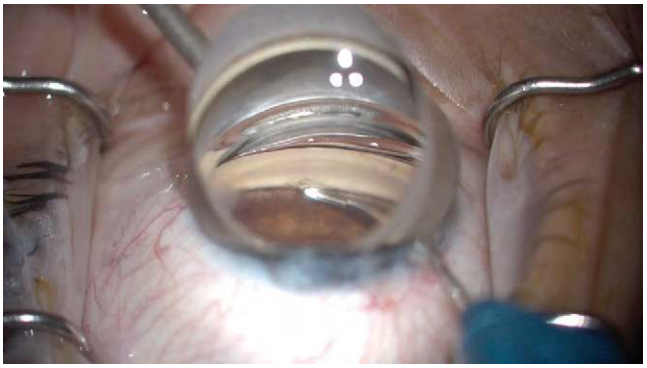

Fig. 36.12 Hydrus engaging TM. The Hydrus is seen entering the eye through the Hydrus incision and engaging the pigmented TM. The tip of the Hydrus is used to incise the trabecular meshwork before stent advancement. *TM*, trabecular meshwork.

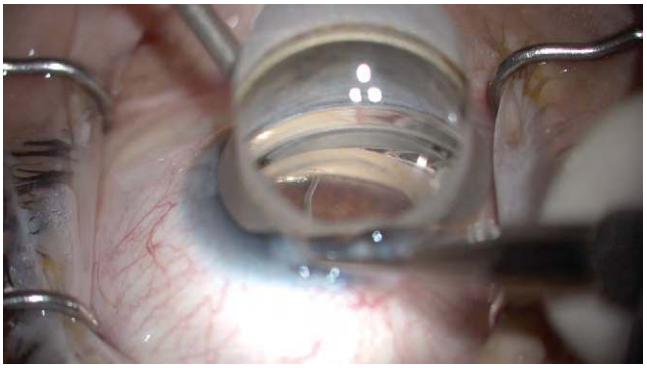

Fig. 36.14 Hydrus positioning with Sinskey. A Sinskey hook is used to advance the Hydrus until only 1 mm of the inlet is visible.

The 8-mm nitinol Hydrus Microstent (Ivantis) occupies three clock hours within the trabecular meshwork, dilating Schlemm's canal. Upon slit-lamp examination, only its roughly 1-mm inlet portion is visible. A 2020 Cochrane review that synthesized data from three prospective trials found "moderate-certainty evidence" that combined cataract extraction with Hydrus reduced IOP and glaucoma medication load versus cataract extraction alone, with an enhanced IOP reduction of 2 mm Hg and 0.41 fewer drops at 18 to 36 months.[23]

The procedure for inserting the Hydrus Microstent is as follows (Video 36.3):

1. Complete the phacoemulsification and leave the cohesive viscoelastic in the eye after IOL insertion.
2. Create the Hydrus incision with a 1-mm incision to the right side of the main wound if you are right-handed. The incision should be oriented parallel to the main wound to allow access to the trabecular meshwork (Fig. 36.11).
3. After obtaining angle visualization, place the Hydrus Microstent inserter through the Hydrus wound. Position the tip of the inserter on the trabecular meshwork at the far right of your view if you are right-handed. If you are left-handed, place the tip at the far left.
4. Enter the trabecular meshwork by advancing the Hydrus while applying gentle pressure at a slight upward angle of no more than 20 degrees (Fig. 36.12).
5. Slowly roll out the stent into the canal and continue cannulation until only 1 mm of the inlet of the device is visible outside the meshwork (Fig. 36.13).

BOX 36.2 Microstent Placement Pitfalls

- Avoid the temptation to place the Hydrus through the main incision. The Hydrus incision will allow the optimal angle for stent placement.
- If you encounter high resistance that prevents stent advancement, the tip of the inserter has likely become caught on the scleral wall. Apply less pressure to allow the stent to resume its path through the canal.
- If the stent cannot be advanced sufficiently into the canal, use the inserter to remove the stent and redeploy the stent in the opposite direction.

6. To adjust the stent position in case that more than 1 mm is outside the meshwork, use a Sinskey or Kuglen hook to advance the stent deeper (Fig. 36.14).

Box 36.2 highlights common Hydrus insertion challenges.

TUBE SHUNTS AND TRABECULECTOMY

Though angle surgeries can be most effective in mild and moderate glaucomas, the IOP control they provide may be insufficient under more dire circumstances. For refractory glaucoma, the two mainstays of intervention that may be combined with cataract surgery are trabeculectomy and tube shunts.[24] Two categories of tube shunts exist:

- Unvalved devices such as the Baerveldt Glaucoma Implant (BGI: Johnson & Johnson Vision) or the Ahmed ClearPath (ACP: New World Medical).

- Valved devices such as the Ahmed Glaucoma Valve (AGV: New World Medical). The AGV's pressure-sensitive valve is meant to prevent excess aqueous drainage and hypotony.

Two major multicenter prospective clinical trials have compared standalone trabeculectomy with tube shunts: the tube versus trabeculectomy (TVT) study and primary tube vs. trabeculectomy (PTVT) study.[24, 25] Both used the BGI as the tube of choice.

- The TVT study at 5 years indicated better surgical success and fewer additional surgeries for the BGI compared with trabeculectomy in eyes with prior cataract or glaucoma surgeries.[24] Similar IOP and glaucoma medications at follow-up were recorded.
- The PTVT study included only eyes with no prior surgery. It found equivalent surgical failures, but trabeculectomy accomplished greater IOP control with fewer glaucoma drops.[25]

Numerous trials compared different tube types.[26–28] According to a 2017 Cochrane review, there were insufficient data across 27 trials to favor one tube type over another, or to favor either tube or trabeculectomy.[29] We advise surgeons to pick the tool that is most comfortable for them and/or is most applicable, given their patient population. This recommendation applies to both standalone and combined procedures.

Maintaining a Bleb During Cataract Extraction

A surgeon may sometimes encounter an eye with a history of trabeculectomy. Cataract extraction can decrease the functioning of preexisting drainage blebs, with worse IOP control and increased medication load.[30, 31] Temporal effects also come into play. The sooner the phacoemulsification is performed after the trabeculectomy, the greater the likelihood of bleb failure.[30, 32] If appropriate, trabeculectomy blebs may be revised with a needling procedure or surgically modified with scar removal at the time of the cataract extraction.

Given the risk for a cataract extraction impairing bleb function, some surgeons advocate using antimetabolites prophylactically in the setting of cataract extraction.

- One study on 5-FU injections at 2, 4, and 12 weeks after cataract surgery in patients with preexisting blebs showed no significant differences in IOP control versus a matched group without antimetabolite usage.[33]
- A separate study of 5-FU application immediately after phacoemulsification in eyes with preexisting blebs showed that the 5-FU group had less need for additional glaucoma medications at 12 months postop, although IOP change was comparable.[34]

To the authors' knowledge, no true randomized controlled trials have yet evaluated how effective antimetabolites after phacoemulsification are on preventing bleb failure.[35] Therefore the benefit to applying MMC or 5-FU to preserve a bleb in the context of IOL insertion remains unclear. Special attention should be paid to the advanced glaucoma patient's IOP in the hours and days after cataract surgery because an IOP spike can damage vision even if there is a functioning bleb.

Considerations for Combining Advanced-Stage Glaucoma Surgery With Phacoemulsification

When a cataract coexists with end-stage glaucoma, one may perform a combined phacoemulsification-tube or phacoemulsification-trabeculectomy. Data on the effectiveness of such combinations are mixed.

- A retrospective case series of combined phaco-BGIs and phaco-AGVs in Asian patients showed favorable IOP and visual acuity outcomes with low complication rates.[36]
- Phaco-BGI vs. phaco-AGV demonstrated similar IOP control, rate of complications, and glaucoma medications at 2-year follow-up.[37]
- Phaco-AGV had a significantly higher failure rate at 2 years.
- Phaco-BGI had a significantly higher rate of postoperative slit-lamp interventions.
- Comparable IOP control effects were observed between phaco-AGV and phaco-trabs.[38]
- The phaco-trab group underwent more bleb leakage events, although the phaco-AGV group had more choroidal detachments.
- In a prospective study of phaco-BGIs vs. delayed sequential phaco, the concomitant procedure showed a significant increase in BGI failure and less IOP control.[39]
- Refractive outcomes were poorer in combined phaco-tube and phaco-trab procedures as opposed to sequential operations.[40, 41]
- Phacoemulsification has been shown to not impact IOP control in eyes with a preexisting AGV or BGI.[42–44] This is in contrast to cataract extraction after trabeculectomy.[31]

Ideally, tube or trab would long follow cataract surgery. However, patients often present simultaneously with both dense cataract and severe glaucoma and/or may resist multiple procedures. In such cases, a combined procedure offers a suitable choice.

COMBINED PHACOEMULSIFICATION-TUBE SHUNT

This section will describe the procedure for a superotemporal (ST) tube shunt placement combined with cataract extraction.

Preoperative Setup

Tube shunt surgeries are unique among glaucoma procedures for using donor patch grafts. During consent, ensure that the patient does not have any objections to this receipt of donor tissue.

- Patch graft type is often dictated by availability and provider preference.
- Generally, the order from least to most cosmetic visibility is as follows:
  - Corneal patch graft
  - Pericardium patch graft
  - Scleral patch graft

Depending on the eye and orbit size, you may want to select a tube shunt with a smaller or larger plate.

- There is evidence that 250 mm^2 plates are similar in effectiveness to 350 mm^2 shunts.[45]
- Plate size can also be adjusted pre- or intraoperatively by trimming with Westcott scissors. Have at least one extra tube shunt available in case the first is deficient upon intraoperative evaluation. Additional steps are specific to the valve type (Box 36.3).

Anesthetic usage is dependent on the extent of tissue dissection one expects to encounter. When an eye presents preoperatively with extensive conjunctival scarring, anticipate a longer operative period that may justify a full retrobulbar block. In more typical cases, a sub-Tenon's injection of 2% lidocaine or similar is usually sufficient.

Surgical Procedure

It is the traditional approach to proceed with the plate placement first, cataract extraction second, and tube tip placement third. Techniques for tube with phaco have been described by Stein in chapter eight of *Essentials of Glaucoma Surgery* (2012).[46]

1. First, to ensure good visualization of the superotemporal region, use a 7-0 traction suture to rotate the eye inferonasally (Box 36.4). Use a hemostat to clamp the traction suture to the operative drape. Apply viscoelastic atop the cornea and cover with a shield.
2. Superotemporally, use nontoothed forceps to grasp a section of bulbar conjunctiva 5 mm posterior to the limbus. Pull to make a tent shape. Incise the conjunctival tent parallel to the limbus with Westcott scissors.

BOX 36.3 Setup Differences Between Valved and Nonvalved Implants

- Prepare an AGV by testing the valve mechanism. An Ahmed valve that has not been primed will not function at all. Inject saline into the tube using a 27- or 30-gauge cannula and check for saline coming out near the plate. If the saline bounces backward or only flows under extreme pressure from the plunger, consider the rare event of valve malfunction. In contrast and equally rare, if the saline flows through with no resistance at all, the valve is likely incompetent. Either scenario suggests the need to use an alternative device.
- A BGI or ACP should also be tested using saline injection. Expect minimal to no resistance before the tube is tied. Once the tube is ligated with a 7-0 or 8-0 vicryl, test again to confirm complete occlusion.
- Standard BGI or ACP Technique: Tie the tube close to the plate multiple times (3-1-1) with a 7-0 polyglactin suture. Tie as many knots as are necessary to prevent fluid flow, understanding that these knots need to be tight. You can test this by using a 27- or 30-gauge saline cannula. No fluid should flow even at high plunger pressure. Even a small amount of fluid flow will likely result in hypotony.
- "Ripcord" technique: Place a 6-0 Prolene suture through the tube lumen. This will serve as a "ripcord" that you can pull at the slit lamp for drainage. Next, tie the tube multiple times with a 7-0 polyglactin suture. Tie as many knots as are necessary to prevent fluid flow. You can test this by using the same saline cannula approach as previously described. Leave the "tail" of the Prolene externalized through the conjunctiva, in the fornix, for removal if the IOP is elevated after 4 weeks.

BOX 36.4 Traction Suture Options

- In cases with an intact, physiologic cornea, one can place the traction suture through the peripheral cornea at 12 o'clock.
- When corneal health is a concern, one may place the suture around the superior rectus.

3. Raise the now transected bulbar conjunctiva with the forceps and initiate blunt dissection underneath using the scissors. Dissect superiorly and temporally for only 2 clock hours, avoiding contact with the recti muscles.
4. Use the nontoothed forceps to lift the exposed Tenon's fascia and cut into it with the Westcott scissors. Grasp Tenon's fascia and execute blunt dissection atop the sclera with curved scissors. Dissect until the scissors can be fully extended into the pocket with minimal resistance.
5. With the pocket created, you can now begin insertion of the plate. Grasp the glaucoma drainage device at the body of the plate with forceps, well posterior to the tube and valve. Avoid damaging these delicate elements.
6. Retract Tenon's fascia, and slip the plate in the pocket between Tenon's and the sclera. The plate should fit snugly. If there is any resistance, perform further blunt dissection. Larger implants require a modified approach (Box 36.5).
7. Use calipers and mark a point 8 mm posterior to the limbus where you will secure the plate. Insert a 9-0 nonbiodegradable suture at this point into the sclera. Pass the suture through the eyelet hole on the plate and tie. Repeat this 9-0 tie for the next eyelet hole. Next, bury these sutures with tying forceps.
8. Use the calipers again to verify that the sutured plate is at least 8 mm posterior to the limbus. If not, one or both sutures should be replaced to minimize corneal complications.

BOX 36.5 Size Effects

For larger implants such as the Baerveldt 350, the procedure for plate placement is similar with exception of the initial tuck. These implants must have their wings underneath or above the superior and lateral rectus muscles. For intact recti, underneath is preferred.

- Use a muscle hook to identify the lateral rectus and superior rectus muscles.
- Reflect Tenon's fascia with forceps. Use the hook to elevate the superior rectus and use forceps to move one wing of the plate underneath both the superior rectus muscle and Tenon's fascia. Repeat for the lateral rectus.
- Pull on an eyelet hole with forceps to test that the plate is snug behind each rectus' insertion point.
- After the fit is confirmed, proceed with the same scleral suturing described in step 7 above.

9. Resume blunt dissection of the space between Tenon's fascia and the sclera. This time dissect anteriorly from the plate of the implant toward the limbus. Stop the dissection once the limbus is reached, and clear any additional adhesions present at the limbus.
10. Release the traction suture from the hemostat to allow the eye and tube to return to a resting position.
11. Estimate the tube length necessary to remain visible on slit lamp exam yet short enough to avoid corneal contact. For anterior chamber placement, the tube should be relatively shorter and face bevel-up anteriorly, both to minimize corneal exposure. For posterior chamber (PC) placement, the tube should be relatively longer and face bevel-down, both to maximize visibility from behind the iris. Grasp the tube with forceps and trim the tube at an angle to create a bevel.
12. Perform the phacoemulsification as usual. Placing some viscoelastic (cohesive or dispersive) into the tube tip *before* phaco will prevent lens material from entering and potentially clogging the tube. At the end of the case, there is no significant need to aspirate or remove the viscoelastic, but irrigation of the tube with a 30-gauge cannula may be helpful.
13. After the IOL has been placed, use a 23-gauge needle bevel-up to perform a sclerostomy for the tube. For anterior chamber ST placement, your point of entry should be at 11 o'clock on a right eye and at 1 o'clock on a left eye, immediately adjacent to the limbus. For posterior chamber ST placement, measure 2 mm posterior to the limbus at the same clock hours. Anterior chamber tube position is preferred post-IOL.
14. Sclerostomy should be made parallel to iris plane such that the tube is not directed anteriorly toward the corneal endothelium (in AC placement) or the iris (in PC placement). Ensure also that the sclerostomy is not performed too closely to the zonular fibers, as this can disrupt IOL stability.
15. Before inserting the tube, take note of the anterior chamber depth. Changes in depth from IOL placement can increase the odds of cornea-tube or cornea-iris contact. Establish ample clearance if possible.
16. With forceps, pinch the tube at its bevel and tunnel it through the sclerostomy into the AC. Hold the bevel at that point for 20 to 30 seconds. Then thread the remainder of the tube into the anterior chamber by grasping and tugging at its more posterior segments.
17. Once the tube is in the chamber, confirm that the tip is not too long. Tie a figure-8 knot with a 9-0 suture to secure the exposed portion of tube onto the sclera.
18. Place a patch graft of your choice from the exposed tube all the way to the plate of the drainage device. Suture it into place with nylon if needed.
19. Traditionally, the conjunctiva is closed with an interrupted or running polyglactin suture.

Combined Phacoemulsification-Trabeculectomy

There is a wide array of surgeon preferences for trabeculectomy techniques that vary in many facets including:

- Limbus versus fornix-based flaps
- Choice, concentration, and duration of antimetabolite
- Single incision with phaco through the trabeculectomy incision versus separate phaco and trabeculectomy incisions
- Phaco first, then trabeculectomy incisions
- Trabeculectomy first with a tight flap tie, then phaco

Limited data exist on the relative merits of each nuance, and these details are beyond the scope of this chapter. Nonetheless, a few general principles can be broadly extrapolated:

- Avoiding toxicity from antimetabolite access into the anterior chamber
- Meticulous tissue handling
- Complete cortical removal to reduce inflammation
- Extra attentiveness in assuring water-tight external wound closures

Again, surgeon comfort with technique and patient characteristics remain important factors in decision making.

POSTOPERATIVE MANAGEMENT AND COMPLICATIONS OF COMBINED SURGERIES

Combined procedures expand the realm of postoperative challenges versus cataract extraction alone. In terms of severity, angle surgeries are safer than trabeculectomies or tube shunts. However, recalls of novel glaucoma implants have occurred in recent times, and some new tools or techniques lack comprehensive long-term safety data.[47] This section will overview the pertinent complications that apply broadly to combined glaucoma-cataract surgeries. Postoperative monitoring for specific approaches is described in Tables 36.1–36.3.

Hypotony

Hypotony is feared primarily for its potential vision-threatening sequelae of choroidal effusion, choroidal hemorrhage, or hypotonous maculopathy. An exact numerical definition of hypotony is elusive.[48] From a practical clinical perspective, we recommend that surgeons monitor closely eyes that present with <6 mm Hg adjusted postoperative IOP and intervene if:

1. That <6 IOP reading persists across at least two consecutive visits and/or
2. Clinically significant changes are noted.

TABLE 36.1 Tracking Patient Progress and Healing After Minimally Invasive Trabecular Procedures (KDB, OMNI, iStent, Hydrus Microstent, etc.)

Time Since Surgery	Positive Signs of Progress	Signs of Potential Complications
1–2 Weeks	IOP controlled and good vision	IOP spikes or hyphema
1 month	Continued IOP control, excellent vision	Failure to taper even one glaucoma medication
2 months	Well-healed procedure	Persistent bleeding or device displacement
6 months	Sustained medication reduction from baseline	Persistent IOP elevation

Risk factors for hypotony are outlined in Box 36.6. Careful anterior chamber examination, fundus examination, and optical coherence tomography analysis are key during the follow-up period. Management strategies are as follows:

- Slightly shallow chambers:
  - Taper the steroid dose.
  - Administer a cycloplegic such as atropine.
- Flat chamber, choroidal effusions, or choroidal detachment:
  - Deliver a cohesive viscoelastic injection (typically Provisc or Healon) with a 30-gauge needle at the slit lamp.
- Persisting flat chamber, serous effusions, choroidal detachment, or maculopathy:
  - Consider surgical revision of the glaucoma implant through reocclusion or removal.

TABLE 36.2 Tracking Patient Progress and Healing After AGV-Phaco

Time Since Surgery	Positive Signs of Progress	Signs of Potential Complications
1–2 Weeks	IOP controlled, chamber shape intact	Hypotony with chamber shallowing; inject viscoelastic if severe IOP near the upper limit of normal; consider resuming aqueous suppressants to prevent hypertensive phase
1 month	IOP controlled, visual acuity unchanged or improved	Early hypertensive phase (IOP > 21 mm Hg)
2 months	IOP controlled	Late hypertensive phase; taper steroids and resume aqueous suppressants if necessary
6 months	IOP target reached	Corneal edema, persistent uncontrolled pressure

TABLE 36.3 Tracking Patient Progress and Healing After BGI-Phaco

Time Since Surgery	Positive Signs of Progress	Signs of Potential Complications
1–2 Weeks	IOP slightly elevated (expected until week 7)	Hypotony caused by insufficient ligating suture or peritubular flow Moderately or highly elevated IOP caused by tube ligation; taper steroids and resume aqueous suppressants if necessary
1 month	Visual acuity unchanged or improved	Moderately or highly elevated IOP
2 months	IOP controlled	Hypotony after ligating suture dissolution; consider tapering glaucoma medications. Fibrin in the anterior chamber from tube reflux; consider topical steroids if symptomatic
6 months	IOP target reached, tube fully open	Corneal edema, persistent uncontrolled pressure

BOX 36.6 Anticipating Hypotony

Patients at greatest risk for hypotony maculopathy include:[49]

- Young patients
- Myopes
- Males
- Individuals without diabetes

Hypotony in the presence of suprachoroidal hemorrhage is a unique situation, which may require multisubspeciality input.

Corneal Damage

Corneal issues after combination surgeries can arise through two main mechanisms:

- Contact between the peripheral cornea and the tip of a glaucoma device, believed to be the primary preventable factor.[50]
  - Careful perioperative trimming and repositioning of tube shunts minimizes risk.
  - For angle-fixated devices, good gonioscopic visualization enables deep and secure placement of the stent of choice.
  - Devices that insert at the level of Schlemm's canal should be anatomically less likely than other implants to contact the peripheral cornea. Angle techniques that do not leave a device obviate this concern.
- Damage to the corneal endothelium from surgical tools. - As little cumulative dissipated energy (CDE) and balanced salt solution (BSS) should be applied as possible.

During follow-up, sequential measurements of endothelial cell count can be compared with early and prior values if it becomes apparent that the device is precariously close to the cornea. If progressive cell loss is noted, prompt reoperation is the best course of action, ideally before corneal decompensation occurs.

Disclosure

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SUMMARY

- Discuss with patients how a standalone cataract removal may raise IOP in the short term but lowers pressures overall. Employ IOP spike prophylaxis in high-risk patients.
- When considering combined cataract and glaucoma procedures, tailor the combination to the patient based on angle features, glaucoma progression, and ability to tolerate device or technique-specific complications.
- For combined angle surgeries, ensure excellent visualization by optimizing tilt, clearing any blood, and using viscoelastic to eliminate corneal striae.
- Phaco-tube and phaco-trab are comparable approaches for the severe glaucoma patient presenting with cataract, with no single tube or trab being definitively the "best." Recognize that better outcomes are generally observed when the tube or trab is placed months after cataract surgery rather than concomitant with it.
- In an eye with a preexisting drainage bleb, it is best to perform the cataract surgery well after the trabeculectomy to minimize the odds of bleb failure. Antimetabolite prophylaxis in this context is understudied, although a surgeon may consider it when an IOP spike could be particularly disastrous to the eye.
- Be aware of extra steps that must be taken to prime a nonvalved tube shunt compared with a valved tube shunt and to attend to placement nuances for larger tube plates versus smaller ones.
- Viscoelastic in the tube lumen can prevent stray lens material from clogging the tube.
- Treat postoperative hypotony with atropine, viscoelastic injections, and surgical reformations if needed.
- Risk for corneal complications is best mitigated by a conservative surgical approach. Less tube, less CDE, and less BSS best protects the peripheral cornea.

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Video 36.1 Ab interno and ab externo techniques for insertion of subconjunctival gel stent.
Video 36.2 Technique of trabecular meshwork unroofing using the Kahook Dual Blade.
Video 36.3 Technique of inserting the Hydrus Microstent.

37

Cataract Surgery in Combination With Corneal Surgery

Joshua C. Teichman

CONTENTS

KEY POINTS

- A number of corneal conditions and surgeries will influence the preoperative, intraoperative, and postoperative course of patients undergoing cataract surgery.
- Although some patients with corneal pathology may require surgical procedures before biometry, combined surgical procedures at the time of cataract surgery, or possibly procedures after the cataract surgery has been performed, others will not require additional surgery; however, the preoperative planning or the cataract surgery itself may be adjusted for improved outcomes.
- With careful preoperative examination and testing, these patients can be identified, categorized, and planned accordingly.
- Careful analysis of biometry, thoughtful decision of postoperative refractive target, appropriate selection of the intraocular lens (IOL), and, where appropriate, modifications to the surgical technique will lead to excellent results in patients with corneal pathology or surgery.

INTRODUCTION

A myriad of corneal conditions and previous, combined, or future corneal surgeries will influence the clinical course of patients undergoing cataract surgery. Where there is relative consensus, it is presented; however, there may not be agreement in many of the subject areas. The author has chosen an anatomic outline to the chapter such that, when the following clinical conditions are encountered, the reader may return to this chapter as a reference.

ANTERIOR CORNEA

Epithelial Basement Membrane Dystrophy (EBMD)

Epithelial basement membrane dystrophy (EBMD) is a condition of the corneal epithelium that presents with maps, dots, and/or fingerprint lines. The condition likely occurs in approximately 5% of the population, meaning on average, one patient per cataract operating room day is likely to have the condition. Although EBMD is one of the most frequently encountered corneal conditions by the cataract surgeon, not every patient with EBMD requires additional treatment. EBMD is a spectrum of disease, ranging from completely asymptomatic to patients with intractable recurrent corneal erosions. Focusing on those more likely to present for cataract surgery, these patients may be divided into two groups:

- Those without corneal or topographic changes within the central cornea.
  - Little more needs to be done preoperatively compared with routine procedures, save for identifying the condition and ruling out central involvement.
- Those with central changes (Fig. 37.1).
  - For those with central involvement and irregular astigmatism, an erroneous value or a nonrepresentative value may lead to incorrect IOL power selection and/or incorrect IOL toricity, with a postoperative refractive error.
  - Placido images from the topographer can be especially useful in identifying irregular astigmatism from EBMD.

The EBMD itself can degrade the quality of vision, and it is not infrequent that treatment of the EBMD may result in not only improved IOL accuracy but also improved postoperative vision from the cornea.

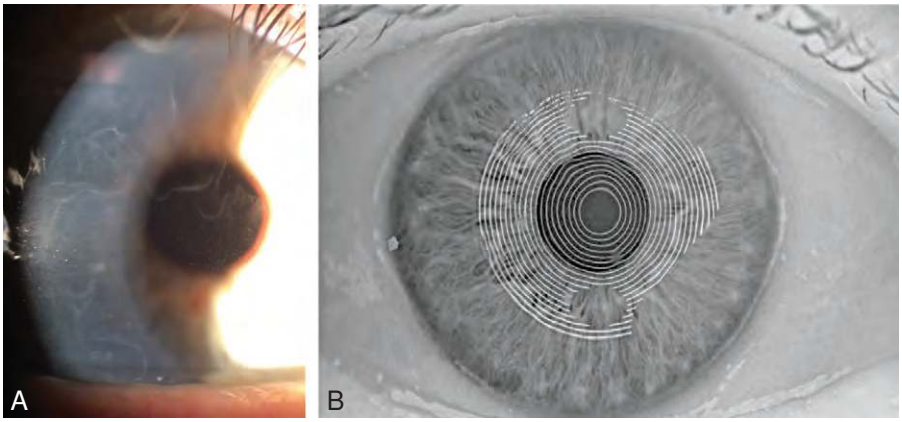

Fig. 37.1 (A) Slit-lamp biomicroscope photograph of a patient with diffuse epithelial basement membrane dystrophy (EBMD) affecting the central cornea. This level of epithelial irregularity is very likely to interfere with topography/biometry and result in incorrect intraocular lens (IOL) power/toricity. (B) Irregular Placido mires in a cornea with EBMD; the eye had been implanted with a toric IOL. After surgical removal of the EBMD, IOL exchange for a nontoric IOL with 1 D more spherical power resulted in unaided 20/20 vision.

If the decision is made to perform a superficial keratectomy:

- We generally suggest removal of epithelium limbus to limbus.
- A Tooke knife is a nice instrument to use, given its blunt, rounded edge, although many may opt for a Beaver blade, crescent blade, or similar.
- In recurrent corneal erosion syndrome (RCES), one may wish to perform diamond burr polishing and/or anterior stromal micropuncture concurrently.
- These additional procedures may further change the corneal shape.
- Once the epithelium has healed, it tends to remodel over a number of months; thus we suggest repeat topography/biometry at the 3-month point, and if it remains variable, following until stable. At this point, IOL calculations and selection proceed as usual.

Once healed, one should take care not to induce corneal abrasions during cataract surgery, as these may be slow to heal or lead to RCES.

Salzmann's Nodular Degeneration

Salzmann's nodules are gray-white elevated subepithelial lesions that may develop after numerous conditions/insults, including contact lens wear or blepharitis/Meibomian gland dysfunction/dry eye disease (Fig. 37.2). Similar to EBMD, Salzmann's nodules may affect the peripheral or central cornea. Peripheral lesions may be observed; however, those that interfere with biometry/topography should be considered for removal before biometry and cataract surgery. These lesions can recur and addressing the underlying etiology will reduce their recurrence. Salzmann's nodules may be removed by superficial keratectomy and, once the plane of the lesion is found, the lesions usually peel off quite easily. Biometry/topography should be performed at between 1 and 3 months postoperatively to allow for the epithelium to remodel before testing. Topography should be inspected for regularity and biometry for stability, until measurements are satisfactory and reliable.

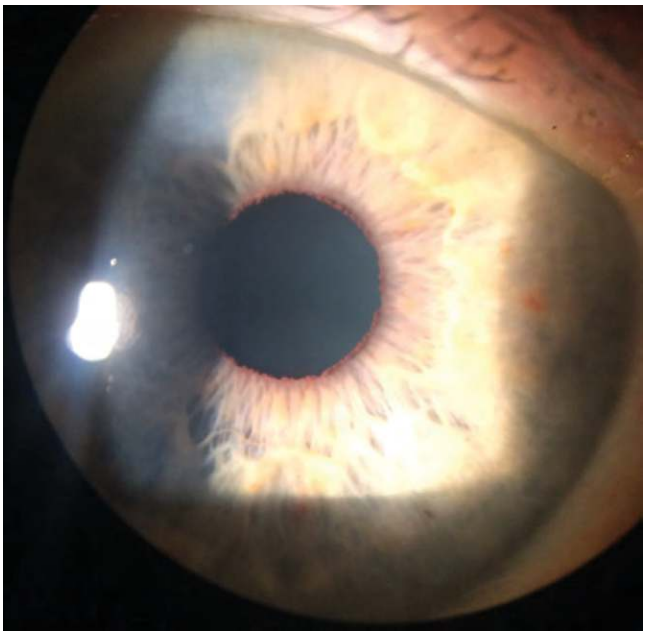

Fig. 37.2 Slit-lamp biomicroscope photograph of a patient with a superiorly located Salzmann's nodule. If the nodule interferes with topography/biometry, it may result in incorrect intraocular lens (IOL) power/toricity.

Pterygium

Pterygia (plural of pterygium) are actinic fibrovascular growths on the nasal or temporal cornea (Fig. 37.3). They often induce local flattening with compensatory steep astigmatism 90 degrees away.

- Earlier removal before cataract surgery allows the cornea to revert to a more normal shape before biometry and IOL selection.
- Historically, surgeons may have removed pterygia concurrently with cataract surgery; however, we recommend against this practice mainly because the change in corneal shape will make the previously selected IOL power/toricity inaccurate, leading to poorer refractive outcomes.
- After surgical removal, we generally suggest waiting 1 to 3 months to repeat the biometry/topography and assess stabilization.
- The time required for the cornea to stabilize may be proportional to the size of the pterygium.
- Most surgeons generally attempt to find a dissection plane just below the pterygium.
- Another technique is to grasp the head of the pterygium at the limbus and mechanically pull it anteriorly to create the structural dissection plane.

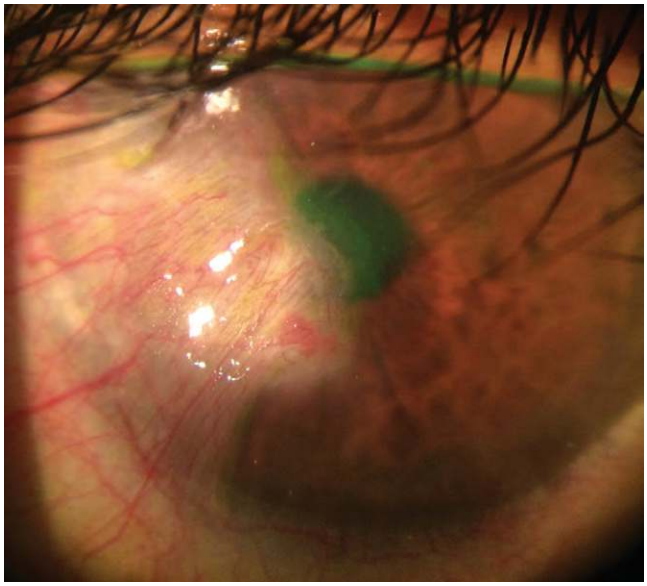

Fig. 37.3 Slit-lamp biomicroscope photograph of a patient with a large nasal pterygium that has encroached on the pupil. A large pterygium will preclude accurate topography/biometry and result in incorrect intraocular lens (IOL) power/toricity.

- If little stroma is removed, the corneal shape reverts to close to normal and may resemble the (unafflicted) contralateral eye.
- A review of pterygium management was recently performed.[1]
  - After the cornea has stabilized, if there remains residual astigmatism or if the cornea has inherent relatively regular astigmatism, it is reasonable to correct this with a toric IOL.
  - Meridional and toric magnitude measurements should agree across various modalities.

With respect to cataract surgery in the setting of a previously removed pterygium, the procedure is unlikely to be different than usual. One rare exception is that, when the excising surgeon dissected deep into the cornea (which is not required), the area planned for the clear corneal incision may be thin and may either be best avoided, or may require a suture at the completion of the case.

ANTERIOR CORNEA PEARLS

- Anterior corneal conditions are commonly encountered by the cataract surgeon.
- Mild and/or peripheral disease may not require additional treatment.
- If topography/biometry are affected, it may be prudent to surgically normalize the cornea before proceeding.
- Repeated measurements are usually obtained 3 months after surgical correction.
- These conditions rarely affect the cataract surgery itself.

CORNEAL STROMA

Keratoconus

Keratoconus is an ectatic corneal disorder with a broad range of severity, from asymptomatic patients discovered at the time of preoperative cataract surgery testing by topography, to those who require corneal transplantation at a young age.

Keratoconus is unlikely to progress after the age of 40; however, some much older patients may experience progression. Moreover, as both keratoconus and some forms of cataract (e.g., anterior subcapsular) are found more often in young atopic patients, the situation may arise where a patient is either progressing or at risk for progressing, and the decision needs to be made as to which procedures are to be performed and in what order.

- In a young patient with progressive keratoconus, we would generally recommend corneal cross-linking (CXL) to stabilize the cornea before cataract surgery, given that any progression is generally irreversible.
  - The cornea will then change and flatten over months to years.
  - There is no time at which the change is considered guaranteed complete; however, the majority of the change usually occurs within the first 3 to 6 months. Thus testing after this time is reasonable.
  - Topography-guided photorefractive keratectomy (tgPRK) and intracorneal ring segments (ICRS) in addition to CXL add additional variables to predicting the IOL power.
- CXL before cataract surgery does delay the cataract surgery, and in rare cases of progressive keratoconus with severe bilateral cataract, it may be justified to perform the cataract surgery first, then cross-linking; however, the patient should be aware that the refractive outcomes are less predictable.
  - The amount of flattening of the cornea after CXL alone is quite variable; however, it averages approximately 1D, and this may be considered in the IOL calculation.
- For the most part, the vast majority of patients with keratoconus presenting for cataract surgery will have stable disease, and the above will not be required.

Some patients with keratoconus will have an apical nodule that may interfere with biometry/topography, and these may be addressed similarly to Salzmann's nodules (see previous section).

Some keratoconus patients are current wearers of rigid gas permeable (RGP), hybrid, or scleral contact lenses and may plan to continue to wear these postoperatively. Patients with keratoconus often have their best vision in these types of contact lenses.

- If they plan on discontinuing RGP or specialty lenses, they should be warned that their quality of vision may worsen postoperatively out of contact lenses.
- If they plan on continuing to wear these lenses, then toric IOLs should be avoided.
- There is no consensus on the amount of time a contact lens wearer needs be out of lenses before biometry/topography. One conservative rule would be 1 month per decade of wear for RGPs (meaning a 60-year-old patient who has worn RGPs since the age of 20 may need to be out of lenses for 4 months).
- Soft contact lenses affect the corneal shape as well, and suggestions range from a few days to 2 weeks out of lenses before testing.
- Testing can always be repeated on multiple occasions until stable. There may be circumstances where a corneal transplant, whether penetrating keratoplasty (PK) or deep anterior lamellar keratoplasty (DALK), may be considered before, combined with, or after, cataract surgery, and this will be discussed in the next section.

BIOMETRY IN KERATOCONUS

There are many preoperative considerations to take into account with respect to biometry and IOL selection.

- It is ideal to obtain multiple measurements on different devices. Generally, we perform:
  - Refraction and/or auto-refraction
    - Auto-refractions may be irregular and artifactual, and refractions may be very difficult because of the multifocal nature of the cornea.

TABLE 37.1 Suggested Postoperative Refractive Target by Level of Keratoconus (Watson), Keratometry (K), Diopter (D)

Keratoconus Severity	Plan
Mild, mean K <48D	Target -1.0D
Moderate, mean K 48–55D	Target -1.5D
Advanced, mean K >55D	Use Ks of 43.25 and target -1.8D

- Manual and/or auto-keratometry
- Topography and/or tomography
- Ultrasound biometry
- Optical biometry

Although we should always look at the patient's current glasses and refraction when planning surgery in patients with keratoconus. Because the cornea contributes the vast amount of astigmatism, the refractive cylinder should line up very well with the testing, and, if it does not, it is likely best to avoid a toric IOL.

Special mechanisms have been described for IOL selection in keratoconus eyes. None of these techniques are particularly accurate. Khandelwal and colleagues at Baylor have shown that the predictability diminishes with increasing keratometry, which gets notably worse over 50D.

- Watson and colleagues provide insightful advice for IOL selection, hedging different degrees of myopic aim based on keratometry in patients with keratoconus undergoing cataract surgery (Table 37.1).[2]
- Kane keratoconus formula.
- Barrett True K formula.
- Patients should understand that IOL exchange may be needed if the results are way off.

TREATMENT OF ASTIGMATISM IN KERATOCONUS

As mentioned, one should avoid toric IOLs in patients planning to continue RGP/scleral contact lens wear because this would require either anterior surface toric contact lenses or spectacles over the cornea-neutralizing contact lenses. There are some criteria to consider for toric IOLs in keratoconus:

- Age: Toric IOLs may be more appropriate in older patients than younger ones. Some surgeons suggest over 50 years of age.
- The meridian and magnitude of the astigmatism should be consistent and align with the refraction/spectacles.
- The topography should be relatively regular centrally, which is often best assessed by covering the peripheral image and assessing the center alone (Fig. 37.4).
- Higher keratometry values (i.e., well over 50D) have less predictability of the spherical equivalent and thus may benefit less from reducing the corneal astigmatism.
- Keratoconic corneas often have high coma, and this may affect astigmatic results.

IOL ASPHERICITY AND KERATOCONUS

Keratoconus eyes have hyperprolate corneas (negative spherical aberration), and as such, IOLs with negative spherical aberration may exacerbate higher order aberrations, and one may consider an aspheric IOL with neutral asphericity or possibly a spherical IOL.[3]

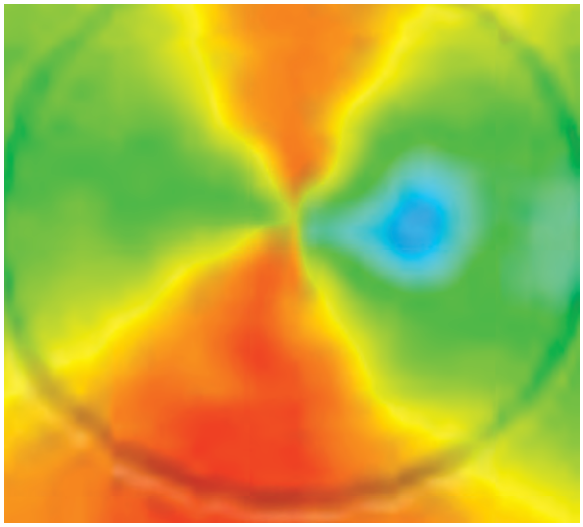

Fig. 37.4 Topographic (axial) image of a keratoconic cornea cropped to the central 3 mm showing relatively regular astigmatism. In the above patient, a toric intraocular lens (IOL) would be reasonable, assuming that the keratoconus is stable.

INTRAOPERATIVE CONSIDERATIONS IN KERATOCONUS

- These eyes may have deep anterior chambers, which can hinder access.
- The peripheral cornea is often of acceptable thickness; however, one should be prepared place a 10-0 nylon suture or sealant product. Alternatively, a scleral tunnel may be used.
- Apical scarring and/or distortions may impede the view, so a lower threshold for capsule dye seems appropriate.
- As these may be larger eyes, consideration may be given to placing a capsular tension ring (CTR) in conjunction with a toric IOL to avoid rotation.
- Finally, incisional techniques to reduce astigmatism (astigmatic keratotomies (AK) and limbal relaxing incisions (LRI)) should be avoided in patients with corneal ectasia, as they are unpredictable and may destabilize the cornea.

PINHOLE IMPLANT

Trindade et al. have reported impressive results using pinhole implants in keratoconus and, especially, using combined toric IOLs and pinhole implants[4] (Fig. 37.5). These implants can be highly effective in neutralizing even impressive amounts of irregular astigmatism and can mitigate spherical error by improving depth of field.

KERATOCONUS PEARLS

- Spherical power calculations are unreliable.
  - Newer, special IOL formulae (Barrett, Kane).
  - Hedging myopic aim (Watson et al., see Table 37.1).
- Toric IOLs may be appropriate in stable, milder KC with a regular central cornea.
- Consider neutral aspheric IOLs because of high negative spherical aberration.
- AK and LRI should be avoided in ectatic corneas.
- Pinhole implants may have a role.

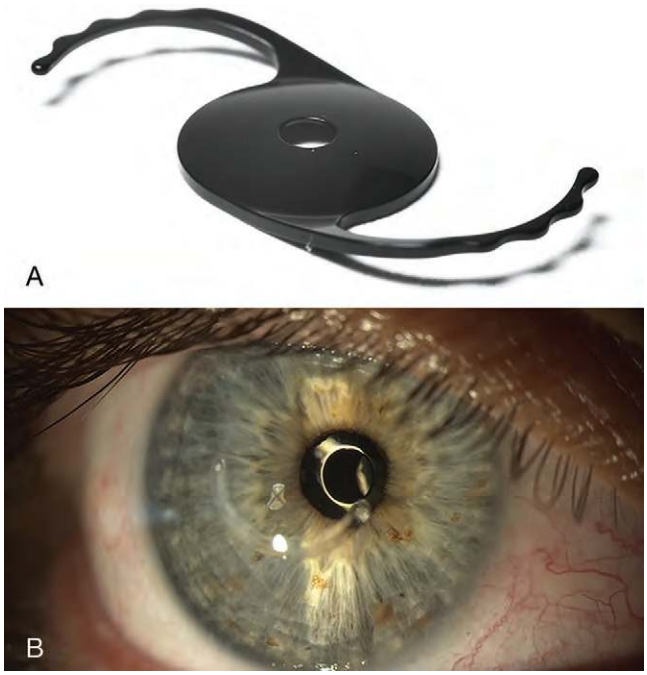

Fig. 37.5 (A) The convexo-concave black flexible pinhole implant can be placed in front of the primary IOL either in the capsular bag or in the sulcus. The concave back surface helps keep the implant centered over the convex anterior surface of the primary IOL. The black material is transparent to infrared imaging and OCTs. (B) A pinhole device *in situ* in a keratoconic eye (which also harbors a ring segment). (The images are courtesy Claudio Trindade, MD and used with permission.)

PENETRATING KERATOPLASTY (PK) AND DEEP ANTERIOR LAMELLAR KERATOPLASTY (DALK)

In penetrating keratoplasty (PK), the entire thickness of the cornea, from epithelium to endothelium, is replaced with donor tissue. In deep anterior lamellar keratoplasty (DALK), the epithelium and all, or nearly all, of the corneal stroma is replaced with donor tissue, leaving behind only endothelium, Descemet's membrane, and occasionally less than 50 um of stroma. The preoperative plan is very different in patients who have previously had a corneal transplant versus those who may have one combined with their cataract surgery.

In patients who have previously undergone PK, the preoperative testing and analysis is remarkably similar to patients with keratoconus. Additionally, one may also consider specular microscopy to assess endothelial cell count and mosaic for prognostication. If there is concern that the cataract surgery will likely precipitate corneal decompensation or there is already early decompensation, then combining the cataract surgery with repeat PK, Descemet's membrane endothelial keratoplasty (DMEK), or Descemet's stripping automated endothelial keratoplasty (DSAEK) under the existing PK graft may be considered. Which option is chosen depends on the precataract vision and astigmatism.

- If there was good precataract spectacle corrected vision, DMEK or DSAEK procedure is preferred.
- If the PK was not capable of good vision before cataract formation, repeat PK may be a better choice.
- Similarly, if the graft has very high or irregular astigmatism, a repeat PK may be prudent.

CATARACT SURGERY AFTER PK

Special considerations for patients whose PK grafts are well functioning and unlikely to decompensate after cataract surgery:

- The measured axial length and keratometry values are used to predict the IOL, and toric IOLs are reasonable given relatively regular astigmatism in the central cornea.
- Contact lens considerations are the same as above.
- All corneal sutures should be previously removed before measurements.
- Unlike in prior eras, toric IOLs are reasonable in post-PK regular astigmatism because regrafts are more likely to be DMEK (or DSAEK) underneath previously failed PKs.
- If there is concern for short or intermediate-term failure, the spherical power of the IOL can be adjusted as per DMEK/DSAEK (see below).
- The reason for the previous corneal transplant must be elucidated. Patients who had previous keratoconus may still "progress" in the periphery over time.
- Patients whose PK was for previous HSV keratitis should be placed on prophylactic antiviral medication (e.g., valacyclovir 500 mg po tid) beginning between 4 to 7 days preoperatively, continued at treatment dosage for 1 week postoperatively, and then reduced to prophylactic dosing (e.g., 500 mg po daily) while on steroids.
- Incisions should be constructed to avoid the graft-host junction.
- The endothelium should be protected with a dispersive ophthalmic viscoelastic device (OVD), with or without the "soft-shell" technique.
- Nuclear disassembly should be maximally gentle.
- The steroids should eventually be tapered to the preoperative baseline level, which in many patients may be once daily.
- Some patients who have had PK may have ocular surface disease or a neurotrophic cornea. In these patients, consider avoiding nonsteroidal antiinflammatory drugs (NSAIDs).

COMBINED CATARACT SURGERY AND PK

The decision to perform combined penetrating keratoplasty and cataract "triple procedure" surgery is usually made based on a patient either having a sufficiently irregular/opacified cornea that is not compatible with good vision in contact lenses (if able to tolerate), or a cornea where cataract surgery alone would not be possible because of the poor view.

PREOPERATIVE DIAGNOSTIC TESTING

Pupillary examination, ultrasound biomicroscopy (UBM), and B-scan ultrasonography are useful objective tests that can identify comorbid pathology for surgical decision making and setting realistic prognoses.

BIOMETRY

- Axial biometry
  - Optical biometry is preferable but may not be possible in some eyes.
  - A-scan ultrasound biometry is an acceptable alternative. Immersion A-scan is more reliable that contact A-scan, when an immersion capture is viable.
- Keratometry
  - Surgeons should audit their own PK cases to find their average keratometry values because this is a surgeon-specific feature.
  - Post-PK keratometry will vary based on the initial indication for PK and the size of the graft.

- Oversized donor graft in comparison to the host trephination leads to steeper Ks. Oversizing a graft helps with watertight closure, reduces excessive postoperative flattening, and may reduce postoperative glaucoma.
- The author has had success using keratometry values of 44D for patients undergoing combined surgery, using the patient's own axial length from the biometry.
- Others have used different values (e.g., 45D or higher).

ANESTHESIA

Any PK or DALK procedure should be performed with a retrobulbar, peribulbar, or sub-Tenon's block. Some surgeons elect to use a Honan balloon or intravenous mannitol to soften the eye.

SURGERY

Intraoperatively, the procedure is dictated by the view.

- Cataract surgery first: If the view is somewhat decent, possibly with the aid of a capsular stain and/or tangential light from a light pipe, one may be able to perform the cataract extraction first in a closed system, which is the preferred method if able to be completed safely.
- Lamellar keratectomy, then cataract surgery, then PK: If the view through the cornea is inadequate, one can partially trephinate the cornea and delaminate the stroma partial thickness similar to a DALK, which may improve the view. The stromal surface can be coated with OVD to improve visualization. Once the cataract surgery is completed in a closed system, the remaining corneal lamellae are removed, and the PK proceeds as usual.
- "Open sky" cataract extraction: After full-thickness corneal trephination and button removal, extracapsular cataract extraction is performed.
  - Greater risk for suprachoroidal hemorrhage.
  - Staining the capsule may reduce elasticity and improve visualization.
  - The capsule is carefully opened initially smaller than usual as the tendency is for the capsulorrhexis to run peripherally, with the goal of a slightly larger than normal capsular opening. To reduce the posterior pressure, a second instrument may be gently pressed on to the lens centrally. Moreover, pulling the rhexis flap centrally seems to balance the posterior pressure allowing the tear to follow a circular path (Fig. 37.6).
  - May need "can-opener" capsulotomy rescue.
  - At this time hydrodissection of the lens is performed and careful intentional prolapse of the nucleus allows for easy removal.
  - If hydrodissection is unable to prolapse the nucleus, OVD may be used in place of BSS.
  - If an edge of the nucleus can be seen, a lens loop may be used (Fig. 37.7).
  - Rarely, a cryoprobe can be employed, though this risks zonulocapsular damage.
  - Irrigation/aspiration may be performed with the usual automated phacoemulsification machine, although some prefer to use manual aspiration with a Simcoe handpiece or similar (Fig. 37.8).
  - Placement of the IOL into the capsular bag is performed and is often a three-piece IOL in this situation. If the bag has been compromised, usually sulcus placement is possible.
  - Once implanted, the corneal transplant is completed by suturing of the donor to the host.

Patients who have previously had DALK who are undergoing cataract extraction are treated as patients who have had previous PK, and their measured axial length and keratometry values are used for IOL prediction. Combined DALK, cataract extraction, and IOL implantation may also be performed in eyes with stromal disease and well-functioning endothelium. Most surgeons do not oversize their DALK donor graft in comparison to the host trephination, and this may lead to a flatter cornea, and, similar to combined PK, it is best if the surgeon audits their cases to elucidate their average post-DALK keratometry values.

CATARACT WITH PENETRATING KERATOPLASTY PEARLS

- Use the measured axial length.
- If previous PK/DALK, use the measured Ks.
- Toric IOLs may be appropriate if stable, unlikely to require repeat PK, and a regular central cornea.
- If planning a combined procedure, use Ks of 44–45D or audit previous results.
- Three-piece IOLs are commonly used in combined cases.
- Prolonged open-sky time increases the risk for suprachoroidal hemorrhage.

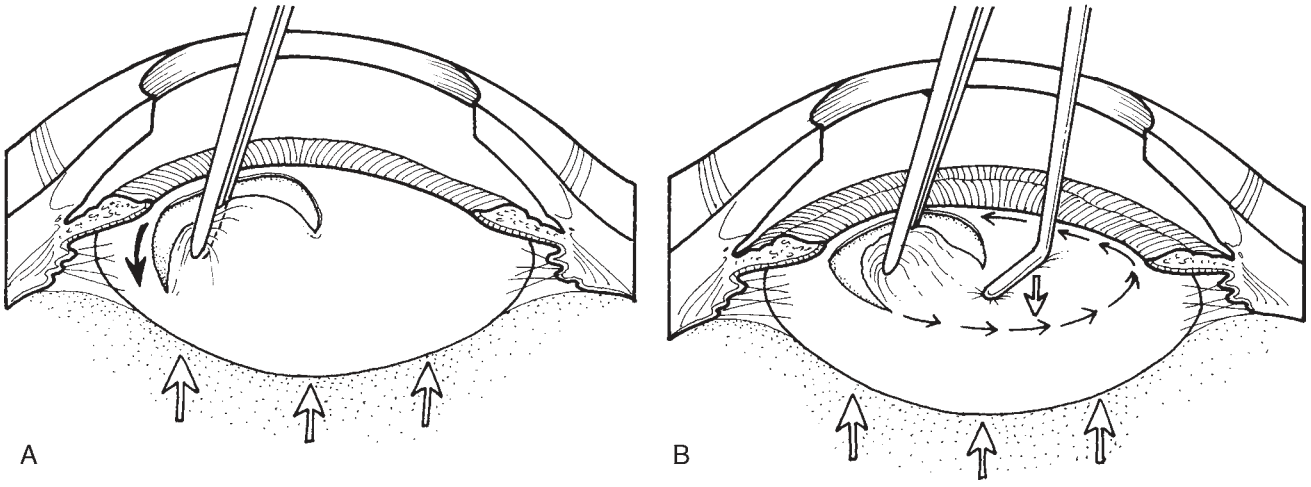

Fig. 37.6 (A) In the setting of penetrating keratoplasty, vitreous pressure is particularly likely to cause a circular tear capsulotomy to extend toward the equator and potentially around to the posterior capsule. (B) In addition to preoperative maneuvers to soften the globe and to dehydrate the vitreous fluid, positive pressure intraoperatively can be counteracted by applying downward pressure on the nucleus itself while completing the circular tear anterior capsulotomy.

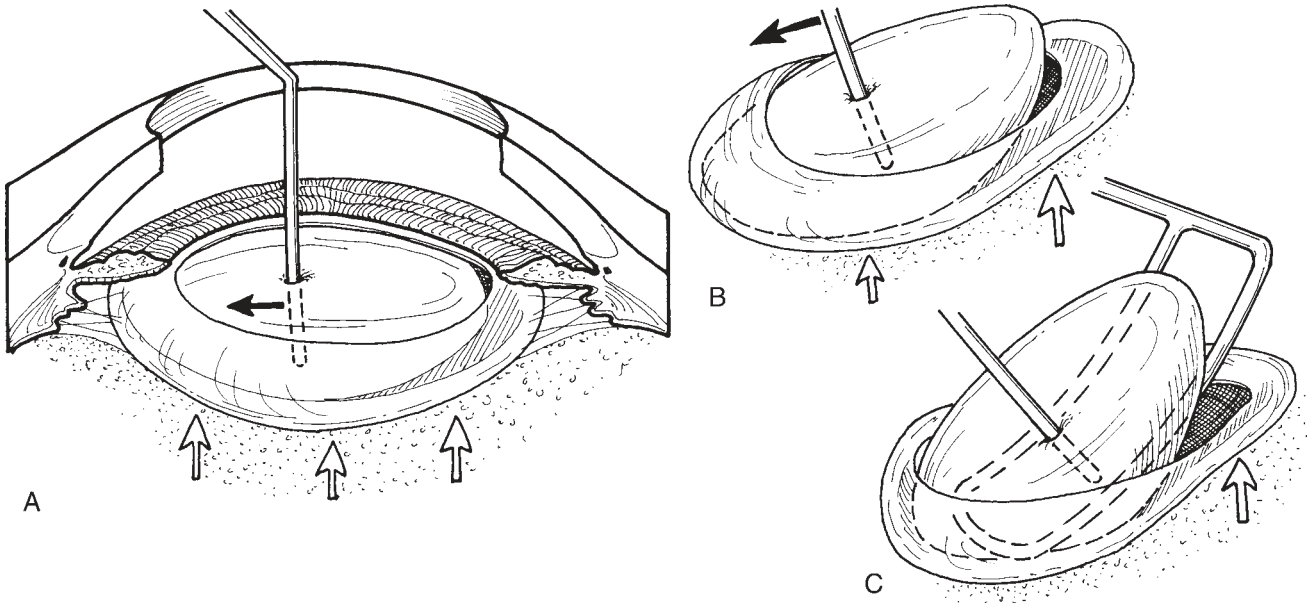

Fig. 37.7 (A) The first step in delivering the nucleus is to rock the nucleus with an instrument such as a cyclodialysis spatula until one pole of the equator presents. Positive vitreous pressure usually facilitates this step; if the eye is particularly soft, gentle pressure on the sclera to create positive vitreous pressure can be helpful. (B) Nucleus is tilted once the equatorial pole becomes exposed. (C) A microsurgical lens loop can then be safely passed behind the nucleus and the nucleus delivered in its entirety.

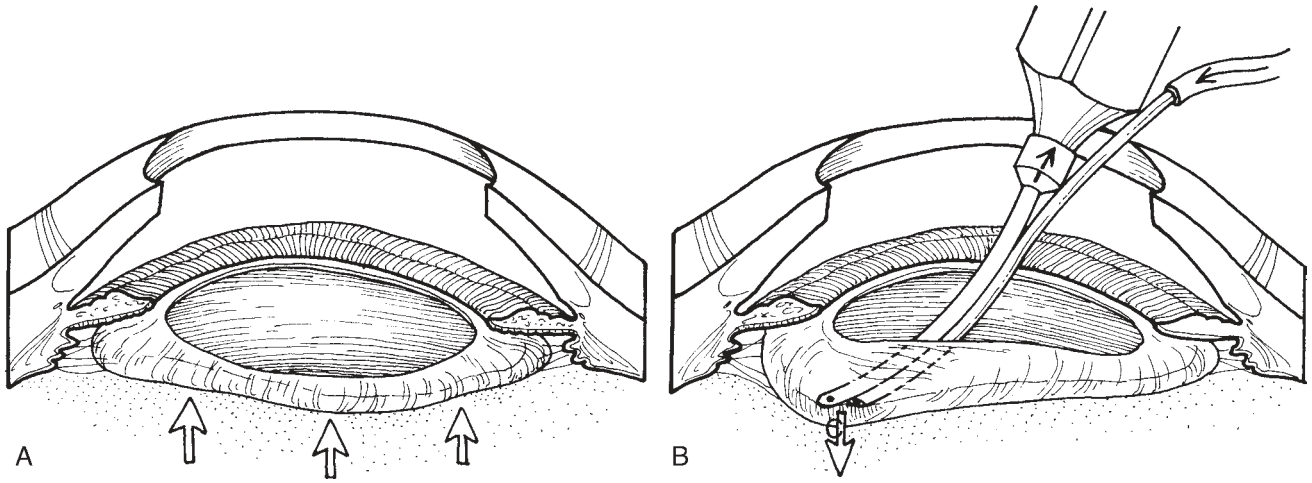

Fig. 37.8 (A) After nucleus delivery, the vitreous pressure flattens the capsular bag with apposition of the anterior and posterior capsules. (B) Cortical clean-up can be performed with a variety of instruments. One device that is particularly well suited to the open-sky situation is the relatively flat and thin "reverse Simcoe" irrigation-aspiration needle. The tip can be gently slid between the anterior and posterior capsules, and then slight downward pressure separates the anterior and posterior capsules, allowing the equatorial cortex to be engaged and stripped safely.

CORNEAL ENDOTHELIAL DISEASE

Fuchs' Endothelial Corneal Dystrophy (FECD)

Historically, for patients with Fuchs' endothelial corneal dystrophy (FECD) undergoing cataract extraction, it was suggested that corneal transplantation be performed when the endothelial cell count was less than 1000 cells/mm^2, the central corneal thickness was greater than 640 um, or there was preexisting edema.[5] Because of better surgical techniques for both cataract and corneal surgery, this older study no longer holds true. Thus many surgeons now base the decision to perform combined DMEK, DSAEK, or DSO (Descemet stripping only) with cataract extraction, and IOL implantation versus cataract surgery alone, on patient symptomatology specifically, the presence or absence of morning blur.

CATARACT SURGERY ALONE

- For patients with endothelial disease where it is thought that they should be able to tolerate intraocular surgery without decompensation, cataract surgery alone should be planned.

- If the risk for corneal decompensation remains low, then biometry and IOL selection proceed as usual.
- Some may aim slightly myopic "hedging their bets" in case endothelial keratoplasty is required, which causes a hyperopic shift postoperatively.
- Avoid hydrophilic acrylic IOLs, which are known to opacify with intraocular air/gas injection.[6]
- Intraoperatively, good protection of the corneal endothelium is imperative, and dispersive OVD, possibly with the soft-shell technique likely provides maximum protection.
- A chopping technique of the nucleus is preferred to minimize phaco energy in the eye.
- Working slightly posteriorly may also reduce the insult to the endothelium.
- Repeated instillation of dispersive OVD for a longer case is advisable.
- Postoperatively, if increased edema is present, increased steroids may be employed and continued for a longer duration. Hypertonic saline drops four times daily and ointment at night may also be added.
- Classically, one may wait 3 months to state that a cornea has not recovered from surgery; however, if there was a high likelihood of decompensation preoperatively with edema postoperatively, transplant at 1 month is reasonable.
- As usual, for any patient with postoperative corneal edema, a careful examination for a Descemet's membrane detachment (more common in patients with FECD), retained lens fragments, viral keratitis, IOL/haptic position, NSAID/medication toxicity, or other causes should be performed.

CATARACT SURGERY WITH TRANSPLANT FOR FUCHS' DYSTROPHY

Posterior lamellar (endothelial) keratoplasty has evolved through numerous iterations. The penultimate surgical procedure was DSAEK, which has been predominantly supplanted by DMEK; however, DSAEK remains the most commonly performed endothelial keratoplasty procedure in many regions. The amount of stroma in DSAEK discs has been successively reduced, and the terms "ultrathin" and "nano-thin" have been applied to thinner and thinner grafts, each with its own thickness cut-off. In DMEK, the patient's endothelium and subjacent Descemet's membrane are harvested without stroma, forming a scroll. Both DSAEK and DMEK may be combined or staged with cataract.

DSAEK, Cataract Extraction, and IOL Implantation

This is the classic "DSAEK triple." When planning for combined surgery, it is important to evaluate the cornea for bullae and assess the quality of the biometry/topography.

- Bullae may give artifactual keratometry values that may lead to poor refractive outcomes.
  - If bullae are present, it may be reasonable to use keratometry from the fellow eye, if it is historically similar.
  - If the fellow eye has irregular astigmatism as well, old prior keratometry, perhaps from contact lens fittings in the past, may be solicited.
  - In the absence of good data, the patient should be counseled about the higher variability of refractive outcome.
- A hyperopic shift commonly occurs after DSAEK, so a more myopic aim than desired is selected. A variable amount of hyperopia usually ranging from 0.75 to 1.5D is induced with DSAEK; thus one should review their own results if performing the EK themselves or know the approximate outcomes of the comanaging corneal surgeon.[7]
- Avoid hydrophilic acrylic IOLs in cases where EK will be performed or staged, as there is evidence that gas/air (which is required to attach the graft) may cause IOL opacification.
- Technically, cataract surgery combined with DSAEK proceeds almost identically to cataract surgery alone, except that after the IOL is implanted, the DSAEK is performed as a same-sitting, sequential procedure.
  - If there is poor visualization caused by epithelial edema, it may be debrided and/or capsular stains may be used.
  - Use only cohesive viscoelastic, as dispersive OVD may become trapped in the interface and lead to either detachment or haze.
- Some perform cataract surgery with DSAEK in a staged manner, with DSAEK performed 1 month after the cataract surgery to allow the inflammation to subside.
- Primary DSAEK may be considered instead of DMEK with cataract surgery in patients with short eyes. These eyes are at increased risk for intraoperative malignant glaucoma with shallowing of the anterior chamber, and, in DMEK (covered below), the anterior chamber is intentionally shallowed to unscroll the graft.

Cataract Extraction After DSAEK

When performing cataract surgery in an eye that has previously undergone DSAEK, the surgeon should:

- Be careful with wound creation to avoid contacting the graft edge on the internal entry.
- Protect the graft endothelium (as with any patient's endothelium).
- Minimize phacoemulsification energy, ideally with a chopping technique.
- Use steroids at higher dosage early on and remember not to reduce below the preoperative baseline levels long term.

DMEK, Cataract Extraction, and IOL Implantation

Like DSAEK, DMEK may be combined with cataract surgery or staged, either before, or after the cataract surgery (the "DMEK triple"). There are specific reasons unique to DMEK why one may choose one approach over the other.

- Chamber shallowing considerations: During the surgery the anterior chamber is intentionally shallowed in an attempt to unfold the DMEK scroll. This shallowing may cause the IOL optic to prolapse through a large or even normal-sized capsulorrhexis if the IOL has not yet fibrosed into place. As such, when performing combined DMEK/cataract extraction, the capsulorrhexis is made smaller (no larger than 4.5 mm).
- Pupil dilation considerations:
  - DMEK grafts are "tapped" to unscroll, and one uses the backboard of the iris to do so.
  - A mydriatic pupil allows a large area of the IOL optic to be exposed, and repeated touch of the graft endothelial cells to the optic can permanently damage these cells.
  - The pupil must be constricted before graft insertion. It can be difficult to pharmacologically constrict a pupil that was maximally dilated; thus most surgeons when performing combined DMEK/cataract surgery only minimally dilate the pupil, perhaps with adrenergic agonists and/or preservative free xylocaine, but without cycloplegics. This may lead to a more challenging cataract surgery.
  - Some use only one agent to dilate, while others who perform blocks for DMEK may use this alone as dilation; still others use intracameral agents.
- Preoperatively, the cornea and biometry/topography are inspected for bullae and artifacts, as noted for the "DSAEK triple."

- DMEK causes a smaller hyperopic shift than does DSAEK, on average 0.5 to 1D.[8]
- DMEK Triple and Toric IOLs: Once the edematous cornea has deturgesced, the astigmatism may decrease, increase, or change meridian in an unpredictable manner. The author uses the following guidelines:
  - In the absence of significant bullae, higher corneal astigmatism (e.g., >2d) is likely to be truly inherent in the cornea, and although it may reduce or change, correcting it or a portion of it is likely to result in an improvement in the patient's vision.
  - Records before corneal edema (or, to a lesser extent, spectacle history) can be used to aid in decision making.
  - Tapping during DMEK has the potential to rotate the IOL in combined surgeries, and one must employ care.
- Hydrophilic acrylic IOLs should again be avoided with DMEK because they may opacify with intraocular air/gas bubble.
- If the view is poor because of epithelial edema:
  - A superficial keratectomy (epithelial debridement) may be performed.
  - Capsular stains may be used.
- Consider staging the cataract and DMEK procedures in cases of complex cataract surgery because a small pupil and small capsulorrhexis may further increase the challenge of the case. Most would schedule the DMEK approximately 1 month later to allow for the inflammation to resolve, while not leaving a patient with corneal edema for a prolonged period of time.
- Staging with DMEK first, then allowing the cornea to heal and then later performing the cataract surgery:
  - Likely has improved refractive outcomes.
    - Once the corneal edema has cleared repeated, biometry is performed.
    - Many still find a slight myopic fudge remains necessary to target plano.
  - DMEK first increases the risks to the graft.

DMEK/DSAEK PEARLS

- In patients without morning blur, cataract surgery alone can often be safely performed.
- For cases that will require EK either staged or combined, be sure bullae do not interfere with K values.
- For DSAEK, aim –0.75 to –1.5D.
- For DMEK, aim –0.5 to –1D.
- Toric IOLs may be appropriate in higher astigmatism.
- Avoid hydrophilic acrylic IOLs.
- Avoid dispersive OVD in combined cases and irrigate thoroughly before graft insertion.
- In combined DMEK/cataract extraction, patients are not maximally dilated preoperatively and a smaller capsulorrhexis is performed.

DESCEMET'S STRIPPING ONLY (DSO) COMBINED WITH CATARACT SURGERY

The most recent advance in the treatment of FECD is Descemet's stripping only (DSO), where the central 4 mm of Descemet's membrane and endothelial cells are removed, allowing the peripheral endothelium to migrate centrally. This procedure is generally only used for FECD where, presumably, central guttae inhibit endothelial cell migration.

- There must not be significant edema.
- A good peripheral endothelial cell count is present.
- Probably heals faster and more often when augmented with topical rho-kinase inhibitors.
- May defer or delay corneal transplantation.
- Reduces the need (and risks) of long-term topical steroids.
- Has estimated 0.5D of hyperopic shift (aim for –0.5D).
- Avoid hydrophilic acrylic IOLs in these patients because they may require a DMEK rescue, perhaps, over time.
- DSO is in its infancy, and knowledge surrounding it is evolving.

Decompensated Fuchs' Dystrophy with a Clear Crystalline Lens

When endothelial decompensation is present with a relatively clear crystalline lens, the EK surgery itself, and the postoperative steroids, may lead to cataract formation. A general "rule of thumb" is to consider removing a clear lens in a patient fifty years of age or greater.

PRESBYOPIA-CORRECTING IOLs

There are some additional general rules that hold true in many of the above situations. In general, an aspheric IOL is a reasonable choice given that most corneas will have positive spherical aberration. In those who do not, a neutral aspheric IOL remains an option. The field of presbyopia-correcting IOLs is expanding rapidly. Multifocal and trifocal IOLs are generally reserved for those with pristine optical systems aside from cataract. In those with ocular surface issues (e.g., EBMD or pterygium) that have been surgically corrected, if the pathology returns over time, the optical system will degrade once more. These scenarios should be evaluated on a case-by-case basis with an informed discussion. In patients with endothelial disease, many undergoing DMEK will ultimately achieve a best-correct visual acuity of 20/20 postoperatively, an amazing feat, given that it was not too long ago that PK was the standard of care. Regardless, one issue is that multifocal IOLs require a near plano result, and it can be difficult to predict the IOL power in these cases. Extended depth of focus (EDoF) IOLs may provide a slightly more forgiving target than a multifocal IOL. Moreover, newer extended range of vision (ERoV) nondiffractive IOLs have been recently released at the time of writing. There are currently no large studies investigating these IOLs in patients with corneal surgery, and, as such, firm recommendations cannot be presented. As a general rule, if the patient has a condition that is likely to reduce quality of vision, whether through inability to correct to 20/20, higher order aberrations, reduced contrast sensitivity, scarring, abnormal curvature, or from other etiologies, one should consider avoiding IOLs that may also reduce the quality of vision significantly. With that said, there are certainly many situations where the above patients may in fact benefit from these technologies, and presence of these pathologies/surgeries does not firmly contraindicate presbyopia correcting IOLs.

SUMMARY

There are a plethora of corneal conditions/surgeries that influence cataract surgery, and although the specifics are varied, certain fundamental rules hold true:

- Assess preoperative keratometry/biometry for artifact.
- If the cornea has an issue that will affect testing, surgical management prior and delayed biometry/cataract surgery should be considered.
- The patient's measured keratometry values are used unless the cornea is expected to change or is significantly abnormal (e.g., combined PK or advanced KC).
- Toric IOLs are reasonable in many circumstances.

- Target postoperative myopia in keratoconus and with endothelial keratoplasty.
- Avoid hydrophilic acrylic IOLs with air/gas injection.
- Visualization may be an issue in combined procedures, and superficial keratectomy and/or capsular stains may be employed.
- Modifications to surgical technique allows for excellent results when cataract surgery is combined with PK, DALK, DSAEK, DMEK, or DSO.

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Cataract Surgery in Uveitic Patients

Sanjay R. Kedhar and Olivia L. Lee

CONTENTS

KEY POINTS

- Visual outcomes of cataract surgery in uveitic eyes are not as good as those for age-related cataracts and carry a greater risk for intra- and postoperative complications. However, the majority of patients will have improvement in their vision with proper perioperative medical management and careful surgical planning.
- A complete preoperative evaluation of the patient with uveitis includes a workup to ascertain the presence of underlying systemic disease or infection and any additional ocular pathology that may affect visual function such as glaucoma, macular edema, and epiretinal membranes (ERMs).
- Inflammation should be controlled for at least 3 months before cataract surgery.
- Cystoid macular edema (CME) is a primary driver of poor visual acuity in these patients. Macular edema should be maximally treated, and ideally eliminated, for at least 3 months before surgery. Eyes should be monitored carefully in the postoperative period and any macular edema treated aggressively.
- Pre- and postoperative steroid treatment is essential to reducing inflammation and achieving good visual outcomes. Patients with uveitis will need closer monitoring and require greater amounts of steroid for longer duration than routine cataract patients. A good rule of thumb is to double the typical dose of corticosteroids and taper over a duration twice as long as usual.

INTRODUCTION

Cataracts, a common complication in patients with uveitis, are a result of both chronic intraocular inflammation and treatment with corticosteroids; they account for a significant proportion of vision loss in this group (up to 40%).[1] The prevalence of cataract depends on multiple factors:

- Anatomic location of inflammation
- Duration of inflammation
- Severity of inflammation
- Preceding clinical course including prior response to therapy
- Use of corticosteroids

Only a small portion of the cataract extractions performed in an average practice will be on eyes with uveitis. However, nearly every ophthalmologist faces such cases periodically. These cases are more surgically demanding and the results often less predictable, owing to increased inflammation, structural abnormalities complicating surgery, and ocular comorbidities affecting visual outcomes. Indeed, cataract surgery in uveitic eyes is associated with the following:

- Worse vision postoperatively,
- Higher rates of elevated intraocular pressure (IOP), and
- More than twice the prevalence of CME.

Care and treatment for the patient with uveitic cataracts may require substantial additional human and pharmacologic resources during each phase of treatment.

Most patients with uveitis undergoing cataract surgery will have improvement in their vision, with several studies noting best corrected visual acuity of 20/40 or better in approximately 60% to 70% of patients.[2–4]

- This number still compares poorly to nonuveitic eyes.
- Patients achieving 20/40 or better have remained relatively constant over the years despite significant improvements in surgical technique and medical management of uveitis, suggesting that the underlying disease still poses a significant risk to vision.[4]

Unlike in age-related cataracts, preoperative visual acuity is a main factor in determining postoperative visual outcomes[2] because poor preoperative visual acuity likely represents a combination of advanced cataract and other comorbidities that affect vision. This not only affects discussion of surgical risk and informed consent, but it also may influence timing of surgery because waiting for the vision to deteriorate before surgical intervention may not be the best option in all cases.

CAUSES

Opacification of the lens is caused by both the underlying inflammatory disorder and corticosteroid treatment. Recurrent or sustained episodes of inflammation may contribute to the development of cataract through a number of factors including the release of oxygen free radicals and lysosomal enzymes, hypoxia, and deposition of immune complexes on the lens capsule.

COMORBIDITIES

Eyes with uveitis may suffer from comorbidities affecting any structure in the eye:

- Glaucoma
- Retinal pathology
  - Epiretinal membrane
  - Choroidal neovascular membrane
  - CME
  - Chorioretinal scar
  - Ischemia
- Optic neuropathy
- Band keratopathy
- Corneal neovascularization
- Corneal scarring
- Corneal thinning

PREOPERATIVE EVALUATION AND MANAGEMENT

Patients with uveitis are at greater risk for intraoperative and postoperative complications than nonuveitic patients; meticulous preoperative medical management, appropriate timing of the procedure, and careful preoperative surgical planning are essential to achieving good outcomes. Among factors affecting visual outcomes, **control of inflammation is probably the most important**.

All patients with uveitis should have attained and sustained quiescence of their ocular inflammation before surgery. Active uveitis at the time of surgery is associated with worse visual outcomes. Uveitis specialists recommend delay of ocular surgery to allow for a 3-month period of quiescence.[5,6] This recommendation, although widely agreed upon, is based upon expert opinion and not prospective study. Nevertheless, eyes with quiescence of less than 30 days are at higher risk for uveitis recurrence. A duration of quiescence longer than 3 months could be considered in patients with history of severe, refractory ocular inflammation such as in the setting of Behcet disease and juvenile idiopathic arthritis (JIA). Quiescence may be achieved by any means, whether spontaneous or with use of medication (topical, local injection, or systemic.)

Exceptions to this 3-month rule may be considered for the following:

- Uveitic conditions with good postsurgical prognosis such as Fuchs' heterochromic iridocyclitis
- Situations in which removal of the lens is the treatment in and of itself (i.e., lens-induced uveitis)
- When cataract prevents adequate visualization of the posterior segment necessary to monitor the disease (i.e., posterior uveitis, intermediate uveitis)
- When cataract prevents adequate visualization of the posterior segment necessary to treat an urgent or emergent condition (i.e., retinal detachment)
- Pediatric cases with the added complication of potential for amblyopia if clearing of lens opacity is not addressed in a timely fashion

CME should be maximally treated (and ideally resolved) in the 3 months before surgery. Patients with CME within 3 months before surgery have a 6-fold increased risk for postoperative CME.[5]

A significant proportion of patients with uveitis may have an associated **systemic disease or infection** underlying the inflammation. For patients without a known diagnosis, a workup before surgery is essential. In some cases the clinical examination alone will be sufficient for diagnosis (i.e., Fuchs' heterochromic iridocyclitis.) However, other patients will require additional laboratory investigations. Testing should be based on the physical examination, patient's history, and review of systems rather than a "shotgun" approach to testing. Commonly performed tests useful in diagnosis include but are not limited to the following:

- Fluorescent treponemal antibody testing
- Rapid plasma reagin
- Chest radiograph with special attention to the hilum (evaluating for signs of sarcoidosis)
- HLA-B27 antigen testing
- Quantiferon gold or purified protein derivative skin test

Referral to a uveitis specialist or rheumatologist is appropriate if the surgeon is uncomfortable with the workup. A complete workup is important for several reasons: undetected infection will require antibiotic therapy, and an underlying systemic disease may direct choice of antiinflammatory therapy or offer insight into disease prognosis and postoperative course.

Evaluation for additional pathology causing visual dysfunction is critical to surgical decision making and appropriately counseling the patient before surgery. Nonlenticular comorbidities such as corneal opacity, vitreous haze, macular edema, or optic nerve atrophy are associated with poorer visual outcomes. Testing should be based on history, examination, and disease course and may include:

- Macular function tests: potential acuity meter, laser interferometry, focal electroretinogram.
- Optical coherence tomography (OCT) evaluation of nerve fiber layer and visual field testing for glaucomatous optic neuropathy.
- OCT evaluation of macula examining for epiretinal membrane, CME, macular thickening, and damage to photoreceptors.
  - Comparison of macular thickness maps between both eyes may help detect subtle macular edema.
- Fluorescein angiography (FA)/indocyanine green angiography can detect inflammation or other pathology not noted on fundus examination. Angiography can be especially useful in cases of intermediate, posterior, and panuveitis; retinal vasculitis; or ischemia. FA can be complementary to OCT in the detection of macular edema in patients with uveitis.[7] In patients for whom the vision is not readily explained by cataract grade, retinal OCT findings, or other pathology, an FA is appropriate to investigate for macular leakage that may be contributing to reduced vision.
- Fundus autofluorescence may reveal retinal pigment epithelium pathology not readily apparent on fundus examination and can be useful for detecting inflammatory activity in posterior uveitides such as serpiginous choroidopathy.
- Specular microscopy: Assessment of corneal endothelium is important in cases of chronic anterior chamber inflammation, glaucoma, or patients with prior ocular surgical history. Eyes with uveitis have lower central endothelial cell density, lower percentage hexagonality

than normal eyes, and increased central corneal thickness, and corneal edema may not be apparent on examination.[3]

- B-scan ultrasound, ultrasound biomicroscopy (UBM): B-scan ultrasound should be performed on all patients with inadequate view to the fundus. UBM can be valuable for evaluating the ciliary body in cases with hypotony and for evaluating the lens in cases of seclusio pupillae. Some indications for UBM include uveitis -glaucoma-hyphema syndrome, pars planitis, and hypotony.

COUNSELING

Because patients with uveitis are more prone to complications from cataract surgery and may not achieve the same visual outcomes as nonuveitics patients, extensive preoperative counseling is essential. Patients should understand that cataract surgery can be performed successfully in most eyes, but expectations should be tempered. In the Multicenter Uveitis Steroid Treatment trial, 62% of patients who underwent cataract surgery achieved vision of 20/40 or better.[8]

- Discuss visual potential in the context of vision-limiting pathology. Patients should understand that visual recovery may take longer and be more limited than in nonuveitic patients.
- Because of the nontrivial risk for intraocular surgery inducing inflammation and exacerbating preoperative vision, consider deferral of surgery if the patient is not symptomatic and the cataract is not impeding visualization of the fundus. Furthermore, if there is no possibility of visual improvement, the risk for surgery would outweigh potential benefit.
- Alert patients to the increased risk for complications, both intraoperatively and immediately postoperatively. Consider the possible need for additional surgical steps such as the following:
  - Capsular tension ring use
  - Scleral fixation of intraocular lens (IOL)
  - Vitrectomy
- Patients should be aware of the need for close postoperative followup to monitor for recurrence of uveitis; the plan for postoperative monitoring and management between the surgeon and uveitis specialist (if they are not the same physician) should be made clear.
- Patients with posterior synechiae may have an abnormal pupil postoperatively with resultant glare and blurred vision.
- Review risk for delayed postoperative complications such as late in-the-bag IOL lens dislocation.
- Emphasize the need for additional medications perioperatively and possible long-term changes to medication regimens to control inflammation after surgery.
- Inform patients of the risk for worsening uveitis after surgery, perhaps long term.
- Emphasize the possible need for subsequent procedures:
  - Higher rate of Nd:YAG capsulotomy
  - Possible glaucoma surgery
  - Possible removal of IOL in a minority of patients
- Although premium IOLs may be a poor choice for many of these patients, a brief explanation of the reasoning for a particular IOL recommendation is helpful. Use of multifocal/EDOF IOLs is generally discouraged because of the following:
  - Presence or possibility for macular pathology/glaucoma over the course of the disease
  - Greater risk for decentration, phimosis of capsule, and posterior capsular opacity
- Femtosecond laser-assisted cataract surgery (FLACS) has not been studied in patients with uveitis but may offer both advantages and disadvantages in this population.
  - FLACS may be helpful in cases where the lens is particularly dense to aid in minimizing damage to corneal endothelial cells.[9]
  - Femtosecond laser has also been found to have higher levels of prostaglandin release in aqueous humor with capsulotomy, particularly with higher amounts of laser energy used, possibly resulting in worsening of inflammation and CME. These effects may be mitigated using topical nonsteroidal antiinflammatory drugs (NSAIDs) pre- and postoperatively.
  - Small pupils and posterior synechiae may also limit the use of femtosecond laser capsulotomy. It may be necessary to mechanically dilate the pupil first with an iris expansion device and suture wounds closed before laser treatment.

DECISION TO PLACE AN INTRAOCULAR LENS (OR NOT)

An IOL can be placed safely in most patients with uveitis with good preoperative control of inflammation. More eyes undergoing cataract surgery with IOL placement achieve best corrected visual acuity of more than 20/40 than those left aphakic (71% vs. 52%).[2]

- IOL implantation can initiate a foreign body reaction and trigger the complement and coagulation cascade, resulting in the following:
  - Increased cellular adhesion to the lens
  - Anterior capsule phimosis
  - Posterior capsular opacity
- In patients with poorly controlled uveitis, IOL implantation should be avoided.
- Placement of an IOL in children with JIA is controversial, and it may be prudent to leave the patient aphakic if inflammation is poorly controlled or if there is extensive structural damage from inflammation.
- Additional relative contraindications to IOL implantation include the following:
  - Hypotony
  - Extensive membranes
  - History of rubeosis irides
- IOL type:
  - There is no definitive evidence for choice of one IOL material over another, however:
    - Hydrophilic or hydrophobic posterior chamber lens implantation in the capsular bag is preferred.[10]
    - Both types of acrylic lenses reduce attachment and adhesion of inflammatory cells and fibroblasts to the IOL surface.
    - Avoid silicone IOLs if there is a possibility for future vitreoretinal surgery requiring silicone oil.
  - Avoid anterior chamber IOLs:
    - Increased risks of endothelial failure
    - Chronic inflammation
    - Pupil ovalization
    - Reactive angle vessels
    - CME
  - Ultimately, control of inflammation is likely more important than choice of IOL material in achieving successful outcomes.

PERIOPERATIVE MEDICATIONS

Most patients with noninfectious uveitis should be treated with perioperative steroids to aid in controlling postoperative inflammation. Although data supporting any one particular regimen is limited, several approaches may be used taking into account the severity and type of inflammation. In patients with more chronic uveitis or those in whom there is likely to be extensive tissue manipulation, the regimens

below are indicated. Ideally, steroids will be given before surgery with sufficient time for corticosteroid-induced gene expression to be active before surgically induced inflammation occurs.

Corticosteroids

The following routes and dosages of corticosteroid are suggested below. The appropriate combination, route, and dosage necessary will vary from case to case. Consideration should be given to the primary site of inflammation, prior response to corticosteroid, and presence of systemic comorbidities.

- Oral steroids
  - Prednisone 1 mg/kg/day (max 60 mg/day) beginning 2 to 3 days before surgery and tapering over 7 to 14 days (Table 38.1)
    - Perioperative oral steroids have been shown to reduce the risk for postoperative CME by 80%[5]
    - Watch for adverse effects and systemic complications:
      - Elevated blood sugar
      - Elevated blood pressure
    - With long-term prednisone use:
      - Medications should be administered to reduce risk for osteoporosis (i.e., bisphosphonates)
      - Gradual taper of systemic steroid
- Intravitreal therapy.
  - 0.7 mg dexamethasone (Ozurdex, Allergan, Irvine, CA, USA)
  - 4 mg triamcinolone acetonide (Triesence, Alcon, Fort Worth, TX, USA)
  - 0.59 mg fluocinolone acetonide implant (Retisert, Bausch & Lomb, Bridgewater, NJ, USA)
  - 0.18 mg fluocinolone acetonide implant (Yutiq, EyePoint Pharmaceuticals, Watertown, MA, USA)
  - Injected several weeks before or at the time of surgery
  - IOP effects: risk for ocular hypertension is as follows:
    - Lowest with the dexamethasone implant (15%)
    - Triamcinolone (31%)
    - Retisert (66%)
- Periocular injection of triamcinolone acetonide:
  - 40 mg administered by posterior superior sub-Tenon's block or inferior orbital floor route 2 to 4 weeks before surgery
- Intensive topical steroids before surgery:
  - Prednisolone acetate 1% every 1 to 2 hours while awake or
  - Difluprednate 0.05% 4 times daily
  - Beginning 2 to 7 days before surgery

Intensive corticosteroid treatment before surgery is not universally indicated for all patients with uveitis. For example, cases not requiring perioperative steroids would include the following:

- Distant history of anterior uveitis without recent recurrence
- Resolved traumatic iritis
- Infectious uveitis that has resolved with antiinfective treatment

ANTIMICROBIAL PROPHYLAXIS

Patients with herpes simplex uveitis should be given prophylactic therapy to reduce risk for recurrence in the postoperative period. Prophylactic treatment of patients with ocular toxoplasmosis is more controversial, and the real risk for recurrence after surgery is less clear.

- Herpes simplex prophylaxis beginning 2 days before surgery and should be continued for 2 to 3 weeks postoperatively at full dosing before reducing to maintenance suppressive dosing for several weeks to months after surgery:
  - Valacyclovir 1 g orally twice daily, then 500 mg or 1000 mg/day
  - Acyclovir 400 mg 5 times daily, then 400 mg twice daily

TABLE 38.1 Medical Therapy for Perioperative Use in Patients With Uveitic Eyes Undergoing Cataract Surgery

Preoperative Antiinflammatory Agents	Route	Common Dosage
Difluprednate 0.5%	Topical	QID beginning 2–7 days preop
Prednisolone acetate 1%	Topical	Q 1–2 hrs beginning 2–7 days preop
Prednisone	Oral	Prednisone 1 mg/kg/day. (max 60 mg/day) beginning 2–3 days before surgery and tapering over 7–14 days
Triamcinolone	Sub-Tenon's injection	40 mg
Triamcinolone	Intravitreal	4 mg
Retisert (fluocinolone acetonide)	Intravitreal implant	0.59 mg
Yutiq (fluocinolone acetonide)	Intravitreal implant	0.18 mg
Ozurdex (dexamethasone)	Intravitreal pellet	0.7 mg
Nepafenac 0.1%	Topical	TID
Bromfenac 0.07% or 0.09%	Topical	1–2 times daily
Ketorolac 0.5%	Topical	QID
Intraoperative Antiinflammatory Agents		
Dexamethasone	Infusional	40 mg in 500-mL BSS bottle
Dexamethasone	Intracameral	400 µg in 0.1 mL at end of case
Triamcinolone	Intracameral	1–2 mg
Triamcinolone	Sub-Tenon's injection	40 mg
Solumedrol	Intravenous	62.5 or 125 mg
Postoperative Antiinflammatory Agents		
Difluprednate 0.5%	Topical	QID
Prednisolone acetate 1%	Topical	q1–2 hrs
Nepafenac 0.1%	Topical	TID
Bromfenac 0.07% or 0.09%	Topical	1–2 times daily
Ketorolac 0.5%	Topical	QID
Prednisone	Oral	1 mg/kg/day (max 60 mg/day) beginning 2–3 days before surgery, and POD1 & POD2, then taper by 10 mg q2 days (standard taper) until at preop baseline or off

BSS, Balanced salt solution; *max*, maximum; *POD1*, XXX; *POD2*, XXX; *preop*, preoperative; *q1–2 hrs*, every 1-2 hours; *q2 days*, every 2 days; *QID*, 4 times a day; *TID*, 3 times a day.

IMMUNOSUPPRESSIVE MEDICATIONS

Current treatment paradigms for uveitis emphasize the use of immunosuppressive medications for long-term control of uveitis and steroid-sparing effect. In some patients, use of immunosuppressive medications will be determined by their systemic disease (e.g., JIA, Behcet disease). In others, factors such as dependence on steroids, evidence for steroid-related side effects, chronicity of inflammation, and risk for vision loss will influence the decision for an immunosuppressive regimen

(i.e., Vogt-Koyanagi-Harada syndrome, sympathetic ophthalmia). Pediatric patients with uveitis and especially those with JIA usually have a more robust inflammatory response to surgery than their adult counterparts and typically benefit from systemic immunosuppressive therapy before surgery. If patients are currently being treated with immunosuppressive drugs or biological agents, they should be continued at their current dosage. There is no need for discontinuation of systemic immunosuppressive medications before cataract surgery; in fact, these should be continued without interruption to prevent a flare of uveitis perioperatively. In patients who are not already on an immunosuppressive medication regimen and planning for cataract surgery, consideration should be given to starting medications in the following situations:

- Ocular inflammation is not adequately or only tenuously controlled on steroid therapy.
  - Steroid responder on maximal medical therapy before surgery (the need for additional steroid therapy in the perioperative period may further aggravate IOP).
  - Poorly controlled diabetes, hypertension, gastrointestinal, psychiatric, or other systemic disease likely to be exacerbated by high-dose systemic steroid therapy.

SURGICAL PLANNING

- Preoperative surgical planning should include assessment of the need for additional procedures. In general, it is best to only do as much surgery as is necessary for the problem at hand; however, in some patients combined procedures may be desirable:
  - Pars plana vitrectomy for treatment of vision limiting vitreous debris, vitreous hemorrhage or to address macular pathology such as ERMs, CME, or tractional retinal detachment.
  - Glaucoma surgery in cases in which postoperative control of IOP is expected to pose a problem; however, in the authors' experience, a staged procedure may be more desirable as the added inflammation from cataract surgery may pose a risk to the outcome of the glaucoma procedure.[4] A higher risk for failure has been noted in idiopathic uveitis, intermediate uveitis, Fuchs' heterochromic iridocyclitis, active inflammation at the time of surgery, and uveitis relapse postoperatively.
  - Elective additional procedures should be avoided if not necessary to address the pathology at hand because excessive surgical manipulation is likely to contribute to postoperative inflammation. For example, suture iridoplasty for cosmesis is not recommended.

SURGICAL PROCEDURE

Challenges faced by the surgeon in uveitic cataract cases are myriad. Factors complicating surgery may include posterior synechiae, pupillary membrane, corneal edema, corneal opacity, zonular weakness, capsular fibrosis, and hypotony. However, the first challenge is often achieving adequate exposure and visualization. Because of the frequent necessity for additional intraocular manipulation of the iris, a peribulbar or retrobulbar block is recommended. Local anesthesia may not be as effective on inflamed tissues. General anesthesia may be necessary in some patients, particularly pediatric patients and those undergoing cataract surgery combined with additional procedures (i.e., penetrating keratoplasty, vitreoretinal surgery).

BAND KERATOPATHY

Band keratopathy may affect the patient's vision if within the visual axis but may also pose problems intraoperatively by limiting view of the lens and anterior segment. Removal may be staged or performed concurrently with cataract surgery. Procedure for chelation of band keratopathy is demonstrated in Video 38.1.

PHACOEMULSIFICATION

Incision

For most patients, a standard clear cornea incision may be used. Avoid scleral tunnel incisions in cases of scleritis or in those patients prone to scleral necrosis. It is often helpful to create more than one paracentesis site in cases of more extensive posterior synechiae to increase access for synechiolysis. In cases in which suture closure is needed, nylon is preferred over polyglactin to reduce risk for inflammation near the incision site.

Small Pupils and Posterior Synechiae

Nearly one-third of all uveitic eyes have small pupils, and uveitic patients have a higher rate of intraoperative maneuvers to achieve adequate visualization. Technique for managing small pupils, posterior synechiae, and peripheral anterior synechiae (PAS) include:

- Examine carefully for posterior synechiae (Fig. 38.1), pupillary membranes, and PAS.
- Inject epinephrine containing preservative-free solution (e.g., Shugarcaine or Cionni mix) through the paracentesis site.
- Release PAS using viscodissection. Inject dispersive viscoelastic while using a circumferential sweeping motion with the cannula to lyse the PAS while avoiding damage to Descemet's membrane/endothelium.
- Inject viscoadaptive, cohesive, or dispersive viscoelastic material to widen the pupil.
- Lyse posterior synechiae with viscoelastic cannula or cyclodialysis spatula by inserting through an open area of the pupil and sweeping toward the area of synechiae. If there is a preexisting peripheral iridotomy, the cannula can be inserted through it and used to sweep across the entire pupil, particularly if no opening in the pupil can be identified.
- If synechiae are tight (as in seclusio pupillae) and it is difficult to find a plane for lysis, use microsurgical forceps (MST, Redmond, WA, USA) to provide countertraction on midperipheral iris tissue while using a cyclodialysis spatula to achieve entry into the pupil via blunt dissection.

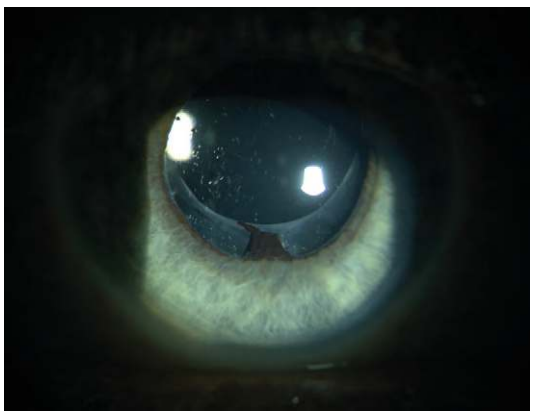

Fig. 38.1 Posterior synechia to anterior lens capsule in a patient with uveitis with suboptimal control of inflammation after cataract surgery. A larger capsulorrhexis at the time of surgery may reduce the risk for synechia formation.

- Iridocapsular adhesions can extend beyond the pupillary margins. Care should be taken to ensure that the iris stroma is not torn during synechiolysis.
- Pupillary membranes can limit mydriasis even after synechiae are lysed.
- Fibrotic membrane can be stripped from the pupil using microsurgical forceps (MST, MaxGrip, Greishaber, etc.) to allow better dilation (Video 38.2).
- Bleeding can be controlled by pressurizing the eye with viscoelastic or balanced salt solution.
- Ultimately, some eyes may need pupil stretching to achieve adequate mydriasis for cataract surgery. Relative contraindications include fibrosis, neovascularization, or an atrophic iris, which can tear if stretched. Procedure for stretching pupil includes the following:
  - Use two Kuglen hooks or collar button hooks to engage the pupil margin 180 degrees apart and stretch the pupil using a push-pull technique. The hooks can be moved 90 degrees to repeat the maneuver if dilation is still not adequate. It is better to use smaller movements multiple times to get the desired dilation as large movements can cause larger tears in the iris.
  - If the pupil dilates less than 4 mm, multiple small sphincterotomies can be made using intraocular scissors (Gills-Welsh or Vannas) (Video 38.3).
- Iris hooks and iris expansion rings can be useful in achieving an adequate view and maintaining mydriasis for the duration of the surgery.
  - In eyes with small pupils and shallow anterior chambers, iris hooks are favored over iris expansion rings. The tension on each hook can be adjusted individually and incrementally to gently dilate the pupil (Video 38.4).
  - In eyes with deep anterior chambers in which the iris is not scarred or atrophic, iris expansion rings may be used. They need fewer corneal incisions for insertion but are more costly than iris hooks and can make it more difficult to visualize the capsulorrhexis if it tears peripherally under the iris (see Video 38.2).
  - If the iris is fibrotic, using a scissors to circumferentially sculpt a pupil will cause less inflammation than stretching (Video 38.5).

CAPSULORRHEXIS

A continuous curvilinear capsulorrhexis of 5 to 6 mm is optimal, but fibrotic capsules present in many patients with uveitis may require sharp discission through the fibrotic portions with a curved microscissors or, alternatively, a can-opener technique (Video 38.6). Surgeons should have a low threshold for use of capsular stain/dye such as trypan blue, especially in cases of fibrotic capsule or intumescent lenses in which the capsulorrhexis may have an increased tendency to tear out. The capsulorrhexis should be made larger than that for a typical cataract because of increased postoperative risk for phimosis of the anterior capsule (Fig. 38.2) and posterior synechiae formation to the anterior capsule (Fig. 38.1). However, the edges of the rhexis should still overlap the lens optic. If a fibrotic edge does not cover the optic, optic capture by the fibrosis and, subsequently, by the iris is a nontrivial risk. Use of a light-pipe to provide side lighting with the microscope light turned off can be helpful to visualize the tearing capsular edge (Video 38.7). At least one acrylic IOL with a larger optic diameter remains available (6.5 mm MA50BM, Alcon Laboratories, Fort Worth, TX, USA) so as to maximize edge coverage and still maximize capsulorrhexis size.

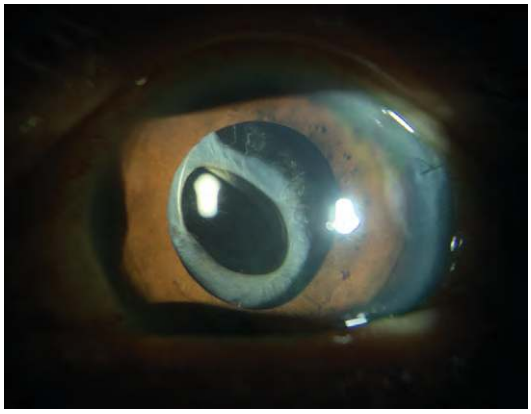

Fig. 38.2 Phimosis of anterior capsule following cataract surgery in a patient with Vogt-Koyanagi-Harada syndrome.

ZONULAR WEAKNESS

Eyes with a history of uveitis may be prone to zonular weakness for a number of reasons including chronic inflammation, use of intravitreal injections, and prior intraocular surgeries.

Surgeons should pay close attention to signs of zonular weakness, both preoperatively (shallow anterior chamber depth relative to axial length, frank phacodonesis) and intraoperatively (difficulty perforating central capsule with the cystotome, excessive mobility of the anterior capsule or excessive wrinkling, and excessive movement of the peripheral lens capsule as the flap is maneuvered with capsule forceps). Both capsular tension rings (CTRs) and capsular hooks may be used to stabilize the capsule. Capsular hooks are favored because they offer less resistance to complete cortical removal than CTRs. Meticulous cortical cleanup is essential in patients with uveitis to limit inflammatory stimulus postoperatively. In cases of lens subluxation, suturable CTR segments (Ahmed segment, FCI Ophthalmics, Pembroke, MA, USA) can be sutured to the sclera for additional support. Rarely, primary pars plana vitrectomy and lensectomy may be warranted if sufficient zonular deficiency is suspected or if the lens is significantly displaced into the vitreous.

Phacoemulsification Technique

Although specific techniques for phacoemulsification are left up to the individual surgeon, several principles should guide choice of technique:

- Limit corneal endothelial cell damage.
- Minimize ultrasound energy used.
- Ensure excellent cortical cleanup.
- Avoid posterior capsule rupture, which increases risk for postoperative inflammation.

INTRAOPERATIVE MEDICAL MANAGEMENT

- Patients pretreated with oral prednisone should be given intravenous corticosteroid in the form of methylprednisolone 62.5 to 125 mg (or equivalent) intraoperatively.
- Intracameral nonpreserved triamcinolone acetonide 1 to 2 mg (Video 38.8) or unpreserved dexamethasone phosphate 400 mg may also be given at the conclusion of surgery but are not a substitute for more vigorous steroid therapy pre- and postoperatively.
- Intravitreal steroids including triamcinolone acetonide (4 mg) and dexamethasone (0.7 mg implant, Ozurdex) may also be used and have shown good efficacy in controlling inflammation and CME in

uveitic eyes. In a prospective, randomized controlled trial comparing intravitreal triamcinolone acetonide and oral prednisone in uveitic eyes undergoing cataract surgery, the authors found no difference in postoperative anterior chamber cell, IOP, or central macular thickness.[11]

- Infusional preservative free dexamethasone (40 mg in 500 cc of basic salt solution) bathes the soft tissues during the entire case.
- Subconjunctival triamcinolone can be useful as an intermediate-term depot as an adjunct.

POTENTIAL COMPLICATIONS

Although uveitic eyes are at higher risk for postoperative complications, if control of perioperative inflammation is achieved with medical therapy as previously described, there is no significant increase in uveitis relapse rate postphacoemulsification compared with the presurgery period.

To minimize risk for complications, it is important not to let postoperative inflammation smolder and to be aggressive with antiinflammatory treatment. Prolonged or severe postoperative inflammation can lead to several potential complications:

- Posterior synechiae
- IOL optic capture
- CME
- ERMs
- Glaucoma
- Pupillary or cyclitic membrane

Cystoid Macular Edema

CME following cataract surgery is significantly associated with poorer vision in uveitic eyes.[1] Risk factors for the development of CME include a prior history of CME (more than 3-fold increased risk), active inflammation within 3 months before surgery (6-fold increased risk), and intermediate, posterior, or panuveitis.

- Patients should be followed with macular OCT at 1 month and 3 months postoperatively. Consider FA if suspicion for macular edema is not confirmed by OCT.
- Mild cases treated with combined topical therapy should be treated as follows:
  - Steroids
    - Topical prednisolone acetate 1%, 2 to 4 times daily
    - Difluprednate 0.05%, 2 to 4 times daily (better penetrance and antiinflammatory activity)
  - NSAIDs
    - Ketorolac 0.5%, 4 times daily (least friend to the ocular surface)
    - Bromfenac 0.07% or 0.09%, 1 to 2 times daily
    - Nepafenac 0.1%, 3 times daily
    - Used in conjunction with steroids
    - Severe or recalcitrant cases
  - Periocular steroid:
    - Sub-Tenon's block or orbital floor injection: triamcinolone acetonide 40 mg
  - Intravitreal triamcinolone acetonide 4 mg, which is more effective than orbital floor injection for triamcinolone[10]
  - Dexamethasone 0.7-mg implant (Ozurdex, Allergan) for noninfectious intermediate, posterior, or panuveitis
  - Systemic oral prednisone (1 mg/kg/day max 60 mg/day) or intravenous methylprednisolone (62.5–125 mg) used in bilateral macular edema, steroid responders, or patients for whom local steroids are contraindicated
  - Alternative strategies for managing CME include the following:
    - Intravitreal antivascular endothelial growth factor injections (bevacizumab 1.25 mg)
    - Interferon ∝2a subcutaneous injections (3–6 million IU daily and then tapered based on response)
    - Oral carbonic anhydrase inhibitors (acetazolamide 250–500 mg twice daily)

HYPOTONY

Prolonged hypotony can lead to phthisis bulbi, so it should be addressed promptly. Risk factors for postoperative hypotony in patients with uveitis include low IOP before surgery (6 mm Hg or less), even while quiescent, diffuse thickening of the choroid or choroidal effusions, and secluded pupil with normal IOP. The procedure for evaluating and managing postoperative hypotony include the following:

- Rule out wound leak or retinal detachment.
- Increase antiinflammatory therapy: frequent topical steroids (prednisolone acetate 1% every hour or difluprednate 4–6 times daily), oral prednisone (0.5–1 mg/kg/day).
- Administer sodium hyaluronate injected into the anterior chamber as adjunctive therapy, but antiinflammatory therapy should take precedence.
- Consider UBM to rule out cyclitic membranes.

OCULAR HYPERTENSION/GLAUCOMA

Postoperative elevation in IOP can occur because of hyphema, pigment dispersion, preexisting glaucoma, or steroid response. If antiglaucoma agents are required, try to avoid prostaglandin analogs and alpha-adrenergic agonists as they have the potential to increase inflammation.

DELAYED COMPLICATIONS

Posterior Capsule Opacification

Eyes with uveitis are at increased risk for posterior capsular opacification (up to 58% of cases), and the risk is increased in younger patients. Indications for Nd:YAG capsulotomy include reduced visual acuity and poor visualization of the posterior segment.

Nd:YAG capsulotomy may exacerbate uveitis and carries with it a higher risk for vision threatening complications in patients with uveitis including ocular hypertension, CME, IOL luxation, and retinal detachment; patients should be monitored closely after treatment.

- May benefit from waiting 6 months after surgery to reduce chance of retinal tear because of posterior ventricular detachment (unless posterior vitreous has already separated)
- Patients should be counseled about risk for worsening ERMs or CME after capsulotomy
- Treat with topical steroids before laser (usually prednisolone acetate four times daily for 1 week prior) and maintain for at least 1 week postprocedure

Anterior Capsule Phimosis

With increased inflammation and scarring after surgery, uveitic eyes are at increased risk for capsular phimosis, which can impair vision (Fig. 38.2). The Nd:YAG laser can be used to create four or more evenly spaced, radial cuts in the anterior capsule to manage phimosis (beam should be focused anterior to the capsule starting with low power to avoid pitting lens). Most Nd:YAG lasers have a *posterior* offset, which increases the risks of pitting when treating an anterior membrane. Some lasers have an anterior offset setting so that the laser may be focused either 0, 50 µm, or 100 µm in front of the aiming beam. If

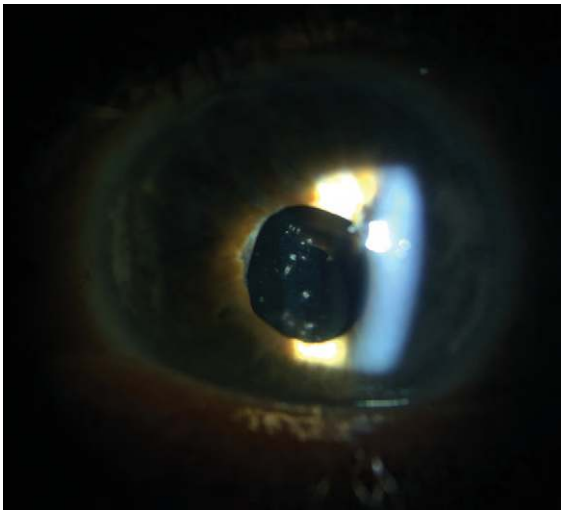

Fig. 38.3 Inflammatory deposits on the anterior surface of an intraocular lens. Control of inflammation is the key to treatment, but an Nd:YAG laser can also be used to dust off the deposits.

laser is insufficient, the anterior capsule can be opened in the operating room using a vitreous cutter (Video 38.9) or microsurgical forceps and intraocular scissors (Video 38.10).

Late in-the-Bag Dislocation of Intraocular Lens

Weak zonules and an increased propensity for capsular contraction increase the possibility of late in-the-bag IOL dislocation. Use of CTRs and prompt management of capsular phimosis with Nd:YAG laser can reduce this risk. The authors suggest placement of a three-piece IOL in favor of a one-piece IOL at the time of cataract surgery for the ease of suture fixation of the existing IOL under this circumstance. Management of the dislocated IOL is discussed in Chapter 53.

Inflammatory Deposits on Intraocular Lens

Chronic postoperative inflammation may result in giant cell or inflammatory deposits on the IOL surface (Fig. 38.3). Primary management should focus on control of inflammation. With quiescent inflammation, deposits may melt away.

Once inflammation is controlled, the Nd:YAG laser can be used to "dust" remaining debris off IOL surface (focus laser anterior to the IOL surface, taking care not to pit the lens surface). This requires very low power and, again, ideally setting the laser with an anterior offset relative to the aiming beam if the deposits are on the front surface (usual location).

INDICATIONS FOR INTRAOCULAR LENS EXPLANTATION

It is uncommon to need to explant the IOL, but this should be considered in cases of chronic, low-grade inflammation unresponsive to treatment. Eyes with inflammation centered on pars plana are at higher risk for IOL intolerance. Complications such as perilenticular membrane or cyclitic membranes causing hypotony and maculopathy should prompt removal of the IOL. If the inflammation is truly not responsive to treatment and a decision is made to explant the IOL, it is best to expedite surgery to minimize complications from chronic inflammation.

POSTOPERATIVE MANAGEMENT

Postoperatively, patients with uveitis require more antiinflammatory therapy and more frequent monitoring. A general recommendation is to use twice as much steroid for twice as long and to monitor uveitis patients twice as frequently than routine cataract patients. Additional guidelines are as follows:

- Monitor closely, more frequently than routine cataract patients (sample postoperative schedule would be 1 day postoperative, 1 week postoperative, and every 2 weeks thereafter for the first 6–8 weeks).
- Be aggressive about controlling inflammation, and do not allow inflammation to smolder.
- Monitor closely for complications such as CME, hypotony, and ocular hypertension, and treat accordingly.
- Do not place patients on a routine steroid, and NSAID taper as per your typical postoperative management without evaluating the postoperative inflammation during the course of the taper.
- Do not discontinue postoperative antiinflammatory therapy when:
  - Postoperative inflammation is unresolved. Minimal residual inflammation should not be ignored.
  - The patient required some amount of long-term maintenance medication preoperatively to sustain the uveitic condition in a quiescent state. In this situation, your goal should be to taper back down to the patient's baseline maintenance dose.

POSTOPERATIVE MEDICAL MANAGEMENT

The choice and dosing frequency of topical steroids depends on severity of inflammation, both before and after surgery and patient history (e.g., remote episodes of inflammation, easily treated with topical steroids may do well with four times daily dosing, patients with a history of fulminant HLA-B27 associated uveitis episodes should have more frequent dosing).

Topical Steroids

- Prednisolone acetate 1% every 1 to 2 hours while awake
- Difluprednate 0.5%, four times daily
- Authors' preference: prednisolone acetate or difluprednate, rather than loteprednol, to ensure optimal control of inflammation
- Dexamethasone containing ophthalmic ointment to provide medication while the patient is asleep

Topical NSAIDs

- Continue for 4 to 6 weeks after surgery.
- Nepafenac achieves the greatest concentration in the aqueous humor at the fastest rate, thus it may be favored over ketorolac and bromfenac.

Cycloplegia

- Helpful to reduce risk for iridocapsular adhesion in severe inflammation
  - Atropine 1%
  - Cyclopentolate 1%
  - Tropicamide 1% with 2.5% phenylephrine

Oral Steroids

- Oral steroids are given preoperatively are continued after surgery.
- Prednisone 1 mg/kg/day (max 60 mg/day) is given for the first two postoperative days, then taper by 10 mg every 2 days (standard taper) until at preoperative baseline or discontinued completely.

- Lengthier tapers can be given depending on the patient (usually over 2–4 weeks).
- Steroids should be tapered when inflammation is quiet or relatively so, but not before then as this may lead to cyclical escalation and deescalation of therapy as the inflammation waxes and wanes.

Immunosuppressive dosage should be maintained after surgery but may need to be escalated after surgery if inflammation becomes more dependent on steroids or is difficult to control.

SUMMARY

- Inflammation should be controlled and CME eliminated for at least 3 months before surgery.
- Ensure that all patients have had a workup to look for associated systemic disease or infection.
- Treat patients with corticosteroids (oral, topical, and/or intravitreal/periocular) perioperatively.
- Watch patients closely for postoperative complications including inflammation and CME, and treat aggressively.

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Video 38.1 Removal of band keratopathy with ethylenediamine tetraacetic acid.
Video 38.2 Pupillary membrane removal and iris expansion ring.
Video 38.3 Sphincterotomy of miotic pupil with fibrotic pupillary membrane.
Video 38.4 Placing and adjusting iris hooks.
Video 38.5 Sharp dissection of fibrotic pupil.
Video 38.6 Management of fibrotic capsule.
Video 38.7 Capsulorrhexis with aid of a light pipe.
Video 38.8 Injection of triamcinolone acetonide in anterior chamber.
Video 38.9 Vitrector capsulotomy.
Video 38.10 Capsulotomy with scissors.

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Retinal Considerations in Cataract Surgery

Carl W. Noble, James M. Osher, and Christopher D. Riemann

CONTENTS

KEY POINTS

- Do not let your cataract surgery get blamed for preexisting retinal disease!
  - Preoperative identification and management of posterior segment disease, especially vasculopathic macular edema and age-related macular degeneration, are essential.
  - Optical coherence tomography is a key part of preoperative assessment to help identify macular pathology, especially in multifocal intraocular lens candidates.
  - Peripheral retinal pathology should be identified preoperatively. Other than a retinal tear, asymptomatic pathology does not always require prophylactic laser before cataract surgery.
- Avoid multifocal lenses in patients with current or likely future macular pathology.
- Consider combination surgery whenever possible if vitreoretinal pathology and cataract coexist.
- Avoid silicone lenses in the setting of any current or potential retinal pathology.

INTRODUCTION

Despite accurate biometry, intraocular lens (IOL) calculations, and flawless cataract surgery, vitreoretinal pathology can lead to disappointing postoperative visual results and unmet patient expectations. A thorough preoperative retinal assessment allows the cataract surgeon to identify and optimize posterior segment pathology before surgery, appropriately counsel patients on vision potential, set realistic expectations, and avoid unhappy postoperative patients.

PREOPERATIVE ASSESSMENT

Vitreoretinal pathology can impact preoperative, intraoperative, and postoperative cataract surgery decision making. We discuss some common conditions encountered in clinical practice.

PERIPHERAL RETINAL PATHOLOGY

Pseudophakia is a known risk factor for rhegmatogenous retinal detachment (RRD) along with RRD in the contralateral eye, family history of RRD, posterior vitreous detachment (PVD), male gender, younger age, lattice degeneration, retinal breaks, axial myopia, and disruption of the anterior vitreous at the time of cataract extraction (CE). The prevalence of RRD after CE is approximately 1% and typically occurs 1 to 2 years after surgery.[1] Assessment of the posterior hyaloid status is an important aspect of preoperative evaluation, and optical coherence tomography (OCT) is a useful modality with a high negative predictive value for the presence of a PVD.[2] PVD formation after cataract surgery is a significant factor leading to peripheral retinal breaks and RRD, but cataract patients with preoperative PVD may also develop postoperative retinal tears and RRD from anterior rotation of the vitreous secondary to reduction of lens volume leading to traction at the posterior insertion of the vitreous base. An IOL has a much smaller volume than the crystalline lens, prompting the vitreous to roll forward and occupy this space. All cataract surgery patients and the ancillary staff fielding their perioperative telephone calls should be counseled on the importance of immediate follow-up for the signs and symptoms of a retinal tear or detachment (photopsias, new or worsening floaters, or peripheral visual loss) before and after CE.

Peripheral retinal breaks should be identified before cataract surgery. A careful peripheral examination, preferably with scleral depression for those with retinal detachment risk factors, is an essential part of a cataract consult, along with a careful history with attention to peripheral symptomatology.

- Asymptomatic retinal breaks rarely require preventative laser retinopexy with the exception of asymptomatic horseshoe tears where the incidence of RRD formation is around 5%.[2]
- Symptomatic flap or horseshoe tears will progress to a RRD in 50% of cases without treatment, and prompt reestablishment of chorioretinal adhesion with retinopexy reduces this risk to under 5%.[2–4]
- Lattice degeneration with or without atrophic holes, operculated retinal holes, and atrophic round holes rarely require treatment. If these are present in the setting of a prior fellow eye RRD, a strong family history of RRD, or any other elevated risk factors, there is no clear consensus if preventative laser is beneficial.[5]
- The risks of peripheral laser retinopexy are generally quite low, and we tend to err on the side of treating these breaks when there is any doubt.

DIABETIC RETINOPATHY

Diabetic retinopathy is the most common cause of vision loss in working age adults and affects one third of patients with diabetes.[6] Diabetes is common among patients with visually significant cataract and is itself a known risk factor for cataract development.[7] Despite the well documented risk for progression or development of diabetic retinopathy after cataract surgery, patients may have significant vision improvement regardless of retinopathy staging.[8,9] It is crucial that all diabetic patients undergo a comprehensive workup for staging of diabetic retinopathy, presence of tractional membranes, diabetic macular edema (DME), and macular ischemia (MI) before prior to cataract surgery.

PROLIFERATIVE DISEASE

Proliferative diabetic retinopathy (PDR) occurs when retinal neovascularization develops, leading to vitreous hemorrhage, fibrovascular membrane formation, tractional retinal detachment, and neovascular glaucoma. Pan-retinal photocoagulation (PRP)[10,11] and anti-vascular endothelial growth factor (VEGF) injections[12] remain the preferred method for managing PDR.[13] PDR and its treatment can be associated with significant tractional epiretinal membrane formation. These membranes occur across a spectrum ranging from severe blinding tractional retinal detachment and "crunch syndrome" to subtle vitreoretinal traction, thickening of the cortical vitreous leading to posterior hyaloidal traction (PHT), and vitreopapillary traction (Fig. 39.1AB). Subtle but visually significant tractional diabetic membranes such as PHT can easily be missed on clinical examination especially in the setting of significant cataract. Useful tips include:

- Preoperative OCT reveals subtle membranes.[14]
- Determine visual significance of membranes preoperatively.
- Avoid silicone IOLs or multifocal IOLs (MFIOLs) in patients with diabetic maculopathy.
- Combination CE and PPV is safe and may be preferred in patients with PDR and cataract.[13]
- Set realistic visual expectations preoperatively.

DIABETIC MACULAR EDEMA

Breakdown of the blood aqueous barrier from diabetic microangiopathy facilitates the release of inflammatory cytokines, increases vascular permeability, and causes DME. This process may be exacerbated by inflammation associated with cataract surgery.[15,16] Aggressive pre- and postsurgical DME management is vital to maximize visual outcomes.[9] Many treatment options exist for controlling DME including medical management of glycemia and systemic hypertension,[17,18] focal laser photocoagulation, intravitreal anti-VEGF agents, and both subtenon and intravitreal corticosteroids. Intravitreal anti-VEGF injections remain the mainstay of DME therapy, with both DME and visual acuity (VA) benefits often plateauing after three to four monthly injections. All commonly used anti-VEGF agents improve VA and decrease central macular thickness (Fig. 39.2), but the burden of monthly treatments is challenging for diabetic patients and potentially unrealistic for many.[19] Sustained-release glucocorticoid preparations effectively treat DME with reduced treatment burden,[20–22] but patients should be monitored for intraocular pressure.[23] Key pearls for cataract management in the setting of DME include:

- Macular OCT is essential for DME management (Fig. 39.3).
- Stabilize and optimize DME preoperatively.
- Suspect MI if anti-VEGF and or steroid injections fail to improve the DME.

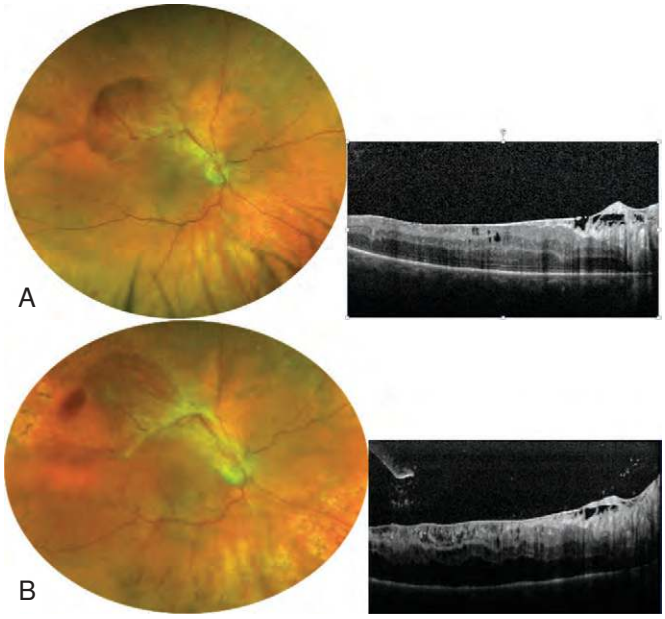

Fig. 39.1 A 56-year-old male with a history of uncontrolled DM presenting with VA of 20/40 OD (A) He developed marked contraction of posterior cortical hyaloid 3 weeks after PRP with central progression of PHT, macular schisis, subretinal fluid (SRF), and VA decline to 20/400 OD. (B) *(Upper left)* Color fundus photograph demonstrating early PHT. *(Upper right)* SD-OCT demonstrating prominent PHT with nasal traction, foveal distortion, and trace cystic intraretinal spaces. *(Lower left)* Color fundus photograph demonstrating contraction of PHT and significant TRD after PRP. *(Lower right)* SD-OCT demonstrating contraction of PHT and ERM progression of inner retina distortion and cystic spaces.

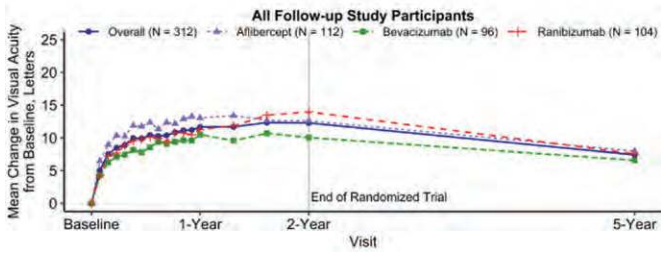

Fig. 39.2 DRCR Net Protocol T 5-year results of all patients demonstrating mean change in VA over time for aflibercept, bevacizumab, and ranibizumab.

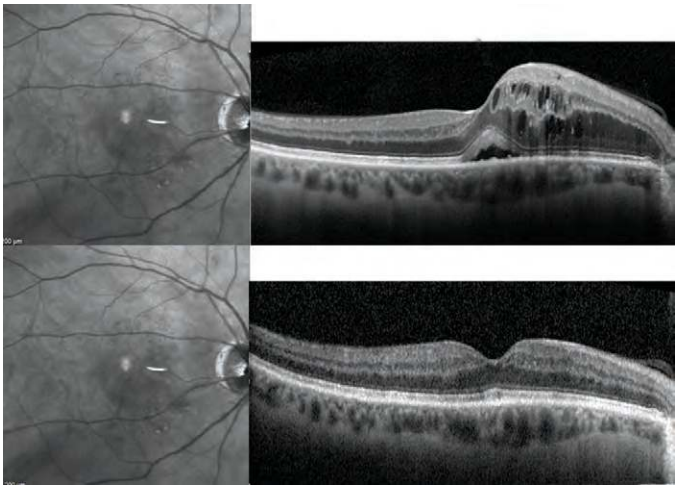

Fig. 39.3 57 year-old female with poor glycemic control, severe NPDR OU and DME OD. VA was 20/40. SD-OCT (upper right) with infrared image (*upper left*) showing moderate macular edema with presence of SRF. After 3 injections of anti-VEGF therapy, vision improved to 20/20 and DME resolved. SD-OCT after treatment (*bottom right*) shows resolution of macular edema and subretinal fluid.

- With persistent DME, do not let cataract surgery disrupt DME therapy.
- When PHT or epiretinal membrane contribute to DME treatment-resistance, consider combination phaco-vitrectomy with membrane peeling and ILM peeling.
- Consider anti-VEGF injections 2 weeks before and 2 weeks after CE or a preoperative intermediate acting steroid injection for patients at high risk for DME postoperative progression.
- Consider adding 40 mg of preservative-free dexamethasone into the 500 mL infusion bottle intraoperatively to reduce inflammation.

MI, with or without DME or PDR, may also significantly limit visual potential in patients with diabetic retinopathy. Intravenous fluorescein and more recently OCT-angiography both effectively identify MI. Conventional OCT is less sensitive for detecting MI. Diagnosing the presence and extent of MI is essential prior to cataract surgery. Despite no available therapies to reverse MI, establishing this diagnosis prior to cataract surgery allows for realistic patient expectations, proper IOL selection and proactive surgical planning with topical, intracameral, or subconjunctival anesthesia, to lower the risk of transient orbital compartment syndrome that occurs in the setting of large retro or periocular blocks. In addition, lower infusion pressures and "slow-mo" phaco techniques may reduce the risk for surgery related vascular occlusions.

OTHER NONDIABETIC VASCULAR RETINOPATHIES

Although separate diseases with their own nuances for diagnosis and treatment are beyond the purview of this chapter, it is important for the cataract surgeon to remain cognizant of other nondiabetic vascular diseases such as retinal arterial and venous occlusion, ocular ischemic syndrome, and sickle cell retinopathy, among others. Many of the general principles applicable to cataract surgery in diabetics can be applied to cataract patients with nondiabetic retinal vasculopathies. Proliferative disease should be controlled, macular edema should be treated, and the perfusion status of the eye should be understood (Fig. 39.4). As with diabetic retinopathy, cataract surgery should not interrupt retinal treatment regimens.

AGE-RELATED MACULAR DEGENERATION

Age-related macular degeneration (AMD) is the leading cause of vision loss in patients over the age of 65 in the developed world, affecting one-third of this demographic, and is more common in:

- Women
- Lighter pigmented patients
- Smokers (400% increased risk for blinding disease)

Wet AMD affects 10% to 20% of patients with AMD, is responsible for 90% of AMD-related visual loss, and is typically managed with anti-VEGF injections. Dry AMD affects 80% to 90% of patients with AMD and is responsible for 10% of severe visual loss. The presence, subtype, and severity of AMD must be known before cataract surgery. Making this diagnosis preoperatively creates the opportunity to set realistic expectations and avoid the pitfall of using an MFIOL in a patient with known compromised macular function, which is a recipe for future IOL exchange and a dissatisfied patient.

DRY AGE-RELATED MACULAR DEGENERATION

Dry AMD is common in the cataract surgery population and is present in up to 30% to 50% of some cohorts. Depending on disease severity, symptoms may range from asymptomatic to severe visual loss. Clinical findings include drusen, retinal pigment epithelial (RPE) changes, and geographic atrophy. Macular OCT may demonstrate irregular RPE contour from drusen and optical transmission defects with overlying outer retinal (photoreceptor) loss in areas of RPE dropout from geographic atrophy (Fig. 39.5). Treatment for these patients is typically

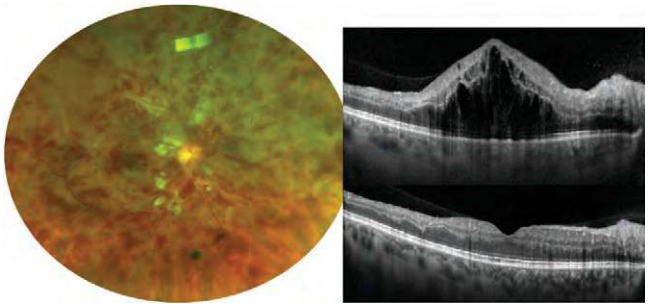

Fig. 39.4 A 52-year-old male with newly diagnosed central retinal vein occlusion OD presenting with initial VA of CF that improved to 20/40 after three intravitreal anti-VEGF treatments. (*Left*) Color fundus photograph demonstrating diffuse intraretinal hemorrhage and cotton wool spots associated with vascular tortuosity. (*Upper right*) SD-OCT showing severe cystoid macular edema (CME). (*Lower right*) SD-OCT with resolution of CME after anti-VEGF therapy.

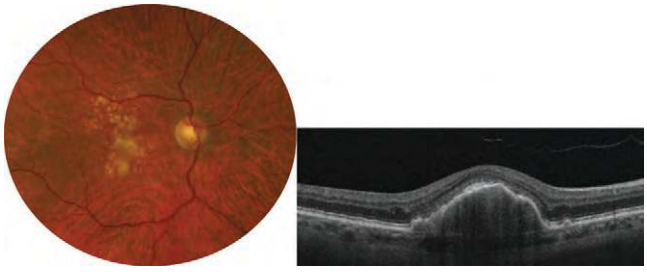

Fig. 39.5 A 78-year-old male who is unhappy after multifocal IOL (MFIOL) placement with subsequent diagnosis of dry age-related macular degeneration (AMD). VA 20/70 OD. (*Left*) Color fundus photograph OD showing foveal hyperpigmentation. (*Right*) SD-OCT displaying a large central pigment epithelial detachment and drusen without exudation.

conservative with smoking cessation, Age-Related Eye Diseases Study vitamin supplementation, periodic dilated fundus examination, and frequent home monitoring, including Amsler grid or a home vernier acuity-monitoring device.[24]

WET AGE-RELATED MACULAR DEGENERATION

Wet AMD and the presence of choroidal neovascularization can present with rapid decline in VA, subretinal hemorrhage, intraretinal edema, subretinal fluid, pigment epithelial detachment, and clinical exudation (Fig. 39.6) or with more subtly minor visual distortions and drusenoid subretinal elevations without obvious clinical exudation. Tips for success when approaching all patients with AMD preoperatively include the following:

- OCT is essential to distinguish wet vs. dry AMD.
- Visual recovery is most often linked with early detection of wet AMD.[25]
- Improvements in OCT anatomy correlate with VA and typically occur after 3 to 6 months of therapy.
- Anti-VEGF therapy will stabilize VA in 90% of wet AMD eyes and recover lost VA in 50% of cases.
- Delay cataract surgery until stable, and ensure surgery does not interfere with treatment regimen.

AMD poses several challenges to the cataract surgeon, including difficulty assessing true visual potential, coordinating anti-VEGF therapy in the perioperative period, and managing patient expectations because VA and reading speed often remain limited by macular pathology after CE. However, cataract surgery commonly results in improved VA and functioning in many patients with both dry and wet AMD. The question of whether cataract surgery increases the likelihood of conversion to wet AMD has been addressed by multiple studies and the consensus is that no causal relationship has been identified.[26–30] Early studies that suggested the contrary failed to properly identify early untreated cases of wet AMD preoperatively, which reinforces the importance of OCT testing as part of the presurgical assessment. Don't let your cataract surgery get blamed for preexisting retinal disease.

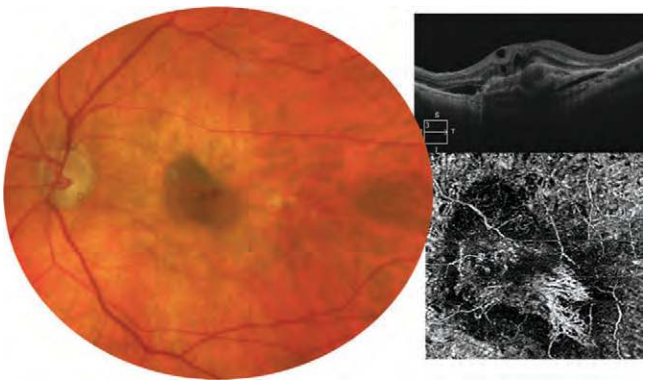

Fig. 39.6 An 82-year-old with known dry AMD presenting with new visual distortions and decline in VA from 20/25 to 20/200 OS. *(Left)* Color fundus photograph OS demonstrating a dark gray elevated macular lesion associated with subretinal hemorrhage. *(Upper right)* SD-OCT showing fibrovascular pigmented epithelial detachment, SRF, and intraretinal edema. *(Bottom right)* En face OCT angiography displaying a large area of increased flow signal corresponding with a choroidal neovascular membrane.

OTHER CAUSES OF CHOROIDAL NEOVASCULAR MEMBRANE

Many other diseases can also cause choroidal neovascular membrane (CNVM) formation (see list). Again, it is important for the cataract surgeon to remain cognizant of other potential causes of CNVM in the perioperative evaluation and to use OCT to better evaluate those at risk. Although the nuances for diagnosis and treatment are beyond the purview of this chapter, many of the same principles used in patients with AMD apply to these disease entities:

- Myopic degeneration
- Presumed ocular histoplasmosis
- Angioid streaks
- Choroidal rupture
- Pachychoroid spectrum
- Inflammation of the RPE (multifocal choroiditis, punctate inner choroidopathy)
- Idiopathic

MEDICATION TOXICITIES

Medication-related maculopathies are not uncommon and should be identified in the presurgical evaluation. Retinal toxicity related to medications may influence IOL selection, visual potential, and threshold for cataract surgery (Table 39.1).

RETINITIS PIGMENTOSA AND OTHER INHERITED RETINAL DISEASES

Inherited retinal diseases and specifically retinitis pigmentosa (RP) represent a group of hereditary disorders with over 100 genetic types of rod-cone dystrophies that diffusely involve photoreceptor and pigment epithelial dysfunction presenting with nyctalopia and progressive peripheral visual field loss.[31] Patients with RP commonly form posterior cortical or posterior subcapsular (PSC) cataracts and have a higher incidence of posterior capsular opacification after CE.[32] Cystoid macular edema (CME) occurs in 10% to 15% of patients with RP, and, although anatomic improvement in macular thickness can be achieved with topical or systemic carbonic anhydrase inhibitors and peri or intraocular corticosteroids, VA may or may not improve with CME reduction.[33] Patients with RP may have significant improvement in functional vision after CE, sometimes despite minimal change in Snellen VA. There is no conclusive evidence that CE worsens preexisting CME in RP.[32] CME in RP typically has minimal leakage on fluorescein angiography, contrasting with the typical robust leakage and disc staining seen in postcataract surgery CME. Given the low overall incidence of this disease process, no clinical guidelines currently exist for perioperative CME for RP.

An important consideration for IOL choice in patients with RP is illustrated by a clinical case: A 35-year-old patient with peripheral visual field loss from RP and 20/40 VA presented with a history of night glare from a 3+ PSC cataract and visually significant vitreous opacities, making it difficult to read. He underwent uneventful combined cataract surgery and PPV; however, he was distraught, reporting visual field loss despite 20/20 uncorrected VA on postoperative day one. He falsely attributed an advancement of RP to his surgery when, in fact, his complaints related to loss of his −10 D myopic spectacle correction courtesy of a successfully attained plano refractive target. The object minification and inherent prism effect of his high myopic spectacle correction effectively increased his visual field. Myopic patients with visual field loss from RP or other diseases should be counseled preoperatively about the potential perception of loss of visual field after

TABLE 39.1 Medication-Associated Toxicity

Medication	Indication	Retinal Findings	Timing	Treatment	Prognosis
Hydroxychloroquine/ Plaquenil	Autoimmune disease	OCT-perifoveal ellipsoid zone loss Late-bullseye maculopathy	>5 years	Stop Rx	Irreversible and can progress despite treatment
Pentosan Polysulfate/ Elmiron	Interstitial crystitis	Paracentral RPE atrophy OCT-paracentral atrophy with outer retinal tubulations FAF-hyper/hypoautofluorescent spots	5–7 years	Stop Rx	Irreversible and can progress despite treatment
Thioridazine/Mellaril	Antipsychotic	Acute-pigmentary retinopathy with RPE granularity Chronic-RPE/choriocapillaris drop out in posterior pole, nummular patter with large area of geographic atrophy	3–8 weeks	Stop Rx	Irreversible and can progress despite treatment
Tamoxifen	Estrogen (+) breast cancer	Crystalline retinopathy (OCT-crystals in NFL/IPL) and CME	Daily dose >120 mg or cumulative dose >100 g	Stop Rx Anti-VEGF for CME	Crystals may improve, or clear CME may be responsive to anti-VEGF
BRAF/MEK	Cutaneous melanoma	Chorioretinopathy and exudative retinal detachment	Hours to weeks	Coordinate with oncologist-observation is reasonable	Most cases gradually resolve over months
Immune checkpoint inhibitors	Wide range of malignancies	Inflammatory uveitis	Weeks to months	Coordinate with oncologist, corticosteroid	Often able to control with corticosteroids

cataract surgery if aiming for a plano refractive outcome. Conversely, patients with RP with preoperative hyperopia can be disappointed by the loss of magnification provided by their spectacle correction if they are made emmetropic with surgery. Again, counseling is advised.

Also, it is important to be aware that very near focal point for highly myopic patients with macular disease provides a larger macular image than what will be achieved with either a plano or near correction. This may convert some patients to require near vision reading aids (in addition to reading glasses), which can lead to patient frustration if not addessed preoperatively.

PRIOR POSTERIOR SEGMENT INTERVENTIONS

A thorough surgical history is essential before cataract surgery. Prior retinal surgery can cause anatomic changes that could complicate surgery. Prior PPV is associated with poor dilation, intraoperative fluctuations in anterior chamber depth, zonular instability, and an increased risk for posterior capsular rupture (PCR), zonular dialysis, and retained lens fragments.[34] A vitreous cavity filled with silicone oil can result in posterior pressure, dense lens opacification, and poor visualization of the anterior capsule caused by diminished red reflex. The buoyancy of the oil causes a posterior capsule convexity, which should be anticipated and countered by more robust OVD use.

CE after vitrectomy may require posterior synechiolysis, iris viscodilation or mechanical dilation with hooks or rings, anterior capsular staining, and capsular tension rings. Appropriate preoperative evaluation and surgical planning will minimize complication risks. (See Chapter 35 for more details on small pupils.)

Prior intravitreal injections are associated with an increased rate of PCR, secondary to direct capsule compromise or anterior hyaloid disruption (Fig. 39.7). These cases require gentle surgical technique to minimize complications. Scleral buckling can lead to conjunctival scarring and caution must be used if peri- or retrobulbar anesthesia is being used given the increased risk for scleral perforation.[35]

Cataract Surgery in Eyes with Indwelling Oil Fill

Cataract Surgery in Eyes with Silicone Oil	Tip
• Identification of indwelling oil	• Review surgical record when possible • Shiny appearance to retina , if visible • High suspicion if unusually long axial length on A-scan ultrasound
• Dense PSC cataract, often with fibrotic plaque	• This is a contraindication to primary posterior capsulorrhexis, unless combined oil removal is planned
• Focal zonulopathy is common	• Maintain positive anterior chamber pressure throughout the procedure and refill the anterior chamber with OVD before instrument removal to prevent oil migration into anterior chamber.
• Buoyant convexity of posterior capsule	• Add additional OVD throughout the procedure, especially under lens fragments in the final stages of phaco. • Work a bit more anteriorly than usual • Consider placing the IOL early before emulsification of the final fragments/quadrant to protect/stent the posterior capsule
• Emulsified oil droplets in the anterior chamber	• Removal of oil bubbles with the I/A should be limited. If oil continues to migrate forward, STOP aspirating and place dispersive OVD over the site of leakage. IOP elevation is preferable to an oil underfill poster operatively.

Fig. 39.7 Slitlamp photograph demonstrating linear defects in the anterior capsule after intravitreal injection and paracentesis to relieve IOP in a patient with glaucoma.

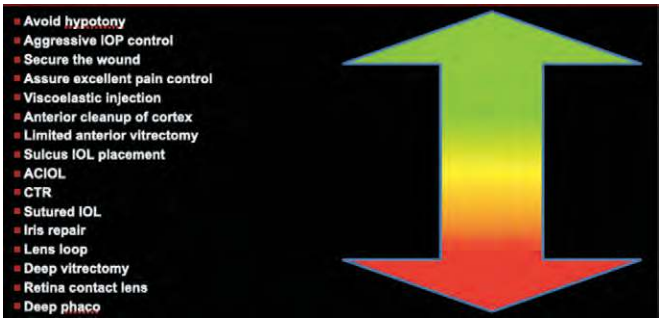

Fig. 39.8 Spectrum of reasonability when approaching intraoperative complications.

POSTERIOR SEGMENT OPERATIVE COMPLICATIONS

The management of intraoperative and postoperative complications involving the posterior segment such as suprachoroidal hemorrhage, luxated lens fragments, luxated IOL, aqueous misdirection, endophthalmitis, and others will be covered elsewhere in this book. However, as the retinal specialist authors, we feel compelled to note that these unfortunate events can be beautifully managed with excellent outcomes a majority of the time. Poor visual outcomes often result not from the pathology or untoward event itself, but from stress-induced aggressive surgical manipulation and/or a delay in referral to a vitreoretinal specialist. When posterior segment complications occur, a sudden and stunning reordering of priorities must occur. The lens extraction, IOL choice, refractive outcome, and astigmatism cease to be the primary objective as the very survival of the globe may be at stake. We like to think about these scenarios in terms of a Spectrum of Reasonability (Fig. 39.8). Some maneuvers are always a good idea, some are always a bad idea, and some fall within a "gray zone" that will vary depending on the specific fact pattern at hand. Honest and self-critical assessment of your and the operating room (OR) team's skillsets, as well as the relative availability and skillset of a vitreoretinal retinal colleague are vital in these stressful situations. Stay within your abilities and limit unfamiliar posterior surgical maneuvers that may cause suprachoroidal hemorrhage, vitreoretinal traction, retinal tears, and retinal detachment. Act prudently and refer to a vitreoretinal colleague promptly.

COMBINED CATARACT EXTRACTION AND PARS PLANA VITRECTOMY

Cataract and posterior segment pathology requiring PPV often coexist, and we strongly advocate for a single-surgery, combined approach whenever feasible. Combination CE with PPV can be performed with excellent anatomic and visual results. Compared with staged procedures, advantages to combined surgery are ample and include the following[36–38]:

- Exposing the patient to one set of surgical risks, psychological stressors, postoperative visits, postoperative medication purchases, and insurance copays[36–38]
- Reduced costs to the medical system
- Improved convenience for patient and family members
- Speedier time to eventual visual recovery

In patients with only cataract, the ophthalmic surgeon determines whether the cataract is responsible for the patient's symptoms, and then the *patient* decides whether these are severe enough to undergo surgery. In patients with both cataract and posterior segment diseases, the decision making is more complex, and the *surgeon's* role is more central to surgical timing and decision making.

Combination surgery may not always be needed or feasible based on the degree of cataract, extent of retinal pathology, and the logistics and coordination of multiple surgeons. Notwithstanding, PPV is known to expedite cataract progression, with 80% of phakic patients requiring CE within 2 years after PPV. The risk for cataract progression is 6- to 11-fold higher in patients older than 50 years old and is 60% higher in patients receiving gas, air, or silicone oil tamponade.[39–41]

Risk Factors for Cataract Progression After Pars Plana Vitrectomy
• Age older than 50 years
• Air/gas-fluid exchange
• Silicone oil tamponade

It can be difficult to determine how much the cataract vs. the retinal pathology are responsible for vision loss and symptoms. OCT can often provide insight into the severity of macular edema, macular hole, vitreomacular traction (VMT), AMD, and epiretinal membranes. OCT also identifies whether the outer ellipsoid layer of the retina is intact, which suggests preserved photoreceptors and a better visual prognosis. OCT can also demonstrate inner retinal layer loss suggestive of possible glaucomatous changes or retinal vascular insufficiency, both of which portend a worse visual prognosis. OCT is mandatory to inform surgical decision making in patients with combined cataract and posterior segment disease. Comparing the index eye to the contralateral eye as a type of internal control may inform clinical decision making. Cataracts are often symmetric, and retinal disease may not share the same symmetry.

Our approach when considering staged versus combination surgery for patients with both cataract and vitreoretinal pathology is to place them into one of four categories to provide a framework for rational decision making: scenarios where the lens must be removed, should be removed, may be removed, and should be left alone.

What to Look for on Macular Optical Coherence Tomography (from Posterior to Anterior)	
Macular Optical Coherence Tomography	**Considerations (Partial List)**
• General	• When OCT finding significance is not clear, have a low threshold to refer • When posterior pathology exists, consider combination phaco-vitrectomy. One surgery is almost always better than two.
• Choroidal mass	• Ocular oncologic consultation for diagnosis and treatment before cataract surgery
• Choroidal thickening	• Pachychoroid disease spectrum: polypoidal choroidal vasculopathy, central serous retinopathy, pachychoroid pigment epitheliopathy, and pachychoroid neovascularization
• Choroidal folds	• Possible hypotony, nanophthalmos, orbital mass, scleritis, or hyperopia
• Choroidal neovascular membrane	• Requires vitreoretinal evaluation for treatment before surgery
• Serous PED	• Pachychoroid spectrum/CSR • Wet/dry AMD, RAP lesion • Requires vitreoretinal evaluation for treatment before surgery • Optical biometry will underestimate axial length resulting in more myopic outcome
• Drusen	• Risk stratification for AMD depending on the following: ▪ number (few vs. many) ▪ location (peripheral vs. central) ▪ type (soft vs. hard) ▪ size (large vs. small)
• Solid/vascular PED	• Look for CNVM; more workup needed
• Subsensory serous fluid	• May have CNVM, optic pit, shallow serous RD, posterior uveitis • Underlying pathophysiology must be identified and treated before cataract surgery.
• Outer ellipsoid zone	• Portends relative prognosis for visual outcome
• Full-thickness macular hole	• Requires retinal consultation for possible repair - consider combined phaco-vitrectomy surgery
• Lamellar macular hole	• Requires retinal consultation to determine relative need for repair depending on other features present
• CME	• Underlying pathophysiology needs to be identified (inflammatory vs. noninflammatory) and maximized preoperatively. • Consider CRVO, BRVO, DME, uveitis, ERM with traction.
• Intraretinal fluid	• Consider DME, CNVM, optic pit, macular schisis, drug toxicity.
• Nerve fiber layer thickness	• Diffuse thinning may indicate prior glaucomatous damage, especially if thinner nasally than temporally (compared with fellow eye). • NFL thinning restricted to one side of the horizontal midline may suggest a prior branch retinal artery occlusion.
• Epiretinal membrane	• Foveal distortion may foreshadow risk for metamorphopsia. • Associated CME? • Tractional detachment?
• Vitreomacular or posterior hyaloidal traction	• Possible combined phaco-vitrectomy approach with membrane peel.
• Vitreomacular adhesion	• Incidental finding, observation only
• PVD	• Present or absent; acute or chronic
• Asteroid hyalosis	• Caution with MFIOL
• Vitreous opacity	• VH, uveitis, PVD, vitreous degeneration • If vitritis, need to identify origin and treat. • If visually significant vitreous opacities, consider vitreoretinal referral and possible combined phaco-vitrectomy.

The Lens Must Be Removed

- Posterior surgery is precluded by severe cataract, and proceeding with CE is mandatory.
- Cataract surgery is required as a result of phacoanaphylactic or phacomorphic changes.
- Example: A 75-year-old patient with a ruptured anterior lens capsule, hypermature cataract, phacoanaphylaxis, and a total RD after a self-sealing open globe injury. He is anticoagulated after myocardial infarction and triple cardiac bypass surgery with stent placement 6 months prior. This is a perfect scenario for combined phaco-PPV when simultaneous surgery expedites the management of the phacouveitis and retinal detachment; in addition, a single trip to the OR minimizes medical risks in this ill patient.

The Lens Should Be Removed

- Posterior segment surgery is mandatory with an advanced/visually significant cataract.
- PPV without CE is possible but technically difficult and poses added risk for intraoperative cataract advancement and unplanned lensectomy.
- Example: A 68-year-old patient with bilateral 3+ cataracts. VA of 20/200 in the index eye as a result of a stage-3 full-thickness macular hole and 20/60 in the contralateral eye. Combination phaco-vitrectomy should be performed in this scenario. The cataract is already visually significant and will only get worse after PPV and gas tamponade. This patient is all but guaranteed a trip back to the OR for cataract surgery after PPV, and there is a significant risk that the worsening cataract may preclude intraoperative or postoperative visualization.

The Lens May Be Removed

- Posterior segment surgery is appropriate but not necessarily mandatory.
- A cataract is present but is borderline visually significant.

- PPV without cataract surgery is possible and technically straightforward.
- The risk for cataract progression is substantial but not in the immediate postoperative period.
- Example: A 52-year-old patient with bilateral 2+ cataract. VA of 20/60 with metamorphopsia in the index eye because of a grade 3 epiretinal membrane and 20/30 contralaterally. There are vague glare complaints, and glare testing is 20/60 OU. OCT shows excellent preservation of the ellipsoid zone and nerve fiber layer. In this scenario, the cataract is not part of the acute problem, and the patient is just over the age of 50. There is a cataract, but the epiretinal membrane is the main reason for the patient's visual loss. In this case, either combined phaco-vitrectomy or staged PPV with subsequent CE would be reasonable. The patient's preference can aid in decision making. The authors strongly advocate for combined phaco-vitrectomy in a vast majority of these scenarios.

The Lens Should Be Left Alone

Scenario 1

- Little to no cataract and a low risk for cataract progression.
- Younger than 50 years and no gas tamponade is being considered.
- Example: A 42-year-old patient with bilateral 1+ cataract. VA of 20/30 with metamorphopsia complaints in the index eye because of VMT syndrome and VA of 20/20 contralaterally. There are no glare complaints, and glare testing is 20/30 OU. We do not recommend combination surgery in this scenario.

Scenario 2

- "When less is more."
- Ischemic, vasculopathic, and uveitic eyes may exhibit exaggerated inflammatory responses to more extensive surgeries, and leaving the anterior segment untouched may lead to a less complicated postoperative course.
- In the setting of vitrectomy with silicone oil placement, it is best to leave the patient phakic whenever possible. A planned staged combination phaco-vitrectomy-silicone oil removal can be performed at a later date once the posterior segment pathology has been stabilized.
- Example: A 39-year-old patient with bilateral 1+ cataract. VA of 20/200 with new floaters and curtain vision changes in the index eye secondary to acute retinal necrosis with RRD. We try to avoid combined phaco-vitrectomy surgery in eyes undergoing retinal detachment repair whenever possible because of increased risk for proliferative vitreoretinopathy formation and subsequent anatomic failure. More surgical steps are best avoided whenever possible.

We believe that simultaneous combined phaco-vitrectomy allows for better and more complete lens removal, more precise reconstruction of the anterior segment with in-the-bag IOL placement, and better refractive outcomes than pars plana lensectomy (PPL) and sulcus IOL placement combined with PPV for posterior pathology in eyes with good visual potential. PPL is within standard of care but phaco-vitrectomy with a PCIOL is usually the more controlled, precise, refined and preferred surgical technique. A clean phaco is essential for combined surgery, and technnique pearls for combined phaco-vitrectomy surgery are listed in Box 39.1. PPL or staged surgeries are always better than a botched phaco-vitrectomy.

BOX 39.1 Surgical Tips for Combination Cataract Extraction/Pars Plana Vitrectomy

- A clean CE/IOL is a must before PPV for posterior segment pathology. Staged surgeries are always preferable to a mishandled phaco.
- Use a large IOL optic (6–6.5 mm).
- DO NOT use silicone IOL or hydrophilic acrylic IOL in patients with retinal disease.
- Complete the phaco, place the IOL, remove viscoelastic, and secure the corneal wounds before beginning the PPV.
- Secured, stable cataract wounds are crucial to limit wound gaping during trocar placement, use of retinal contact lens, and scleral depression during the PPV.
- Self-sealing cataract wounds are OK, but a suture is highly recommended especially with less experienced surgeons performing combined surgeries.

Fig. 39.9 Intraoperative photograph showing silicone oil marring of silicone IOL.

INTRAOCULAR LENS CONSIDERATIONS IN THE RETINA PATIENT

The cataract surgeon has an ever-expanding selection of IOLs from which to choose, and it is important to systematically evaluate each patient to make an appropriate IOL selection. As vitreoretinal surgeons, we offer some thoughts on IOL choice in the patient undergoing retina surgery.

- Silicone IOLs can develop visually significant surface opacifications during and after retina surgery (Fig. 39.9).
- Silicone oil IOL marring and fogging during a fluid air exchange can force IOL displacement or removal to visualize the retina.
- Hydrophilic acrylic IOLs are associated with localized calcification during or after PPV, often in the setting of air or gas tamponade.[42]
- If a patient has any posterior segment pathology that may warrant surgical intervention during their lifetime, do not use silicone-based IOLs.
- Hydrophilic acrylic IOLs can opacify with intravitreal (or anterior chamber) gas bubble and should be avoided.

TORIC INTRAOCULAR LENSE

Addressing astigmatism during cataract surgery has become standard of care, and combined phaco/PPV is no exception to this rule. If retinal visual potential is greater than 20/60, and, if the patient wishes to address corneal astigmatism at the time of combined cataract/PPV surgery, we

strongly advocate for offering a hydrophobic, acrylic toric IOL. Toric IOL placement in the setting of combination phaco-vitrectomy surgery is associated with excellent anatomic, visual, and refractive outcomes and documented rotational stability.[43]

MULTIFOCAL INTRAOCULAR LENSES

Presbyopia-correcting MFIOLs are available for patients who wish to decrease their dependence on spectacle correction after cataract surgery. These IOLs split the incoming light into multiple focal planes to achieve multifocality at the expense of reduced contrast sensitivity.[44] Although most patients can achieve excellent uncorrected distance and near vision, MFIOLs should be avoided in patients with macula-involving pathology where contrast sensitivity may already be compromised. Placing a contrast sensitivity-reducing MFIOL in these eyes can have an additive effect resulting in markedly reduced contrast sensitivity and an unhappy patient. MFIOLs should be avoided in patients with macular hole, macula involving retinal detachments, AMD, DME, other macular vasculopathies, and used with great caution in the setting of ERM.[45] A meticulous macular exam with OCT is highly recommended to better understand macular health in any patient being considered for a MFIOL. Vitreoretinal consultation, intravenous fluorescein angiography, OCT angiography, or indocyanine green angiography may help in more challenging clinical scenarios. This type of comprehensive evaluation allows the cataract surgeon to set realistic expectations and reduces the risk for an unhappy premium IOL patient. ***Do not let your cataract surgery get blamed for preexisting macular disease!***

When an MFIOL is considered in the setting of vitreoretinal pathology, the specific MFIOL should be carefully chosen, as they are not all alike. In addition to contrast sensitivity issues, some diffractive MFIOL platforms can impede detailed visualization needed for membrane peeling, and an MFIOL with the least impact on contrast is preferred.

Visually significant vitreous opacities, or floaters, represent an interesting scenario for combined phaco-vitrectomy and MFIOL implantation.[46] In a recent large series of patients undergoing vitrectomy for floaters, the duration of symptoms before PPV for floaters was much shorter in patients with MFIOL vs. monofocal IOLs (9 vs. 24 months).[47] The reason for this is unclear but may relate to the contrast sensitivity reduction of MFIOLs piggybacking on the reduced contrast sensitivity from the vitreous opacities themselves. Anecdotally, the authors have converted unhappy MFIOL patients into happy MFIOL patients by removing visually significant floaters, which raises the question of whether it is reasonable to alter the threshold for offering combined phaco-vitrectomy for MFIOL in the setting of visually significant vitreous opacities.

SUMMARY

- Diagnose, understand, and optimize retinal disease *before* cataract surgery.
- Do not let cataract surgery interfere with the management of retinal disease.
- Do not let cataract surgery get blamed for preexisting retinal disease.
- Use OCT as part of your preoperative assessment.
- Avoid MFIOL in patients with macular disease.
- Avoid silicone IOLs in patients with any retinal pathology or at risk for surgical retinal disease.
- Strongly advocate for combined phaco-vitrectomy surgery over staged surgeries.

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Pediatric Cataract Surgery

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CONTENTS

KEY POINTS

- Pediatric cataract is an important cause of treatable blindness in children.
- In addition to the cataract, several comorbidities can be present in a child's eye, and these can impact visual prognosis and require adjustments in the surgical technique and/or postoperative drug regimen.
- Careful preoperative assessment is important for surgical planning and follow-up.
- Successful outcomes depend on the surgical technique implemented, effective postoperative inflammation modulation, and aggressive amblyopia treatment.

INTRODUCTION

Pediatric cataract is one of the leading causes of reversible blindness in children.[1] Early diagnosis and adequate management are key for visual prognosis. In cases where surgical intervention is necessary, important factors for visual development include the timing of the procedure, presence of comorbidities, surgical technique implemented, use of intraocular lens (IOL) or contact lenses for aphakia correction, adequate postoperative inflammation modulation, and management of amblyopia.[2,3] In this chapter, several nuances of pediatric cataract surgery are discussed.

CAUSES

Most unilateral and bilateral pediatric cataracts are considered idiopathic.

Specific causes include the following:

- Genetic abnormalities
- Syndromes that primarily affect other organs
- Metabolic disorders
- Congenital infections
- Other causes (e.g., trauma, prolonged steroid use, ocular diseases such as uveitis)

COMORBIDITIES

Microphthalmos and Microcornea[4,5]

Children with cataract may also have microphthalmos, which can be classified as simple, complex, or relative anterior microphthalmos, as follows:

- Simple microphthalmos: eye with an axial length at least 2 standard deviations below the mean for that age with otherwise normal morphologic appearance.
- Complex microphthalmos: eye with same criterion of small axial length as simple microphthalmos, but with other associated anatomic malformations of the anterior and/or posterior segment.
- Relative anterior microphthalmos: eye with a normal axial length with a disproportionally small anterior segment.

Furthermore, cataract can be present in the scenario of microcornea (horizontal corneal diameter <10 mm).

Surgery is more challenging in eyes with microphthalmos and microcornea, and the visual prognosis is poorer than in eyes with only pediatric cataract. However, in recent years, advances in surgical techniques have improved the results in these eyes.

In those with complex microphthalmos and extreme simple microphthalmos or microcornea, the decision to proceed with surgery is determined after specifically analyzing the patient's eye and weighting surgical risk versus potential benefits.

MICROSPHEROPHAKIA[6]

Children with cataract can have associated microspherophakia, which is usually bilateral and characterized by a crystalline lens with a reduced equatorial diameter and an increased anteroposterior diameter.

In cases with mild to moderate zonulopathy and a stable capsular bag, the bag can usually be preserved even with severe zonulopathy. Techniques unique to capsulorrhexis and bag fixation in significant zonular laxity are covered in more detail in Chapter 34. Once the capsulorhexis has been created and is intact, care is taken throughout the surgery to avoid further zonular damage.

- In eyes with more advanced zonulopathy and unstable capsular bag, the insertion of an 8/10 mm endocapsular tension ring (CTR) and the scleral fixation of an endocapsular tension segment (CTS) can provide bag stabilization.
- Sometimes the capsular bag is too small to accommodate even the smallest commercially available CTR. In such cases, the ring can be manually constricted before insertion (Video 40.1).
- Alternatively, a lensectomy and anterior vitrectomy can be performed, with the eye being left aphakic or pseudophakic through scleral fixation of the IOL.
- Usage of an iris-claw supported IOL has not been well studied in this young demographic.

When the bag is preserved, depending on its diameter, a 1-piece or 3-piece IOL can be implanted in the bag. In even smaller bags, it may be necessary to partially amputate both haptics of a 3-piece IOL for in-the-bag implantation (Fig. 40.1).

CONGENITAL ANIRIDIA

Most cases of congenital aniridia—which is characterized by partial or complete absence of the iris—are autosomal dominant. Sporadic cases may be associated with WAGR syndrome (Wilm's tumor, aniridia, genitourinary anomalies, and mental retardation). Thus it is important for children with cataract and aniridia to be evaluated by the pediatrician.

Visual prognosis in these patients is relatively poor because of the common association with foveal hypoplasia, optic nerve head hypoplasia, glaucoma, and keratopathy. Because of advances in IOLs and prosthetic iris devices that have opaque peripheries and normal pupillary apertures, cataract surgery can also decrease the intense glare and photophobia.[7] Aniridia fibrosis syndrome is an idiosyncratic profound fibrovascular proliferation that begins in the anterior chamber in roughly 5% of aniridic cataract surgeries and can be sight threatening. There does not appear to be an identified surgical technique or patient factor to predict which eyes suffer this syndrome, and it can occur unilaterally even with bilateral symmetric surgery. Patients' families should be counseled about this in advance.[8] Indocyanine green dye is preferred over trypan blue in these cases because the anterior capsules are much thinner and more friable than normal capsules.[9]

PERSISTENT FETAL VASCULATURE[10]

Most cases of persistent fetal vasculature (PFV) affect only one eye. Based on the location of the vascular abnormalities, PFV is classified as purely anterior, purely posterior, or combined.

- Purely anterior PFV may be associated with cataracts, retrolental opacity, elongation of the ciliary processes, and glaucoma.
- In combined PFV, besides the association with these abnormalities, the eye can present with microphthalmia, corneal opacification, optic nerve hypoplasia, and retinal proliferative membrane, fold, or detachment. PFV is associated with many cases of unilateral cataracts.
- When there is an opacification at the level of the posterior capsule or retrolental space, even if small or mild, there is a significant risk for deprivation amblyopia because of the closeness to the nodal point.
- In isolated anterior PFV, a good visual outcome may be obtained with early surgical treatment and aggressive amblyopia therapy. The prognosis in posterior or combined PFV is limited because of concomitant posterior pole abnormalities.
- Patients with cataract and PFV have a tendency for more exacerbated postoperative inflammation—which should be taken into consideration to titrate postoperative treatment—and are at higher risk for requiring additional procedures. After surgery, frequent visits to ensure adequate ocular healing are important.

LENTICONUS[5]

Lenticonus is a condition in which there is a conical configuration of the anterior or posterior lens capsule. Most cases of anterior lenticonus are associated with Alport's Syndrome; posterior lenticonus is usually sporadic and is an isolated ocular finding. Surgical treatment might be necessary when there is associated lens opacification or significant limitation in visual development caused by the optical aberrations resulting from the conical capsular shape.

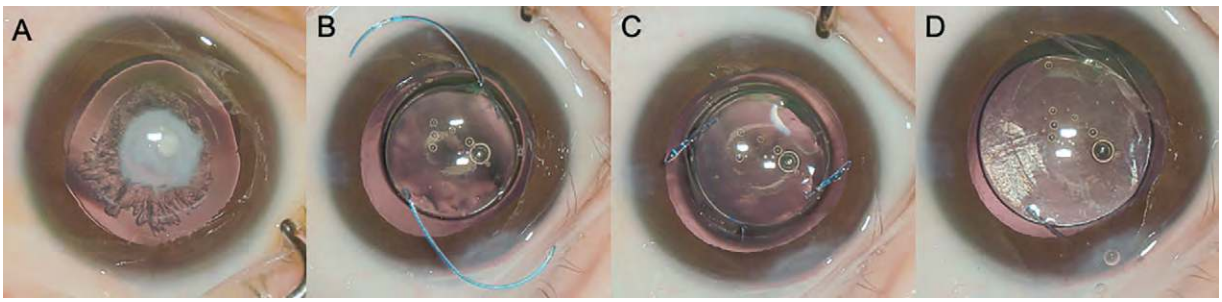

Fig. 40.1 (A) Surgical microscope view at the beginning of surgery in a patient with congenital cataract and microspherophakia. The reduced equatorial diameter is evident. (B) Immediately before IOL implantation, it is clear that this 3-piece IOL with 5.5 mm of optic diameter and 12.5 mm of haptic-to-haptic diameter will not fit with its original configuration in this small capsular bag. (C) Both haptics of the 3-piece IOL are partially amputated. (D) At the end of the procedure, the IOL is in the bag and stable, with both partially amputated haptics anchoring it to the bag, avoiding its anterior or posterior dislocation, in spite of the anterior and posterior capsulorrhexis.

Anterior Lenticonus

The anterior capsule may be more elastic than usual and has a high tendency to easily tear, which should be considered when performing the anterior continuous curvilinear capsulorrhexis (CCC). Also, care must be taken throughout the surgery to avoid unnecessary stress on the posterior capsule because of the possibility of posterior capsular fragility or even coexistent posterior lenticonus. Thus hydrodissection and posterior capsule polishing should be either avoided or used with great caution, and the maneuvers for IOL implantation should be done cautiously.

Posterior Lenticonus (Video 40.2)

In posterior lenticonus, spontaneous posterior capsule rupture can occur. In this scenario, the cortex overlying the capsular defect presents with progressive opacification, and white deposits can be found delimitating the capsular opening (Fig. 40.2). In some cases, a white total cataract is seen. Preoperative ultrasound may identify the conical configuration of the posterior capsule or multiple hyperreflective foci in the retrolental space, suggesting a spontaneous posterior capsule rupture.

- Intraoperatively, hydrodissection should not be performed. Cataract removal should start with aspiration of the peripheral cortex, followed by the nucleus.
- Care must be taken to avoid enlarging a posterior capsule defect that is already present or to avoid causing an uncontrolled opening of an intact posterior capsule caused by inadequate surgical maneuvers.
- When there is no posterior capsule defect, posterior capsulorrhexis and anterior vitrectomy are performed to remove the opacification that extends to the anterior vitreous in many of these eyes, besides decreasing the risk for secondary visual axis opacification.
- When there is a small central posterior capsule defect, it is usually possible to successfully implant an IOL in the bag. However, it is imperative to avoid unnecessary capsule stress during the IOL implantation.
- Ideally, a primary posterior capsulorrhexis will result in a maximal structural integrity. In cases with large posterior capsule openings, a 3-piece IOL can be placed in the sulcus with posterior optic capture (Fig. 40.3).

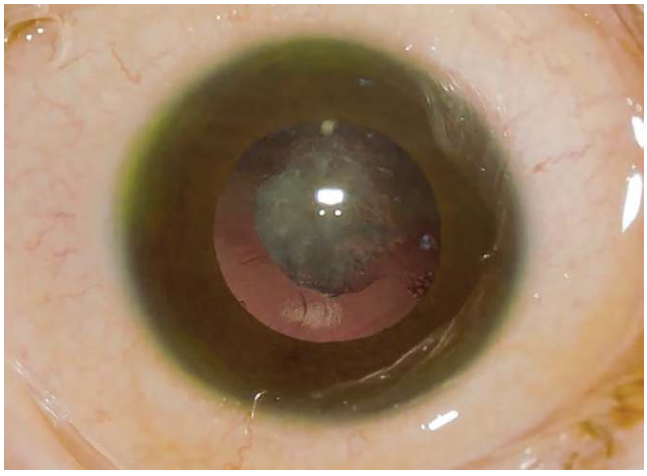

Fig. 40.2 Surgical microscope view of an eye with posterior lenticonus with the lens opacification delimitating the posterior capsular opening.

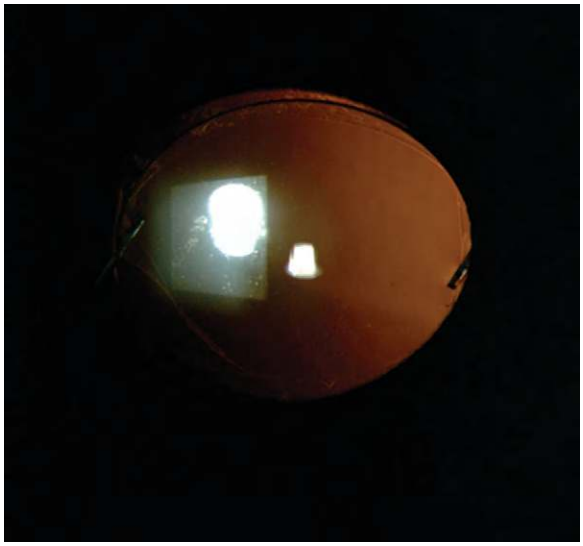

Fig. 40.3 Slit lamp photograph evidencing a 3-piece IOL with posterior optic capture. This IOL was implanted in the sulcus with its optic posteriorly captured because the child had a spontaneous large posterior capsular defect.

ZONULOPATHY[11]

Eyes with cataract can have associated congenital, developmental, or posttraumatic zonulopathy. In patients with posttraumatic cataract, even when zonular impairment is not identified preoperatively, care must be taken during surgery, considering the high risk for zonular damage.

Depending on the degree of zonular laxity, lens subluxation, and presence/absence of transzonular vitreous, adjustments in the surgical technique are necessary. Exercise caution throughout the procedure to protect the zonular remnants. In cases with mild to moderate zonulopathy, the bag may be preserved. Performing the capsulorrhexis is challenging because of the decreased zonular counter-tension. The cataract is removed carefully. Capsular hooks can be used to stabilize the capsular bag. A CTR should be implanted as soon as needed to aid in bag stabilization, but as late as possible. If necessary, the CTR or a CTS may be sutured to the sclera to stabilize and center the capsular bag.

With regards to the IOL, when the capsular bag is preserved and stable, it is possible to implant the lens in-the-bag. Several techniques have been described, including the use of a single-piece acrylic IOL, an intact 3-piece IOL or a 3-piece IOL with partial amputation of one of the haptics (Fig. 40.4). Additional details on cataract surgery in zonulopathy can be found in Chapter 34.

In cases where the bag is too unstable, a lensectomy can be performed, followed by anterior vitrectomy or pars plana vitrectomy, and IOL scleral fixation or placement of an iris-claw supported IOL.

PREOPERATIVE MANAGEMENT

A thorough preoperative assessment is essential to adequately evaluate the cataract's morphology and visual impact to investigate ocular comorbidities and decide between clinical or surgical treatment. In cases that will be operated, it is also important to determine the timing of the procedure and to properly plan the surgery.

- Visual acuity and pupillary reflex should be assessed. Retinoscopy is used to evaluate how the cataract affects the red reflex and to determine the cycloplegic refraction.

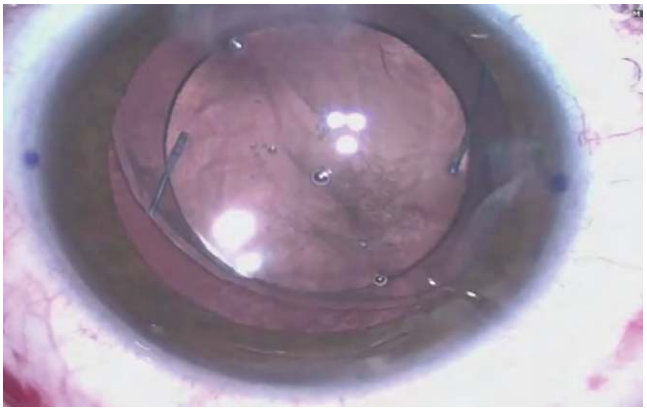

Fig. 40.4 Surgical microscope view of a right eye with crystalline lens subluxation treated with the Ventura IOL haptic technique, in which an endocapsular tension ring is inserted, followed by the in-the-bag implantation of a 3-piece IOL with partial amputation of one of the haptics to center the lens optic in the patient's visual axis, even though the capsular bag is not centered to the limbus.

- In monocular cataracts, the refraction of the contralateral eye is taken into consideration when determining the IOL power to be implanted.
- If in spite of the presence of the cataract, there is any chance of binocularity, preoperatively testing stereopsis is important to understand how well the eyes function together. Strabismus should be evaluated.
- The presence of nystagmus should be noted because it is a sign of worse visual prognosis.
- Electrophysiologic testing may be performed to assess the neurologic function of the retina.
- The anterior segment should be first examined without pupil dilation and repeated after mydriasis. It is important to determine the size, density, and location of the cataract. Observe for signs of preexisting posterior capsule defect, anterior or posterior capsule fibrotic plaque (Fig. 40.5), intumescent cataract, poor pupillary dilation, zonulopathy, or any other comorbidity.
- When the clarity of the media permits, the posterior pole should be examined carefully using an indirect ophthalmoscope. When the cataract precludes visualization of the posterior pole, a B-scan ultrasound and/or ultrasound biomicroscopy (UBM) can determine whether there are associated PFV, signs of posterior lenticonus, retinal detachment, retinal lesions, or vitreous abnormalities.

SURGICAL PEARLS

- Whenever poor pupillary dilation hinders minimum adequate visualization of the intraocular structures to allow a safe surgery, iris hooks can be used.
- When iris manipulation is necessary, there is a tendency for more exacerbated postoperative inflammation.
- Take this into consideration to titrate drugs used to modulate postoperative inflammation to avoid fibrinous uveitis and inadequate healing.

- In children who are old enough to cooperate with optical biometry, this should be performed, along with a corneal topography, especially when the measured keratometry is suspicious for keratoconus or in children with an increased risk for keratoconus (e.g., Down syndrome).
- Whenever media transparency permits, retinal imaging should be obtained preoperatively and routinely over the years. A RetCam (Massie Research Laboratories, Inc., Dublin, California) can be used to obtain fundus images in small children.
- To avoid any measurement error caused by poor collaboration in children who do not cooperate with optical biometry, axial length and corneal curvature should be measured under general anesthesia before cataract extraction or during an examination under anesthesia. Immersion ultrasound biometry is preferred to contact ultrasound biometry whenever possible, because of its greater accuracy. A handheld portable keratometer can be used to determine corneal curvature.
- Measurement of the central corneal thickness, horizontal corneal diameter, and intraocular pressure (IOP) are also important. The IOP can be measured in the office using a Goldmann or an iCare tonometer. Alternatively, it can be assessed during the exam under anesthesia using a Tonopen or Perkins tonometer.

FAMILY COUNSELING PEARLS

If surgery is warranted, explain that:

- There are inherent long-term risks associated with pediatric cataract and pediatric cataract surgery.
- The procedure is the first step in a long road of regular follow-up visits.
- Compliance with the postoperative drug regimen is essential to decrease the risk for adverse events after surgery.
- Adequate amblyopia treatment with glasses or contact lenses despite IOL implantation—associated with visual rehabilitation and commonly occlusion therapy—plays a key role in visual development.
- Further interventions may be required.

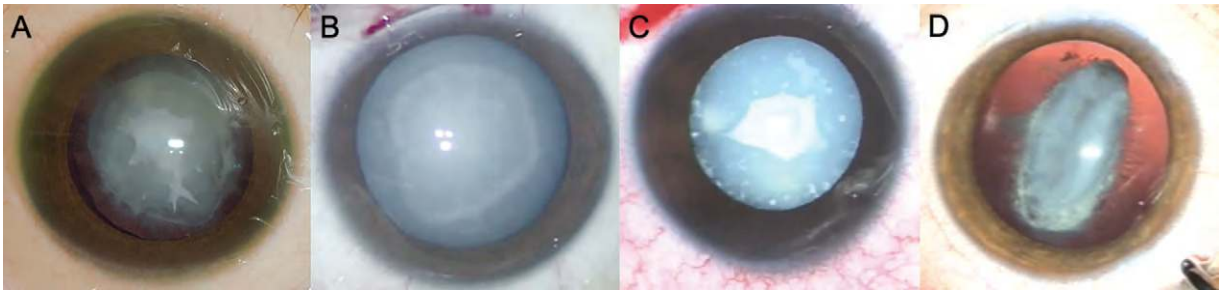

Fig. 40.5 Surgical microscope view of pediatric eyes with capsular fibrotic plaques. (A) Anterior capsule central fibrotic plaque. (B) Large anterior capsule central fibrotic plaque. (C) Anterior capsule central fibrotic plaque associated with multiple points of fibrosis throughout the entire anterior capsule. (D) Large posterior capsule fibrotic plaque.

INDICATIONS OF SURGICAL TREATMENT

- Visually significant central cataracts larger than 3 mm in diameter
- Dense nuclear cataracts
- White or membranous cataracts

Certain cataracts such as anterior polar, sutural, lamellar, or blue dot cataracts may be compatible with good vision and may be followed regularly to ensure normal visual development. Cycloplegia with occlusion therapy, when necessary, may be implemented in small or decentered cataracts, or in the presence of anterior or posterior lenticonus, in which the vision is initially not normal for the age. If this clinical treatment does not revert amblyopia, surgery is justified.

There is no consensus on the exact timing for surgical intervention. However, most studies indicate that surgery should be performed in the first few months of life. Unilateral cataracts have a better prognosis when operated on earlier. In bilateral cases, surgery on the contralateral eye can be done on the same day or ideally up to a week apart.

ANESTHESIA

General anesthesia with laryngeal mask airway or endotracheal tube can be used for surgery.

Some advocate bilateral simultaneous surgery to decrease the number of general anesthesia episodes to which a child is exposed; however, this is not a consensus. Nevertheless, the number of surgeries under general anesthesia and their duration should be minimized. Thus, if possible. Performing the exam under anesthesia to obtain preoperative data immediately before surgery in one eye is better than submitting the child to two anesthesias. In the same manner, the postoperative exams under anesthesia should be performed whenever necessary, but as infrequently as possible.[12]

SURGICAL PROCEDURE[2,3,13,14]

Pars Plana, Limbal, or Combined Approach

The pars plana approach to lens removal potentially decreases the retinal traction when performing the anterior vitrectomy. However, there is loss of capsular bag integrity, which usually impedes in-the-bag IOL placement. Furthermore, there is increased risk for iatrogenic retinal or ciliary body detachment.

The limbal approach enables surgeons to perform an anterior CCC, complete removal of the cataract, CTR insertion, a posterior continuous curvilinear capsulorrhexis (PCCC), IOL in-the-bag implantation, IOL optic capture, and anterior vitrectomy.

Some surgeons prefer a combined approach, in which they first use a limbal approach to perform an anterior CCC and to implant an IOL in the bag, followed by pars plana posterior capsulotomy and anterior vitrectomy.

To date, there is no evidence of one approach being superior to the others in the hands of various surgeons. It is possible to obtain good surgical results with the different approaches. However, it is clear that pediatric cataract surgery is a procedure in which a successful outcome depends on meticulously performing each surgical step, in association with careful postoperative inflammation modulation. Thus the surgical approach will vary based on each surgeon's preference.

INCISION

The sclera in a child is very elastic, and thus the wound tends to be less stable than in adults. The main incision can be done as a scleral tunnel incision to improve stability and decrease the risk for wound-related postoperative complications. The paracentesis incision is created in the clear cornea (Video 40.3).

- Step 1: Perform a peritomy.
- Step 2: Make a scleral scratch incision in the posterior limbus.
- Step 3: Use a crescent blade to dissect a scleral tunnel until the emergence of the vessels on the cornea.
- Step 4: Perform the paracentesis incision in the clear cornea.
- Step 5: After injecting diluted adrenalin in the anterior chamber, stain the anterior capsule with trypan blue either directly or under a single air bubble to reform the anterior chamber. The single air bubble pushes the trypan blue against the anterior capsule, increasing its staining. The trypan blue decreases capsule elasticity, aiding in the creation of the anterior CCC.
- Step 6: Wash out the trypan blue through the paracentesis incision, fill the anterior chamber with a viscoelastic agent and then proceed in creating the main entry. Alternatively, maintain the anterior chamber formed by a single air bubble and proceed in creating the main incision before washing out the trypan blue and filling the anterior chamber with a viscoelastic agent. The latter should be performed with caution because depression on the blade while entering the anterior chamber could lead to bubble loss and inadvertent early capsule entry.

SURGICAL PEARLS

- The final diameter of the main incision will depend on the IOL used.
- When using folding forceps to implant a 3-piece IOL in a very controlled fashion, usually a 3.5 mm incision is required; when implanting a single-piece IOL using an injector, a smaller incision is possible.
- If you choose to implant a 3-piece IOL using folding forceps, during the steps before IOL implantation, a smaller main incision is required.
  - Prepare your main wound (scleral scratch incision and crescent blade dissection), considering your final incision size.
  - Initially make a smaller opening to the anterior chamber to improve stability throughout the procedure (e.g., if you are using instruments for 2.4 mm incision, initially make an internal entry in the anterior chamber of this size).
  - Before IOL implantation, enlarge your main incision to its planned final diameter.

ANTERIOR CAPSULORHEXIS

The pediatric capsule has increased elasticity, which imposes challenges when performing the anterior CCC because of its tendency to tear out to the equator. The younger the child, the more elastic the capsule. Some associated comorbidities (e.g., zonulopathy; microspherophakia) can also enhance this characteristic. Trypan blue has the unique quality in decreasing the elasticity of the anterior capsule.[15] This effect is contact time dependent. Thirty to forty seconds seems to provide an acceptable effect.

A manual anterior CCC may be achieved using a bent needle, cystotome, forceps, or a combination of these (Video 40.4).

- Step 1: First, a small central puncture is made using a bent needle, cystotome, or capsulorrhexis forceps.
- Step 2: Use the same instrument to guide the tear radially out to the desired circumference.
- Step 3: Grasp the leading edge of the tear and perform the anterior CCC. A central capsulorrhexis of approximately 5 mm is usually adequate to cover the IOL optic in all directions.

SURGICAL PEARLS

- When performing the anterior capsulorrhexis in a child, make sure that the anterior chamber is adequately pressurized with enough viscoelastic agent. Inject more as necessary.
- In older children (e.g., 10 years old and older), the vector forces to perform the capsulorrhexis are similar to those in adults.
- In younger the child, more adjustment of vector forces centripetally is required to successfully obtain a CCC because the capsule is increasingly more elastic.
  - Several repeated grasps at the leading edge of the tear are recommended for maximal control during capsulorrhexis propagation.
  - Because elasticity varies from case to case, frequent relaxing and regrasping of the leading edge of the capsular tear with careful observation and redirection of vector forces ensures a CCC of an adequate size.
  - To overcome the tendency of evolving radially, the leading edge of the tear is pulled on the same plane of the anterior capsule, toward the center of the bag (considering its circumference); if this is not enough, the vector force is directed toward the posterior capsule or even pulled backward (retrograde) from the intended path.[16]

Alternative techniques to perform capsulorrhexis in children include vitrectorhexis, radio-frequency diathermy, femtosecond laser, and Fugo plasma blade. They can be good options in certain cases; however, the capsulotomies performed in these ways are often less elastic than a manual CCC.

In patients with a dense fibrotic plaque in the anterior and/or posterior capsule, the radio-frequency diathermy and Fugo plasma blade can be of great use to perform a circular capsulotomy (Video 40.5). If the fibrosis is thick, the radio-frequency diathermy tip can be used to pass through the fibrotic plaque as many times as necessary to complete the cut. It is unclear if the Fugo blade is still commercially available.

CATARACT REMOVAL

Most cataracts in children are soft and easily aspirated with the irrigation-aspiration (I/A) or phacoemulsification handpieces without the use of ultrasound energy. Cataract removal should start with the aspiration of the peripheral cortex, followed by the nucleus, in light of the inherent for posterior capsule defect, even in cases where you do not suspect this.

For surgeons that prefer coaxial I/A, the sub incisional cortex can be easily manually aspirated using Robert Osher's technique of "dry aspiration" using a 3-cc syringe half-filled with balanced salt solution and blunt cannula through the paracentesis incision under an anterior chamber filled with OVD, if necessary.

In rare cases, a harder nucleus may require a minimal amount of ultrasound energy for phacoemulsification.

ENDOCAPSULAR TENSION RING IMPLANTATION

The CTR was first designed to manage zonular dialysis during cataract surgery. However, it also lowers the incidence of capsule contraction, stabilizes the capsular bag, and enhances IOL centration. Thus it has been used routinely by some pediatric cataract surgeons. In young children, the insertion of a CTR avoids the ovalization of the capsular bag, which typically occurs after a 3-piece IOL implantation (Fig. 40.6). When a single piece IOL is implanted, the ring reduces the risk for capsule contraction and capsular phimosis.

The CTR can be inserted using an injector or forceps. A standard 10/12 mm sized CTR fits in the capsular bag of children of even just a few months of age. Whether to place the CTR before or after posterior curvilinear capsulorrhexis (PCCC) creation is a matter of surgeon preference, each with merits.

- The authors prefer to place the TR before PCCC, as this precludes inadvertent migration of the ring through the opening and provides uniform distribution of tension across the capsule. The increased, though uniform, tension may change the vector forces required in a more centripetal direction compared with a PCCC performed without a CTR in place.
- Some surgeons may prefer to perform the posterior capsulorrhexis first, then place the ring after the continuous tear is complete. The latter approach has more familiar vector forces, though it requires greater attentiveness during initiation of ring insertion, and, of course, if the PCCC cannot be completed and extends peripherally and the ring has not yet been placed, then ring placement would have to be deferred.

CTR implantation should be avoided in cases that already present with posterior capsule degeneration (e.g., posterior lenticonus) or points of fragility in either the anterior or posterior capsule (e.g. outwardly directed points or fibrotic plaques). Also, in infants with microspherophakia, the 10/12 mm CTR can overly distend the small capsular bag, resulting in radial tears of either capsulorrhexis and/or technical difficulty in implanting the IOL in the bag, between the anterior and posterior capsulorrhexis. Thus the decision of implanting a CTR in these eyes should be made with caution and, if considered, should be smaller than the 10/12 mm. This can be achieved by creating multiple small bends in the ring to decrease its diameter (Video 40.1).

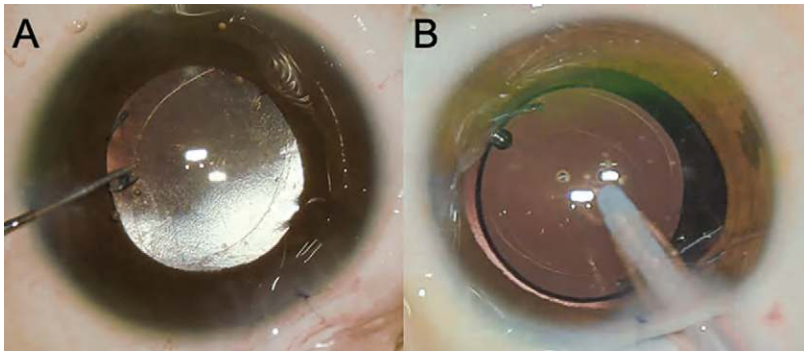

Fig. 40.6 Surgical microscope view of two pediatric cataract surgeries in which a 3-piece IOL with overall diameter of 12.5 mm was implanted in the bag. (A) Capsulorrhexis ovalization is seen because an endocapsular tension ring (CTR) was not inserted. (B) The capsulorrhexis maintains its circular shape in spite of the presence of a 3-piece IOL in the bag because a CTR was implanted.

POSTERIOR CAPSULORHEXIS

Primary PCCC is performed in children in whom posterior capsule opacification is likely to occur (usually up to 6–8 years of age) and in those with posterior capsule fibrosis who can not cooperate with postoperative Nd:YAG laser capsulotomy. To further reduce the incidence of secondary visual axis opacification, posterior capsule optic capture and/or anterior vitrectomy is done. The anterior vitreous is more reactive in young children, and the intact vitreous face acts as a scaffold for lens epithelial cell migration and proliferation.

The PCCC is usually performed with a diameter 1 mm smaller than the anterior CCC. It can be made using capsulorrhexis forceps, a vitrector, radio-frequency diathermy, or a femtosecond laser, which requires docking the eye after the cataract has been removed. The following steps describe the technique using a capsulorrhexis forceps:

- Step 1: Pressurize the anterior chamber with OVD until it is flat or there is a posterior-facing concavity to the posterior capsule.
- Step 2: Use a cystotome or bent tip of a disposable needle to engage the central capsule tangentially, lift it toward the surgeon, and at the same time initiate the puncture.
- Step 3: Inject viscoelastic material through the central puncture of the posterior capsule to push the vitreous face away.
- Step 4: Hold the flap with a capsulorrhexis forceps and perform the PCCC. Sometimes using a small gauge coaxial microforceps through fresh paracenteses can help guide the tear circumferentially from additional directions.

ANTERIOR VITRECTOMY

Anterior vitrectomy is commonly performed in young children to remove the hyaloid face as a scaffold upon which lens epithelial cells can proliferate. Accordingly, it is important to remove the anterior vitreous face, being careful not to grasp the posterior capsule inadvertently. Some surgeons use triamcinolone as a vitreous "dye" to aid in this step.[17] In older children, this may be an unnecessary step, especially in eyes of Marfan's syndrome patients, in whom there is an increased risk for retinal detachment.

SURGICAL PEARLS FOR ANTERIOR VITRECTOMY

- When you begin the anterior vitrectomy, you will notice that the border of the PCCC trembles, indicating the presence of vitreous against the posterior capsule.
- When a sufficient amount of anterior vitreous has been removed, activation of the vitrector near the PCCC border no longer causes this capsular movement. This demonstrates separation of the vitreous from its capsular attachments via the so-called Weigert's ligament.

Posterior capsule optic capture may be carried out before the viscoelastic material is removed. One side and then the other of the IOL optic, 90° from the haptic-optic junctions, are slipped through the PCCC using a spatula or a cannula. The haptics remain in the bag, while the IOL optic is positioned behind the PCCC in Berger's space. After viscoelastic aspiration, it is important to confirm that the optic is still captured.

INTRAOCULAR LENS

There is no consensus on the specific age to start implanting IOLs in children. However, over the last years, with improvements in surgical techniques, surgical instruments, and lenses, more and more surgeons are choosing earlier IOL implantation in children. Many start implanting lenses in the first few months of life. Pseudophakia offers the method of optical correction that requires the least compliance and induces minimal aniseikonia. Relative contraindications for IOL implantation include persistent or recurrent uveitis, severe microphthalmos, complex microphthalmos, and other ophthalmic defects that preclude useful vision.

IOL material, size, and especially site and method of fixation are important determinants of immediate and long-term outcomes. In-the-bag implantation is the preferred site of IOL positioning. In cases without support, a 3-piece lens can be placed in the sulcus with the optic captured through the anterior capsulorrhexis opening or through both the anterior and posterior capsulotomy opening.

The most commonly used lenses in children are single-piece or 3-piece foldable hydrophobic acrylic IOLs. They allow for smaller incisions, maintain good centration, and have good long-term biocompatibility. Single-piece foldable IOLs are easier to implant than 3-piece lenses; however, they are less resistant to capsular contraction, which can lead to IOL decentration over time. In children, a CTR is advisable in eyes in which a one-piece foldable IOL is placed. Also, because they have wider haptic-optic junctions, the incidence of secondary visual axis obscuration because of epithelial cell proliferation and migration may be higher.

SURGICAL PEARLS (VIDEO 40.1)

Helpful tips for implanting a 3-piece IOL in a pediatric eye:

- Use folding forceps to insert the lens in the eye in a very controlled maneuver.
- Place the leading haptic in the bag.
- Let the IOL optic unfold gently in the anterior chamber.
- Reform the anterior chamber with the viscoelastic agent.
- Position the IOL optic in the bag.
- Use a modified H hook in your left hand through the paracentesis incision and a Y hook in your right hand through the main incision to guide the trailing haptic into the capsular bag, without stressing the anterior CCC.

Because the pediatric eye undergoes significant biometric changes in the first few years of life, controversy surrounds the correct choice of lens power for implantation. Planning an initial undercorrection prevents or modulates the magnitude of future myopia, which can be amblyogenic and lead to further procedures. The desired hyperopia is correlated to the child's age at surgery, although the contralateral eye's refraction is taken into consideration in monocular cataracts to minimize anisometropia. This hyperopia is corrected with spectacles or contact lenses, adjusted as the eye grows.

There are many ways of calculating the amount of undercorrection to be made. Some defend implanting an IOL that will undercorrect 20% in infants and 10% in toddlers. Others follow tables that specify the amount of undercorrection based on the child's age at surgery. Table 40.1 is an example of such a table. It is important to note that the amount mentioned is of diopters of undercorrection in the IOL power relative to a plano target, not the amount of anticipated hyperopia.

In patients in whom spectacle correction or contact lens wear compliance is questionable, a plano target may be a better choice to avoid early amblyopia, recognizing that there will likely be a later myopic shift, which can be address subsequently by contact lenses, spectacles, or even laser vision correction, once the child reaches early adulthood.

The use of multifocal implants in younger patients is controversial, and to date there is no definitive consensus with currently available lenses. Critics argue that the contrast reduction of multifocality and the negative impact of residual refractive errors could hamper amblyopia

TABLE 40.1 Amount of Undercorrection for IOL Calculation in Pediatric Patients Based on the Child's Age at Surgery

Age at surgery	Undercorrection in IOL power (Diopters)
3 months	9 D
6 months	7 D
9 months	5 D
12 months	4 D
18 months	3 D
24 months	2 D
36 months	1 D
48 months	Emmetropia

treatment, but adequate data to support or refute this supposition are lacking. Older children with developmental cataract may adapt well to multifocality, perhaps caused by the excellent neuroplasticity of youth. It is important to recognize and to inform the parents that multifocality corrects for presbyopia, but because refractive error can shift through adulthood, a distance correction is still likely.

FINAL SURGICAL STEPS

Suture all incisions due to the low scleral rigidity and the child's tendency to rub the eyes. The suture can be of 10-0 nylon or 10-0 Vicryl, with the later having the advantage of being absorbed, decreasing the need for suture removal under anesthesia.

To aid in modulating postoperative inflammation, preservative-free triamcinolone can be injected into the anterior chamber at the end of the procedure, after constricting the pupil with carbachol and refilling the anterior chamber with a single air bubble (Fig. 40.7).[17,18] Many surgeons also inject subconjunctival dexamethasone.

A ventilated acrylic eye shield may be used in the immediate postoperative period to decrease the risk for eye rubbing and ocular trauma, even in older children, especially during arousal from general anesthesia.

POSTOPERATIVE MANAGEMENT

Patients should return for evaluation on the day after surgery and a week after the procedure. Visual acuity is verified, and the inflammatory response assessed to determine whether any adjustment in the postoperative regimen should be done (Table 40.2). Two weeks after surgery, the patient is seen by a pediatric ophthalmologist to start amblyopia treatment.

Based on the ocular examination a week after surgery, the timepoint of the next follow-up visit with the surgeon is determined (usually between the 3rd and 4th week after surgery). In this visit, besides evaluating the vision and ocular healing, IOP is also assessed.

In patients with ocular comorbidities or characteristics that make them at higher risk for undesirable ocular healing, the frequency of follow-up visits is increased.

POTENTIAL SURGICAL COMPLICATIONS

Fibrinous Uveitis

Regular follow-up visits enable early detection and adjustments in the postoperative regimen to revert this complication. In more exacerbated cases, reoperation is necessary, followed by an aggressive antiinflammatory regimen, which may include some combination of intracameral, peri-orbital depot, topical, and systemic steroids.

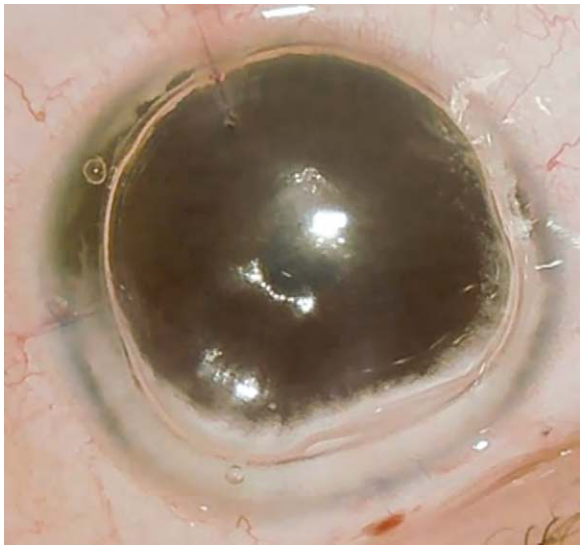

Fig. 40.7 Surgical microscope view at the end of a pediatric cataract surgery, in which the preservative-free triamcinolone crystals can be seen in the periphery of the anterior chamber. The pupil was first constricted by injecting intracameral carbachol, and the anterior chamber was reformed using a single air bubble, which keeps the triamcinolone crystals in the periphery of the anterior chamber.

TABLE 40.2 Sample Postoperative Drug Regimen

Drug	Prescription
Topical antibiotic	Every 4 or 6 hours for 2 weeks
Topical steroid (e.g., prednisolone acetate)	Every 3 hours, tapered over 6 weeks
Mydriatics (e.g., tropicamide)	Every 8 or 12 hours for 2 weeks
Topical hypotensive drops (e.g., dorzolamide)*	Every 12 hours for 30 days

*When intracameral triamcinolone is left in the eye.

Secondary Visual Axis Opacification

Based on the child's age, secondary capsular opacification can be treated with Nd:YAG laser capsulotomy or surgical capsulotomy and anterior vitrectomy. For children who are unable to cooperate with Nd:YAG laser slit lamp delivery system, Nd:YAG capsulotomy under general laryngeal mask anesthesia can be performed readily and rapidly in the operating room. The laser is rolled up to the side of the bed at the head. When the child is asleep, the operating room team can gently roll the patient on their side, opposite the side of intended capsulotomy. The face is placed into the slit lamp with the contralateral (lower) ear on the chinrest. The laser can be performed as usual and the patient can be returned to supine positioning and aroused. This paradigm obviously requires a center in which both a Nd:YAG laser and general anesthesia capabilities are available. It also requires at least one extra circulating nurse or assistant in the room to help with positioning.

Glaucoma[19]

Glaucoma can occur at any time after pediatric cataract surgery. The incidence of glaucoma in pseudophakic eyes is lower than in aphakic patients if the IOL is in the bag or separating the anterior and posterior compartments.

Glaucoma is diagnosed is children when there are ≥2 of the following criteria:

- IOP > 21 mm Hg
- Progressive increase of the cup-to-disk ratio ≥0.2
- Corneal findings (e.g., Haab striae; corneal edema; corneal diameter ≥11 mm in newborns, >12 mm in children younger than 1 year of age and >13 mm after this)
- Progressive myopia associated to continuous increase in axial length outside the normal limits of ocular growth
- Reproducible visual field defect consistent with glaucomatous optic neuropathy

Other Rarer Surgical Complications

Endophthalmitis and retinal detachment can occur as with any cataract operation.

AMBLYOPIA TREATMENT AND VISUAL REHABILITATION

This is of course essential for maximal visual development after surgery. Cataract surgeons who are not facile with amblyopia management should establish a relationship with a pediatric ophthalmologist for amblyopia management.[20]

SUMMARY

- Pediatric cataract can be an isolated finding or present with other ocular comorbidities.
- Careful preoperative assessment is important for surgical planning and follow up.
- Understanding the unique features of pediatric eyes is important to perform timely and adequate intervention, besides anticipating visual prognosis.
- If surgery is indicated, it should be done in the first few months of life.
- More surgeons are advocating earlier primary IOL implantation, although there is still no consensus on the exact age.
- Each surgical step should be done meticulously.
- Adjustments in surgical technique and the regimen to modulate postoperative inflammation are made based on cataract features and presence of comorbidities.
- Close postoperative follow-up is important for early detection of surgical complications that might require timely intervention.
- Besides the ocular characteristics and surgical anatomic results, aggressive amblyopia treatment determines visual prognosis.
- After surgery, children must be followed regularly in view of the lifelong risk for complications (e.g., glaucoma).

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Video 40.1 Video of extraction of small subluxated lens in eye with Marfan syndrome, showing method of reducing ring diameter to accommodate the small capsule.
Video 40.2 Video of a surgical case of posterior lenticonus, in which a spontaneous posterior capsule rupture was evidenced when the cataract was aspirated.
Video 40.3 Video illustrating how to perform the main incision and the paracentesis incision in pediatric cataract surgery.
Video 40.4 Video illustrating how to perform an anterior capsulorrhexis in a child with cataract.
Video 40.5 Video of two surgical cases that presented with an anterior fibrotic plaque illustrating the use of a radiofrequency cautery to perform the anterior capsulotomy.

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Intraocular Lens Exchange and Secondary Intraocular Lens Placement

Elaine J. Zhou and Zaina Al-Mohtaseb

CONTENTS

KEY POINTS

- The most common indications for intraocular lens (IOL) removal and exchange include IOL decentration, refractive error, and dysphotopsia.
- Secondary IOL implantation is often required for patients with a history of aphakia after complex cataract surgery or trauma.
- New techniques and technologies have made secondary IOL implantation safer with better visual outcomes.
- Suture-less scleral-fixated IOLs are the newest and most promising techniques but more research with long-term follow-up results is still needed.
- Surgeons should consider the advantages and disadvantages of these techniques in patients with a diverse array of pathology and perform only the procedures they are comfortable with.

INTRODUCTION

Ideally, cataract extraction and placement of an intraocular lens (IOL) is performed in one operation, and the IOL is placed within the capsular bag. However, complicated extracapsular surgery, trauma, poor refractive outcome, or other patient factors may necessitate IOL removal, exchange, or secondary IOL placement. Historically, secondary IOL options were thought to have higher complication rates, which may include corneal edema, uncertain refractive outcome, cystoid macular edema (CME), bleeding, or choroidal detachment, depending on the technique.[1,2] New IOL extraction techniques, IOL fixation techniques, IOL designs, and sutures have expanded dramatically over the last decade. With these innovations, patients can have excellent anatomic and refractive outcomes after IOL exchange and secondary IOL implantation with minimal complications. This chapter reviews indications, advantages, and challenges of IOL exchange and the most common and most promising IOL fixation options.

This chapter will primarily cover the following:

- Standard capsular-bag-fixated or sulcus-fixated posterior chamber (PC) lenses
- Scleral-fixated PC lenses
- Iris-fixated IOLs
- Anterior chamber (AC) lenses

INDICATIONS

There is a wide range of indications for removal of an IOL and placement of a secondary IOL. Many patients who require secondary IOLs have extensive damage to anterior segment structures or have history of trauma or posterior segment abnormalities. The indication for surgery, ocular comorbidities, and medical comorbidities will certainly affect the choice of IOL and its placement. IOL exchange and in-the-bag secondary placement may be possible in patients with an intact capsule. However, this is rare in patients with complex ocular histories. Additionally, removal of the original IOL may result in loss of capsular support, and capsule-fixated implantation may not be possible. As always, discussion with patients about their visual goals and the risks for surgery is necessary to tailor surgical decision making.

PATIENT COMORBIDITIES

Numerous pathologies can lead to the final common pathway of aphakia or need for IOL exchange.[3]

- Progressive zonulopathies
  - Pseudoexfoliation
  - Retinitis pigmentosa
  - Pigment dispersion syndrome

  - Marfan's syndrome or Ehlers Danlos syndrome
  - Uveitis
  - High myopia
  - Prior vitreoretinal surgeries
- Trauma
- Prior pars plana lensectomy (e.g., for complex anterior loop traction in RD)

INTRAOPERATIVE COMPLICATIONS DURING PHACOEMULSIFICATION

Disruption of the capsular bag during cataract surgery may limit IOL placement options. The first step is to assess the remaining capsular support structures.

- Small, round, posterior ruptures in the posterior capsule or ones that can be converted by posterior capsulorrhexis to a curvilinear opening may still allow for in-the-bag placement of an IOL.
- Larger or peripheral breaks in the posterior capsule risk subsequent IOL dislocation posteriorly into the vitreous cavity. In these cases, sulcus placement of an IOL with or without optic capture may be an option.
- If there is a question about anterior capsular integrity, other options such as scleral-fixated IOLs or, less preferably, iris-fixated or anterior-chamber IOLs can be considered.
- If primary placement of an IOL is not safe or the cataract surgeon does not have either the tools needed or requisite skill set for the best available IOL option, aphakia with subsequent secondary IOL placement is also very reasonable.

POSTCATARACT SURGERY COMPLICATIONS

Common indications that may necessitate IOL removal, repositioning, or exchange include the following:

- IOL malposition, subluxation, or dislocation
- Uveitis-glaucoma-hyphema (UGH) syndrome
- Pseudophakic or aphakic bullous keratopathy
  - This may necessitate concomitant corneal transplantation.

PATIENT DISSATISFACTION

In this age of refractive cataract surgery, unacceptable refractive or optical outcomes may precipitate IOL exchange.

- Refractive surprises:
  - Hyperopic
  - Myopic
  - Astigmatic
  - Presbyopia
- Positive dysphotopsias:
  - Glare
  - Halos
  - Starbursts
- Negative dysphotopsias

Dysphotopsias are more common with (but not exclusive to) multifocal intraocular lenses (MFIOLs). These patients may complain of limited quality of vision, reduced sharpness, or visual aberrations. In one study of 43 eyes with unwanted visual symptoms after MFIOL implantation, 7% ultimately required IOL exchange, although this study was with the older generation of multifocal IOLs.[4] IOL exchange of multifocal lenses in current cohorts is probably less than 1% of all MFIOLs implanted. Sometimes we now even see patients who choose to have an IOL exchange from a monofocal IOL to a multifocal IOL when the surprise of presbyopia is greater than anticipated. Accordingly, IOL exchange of a well-placed in-the-bag posterior-chamber intraocular lens (PC-IOL) is not uncommon.

PATIENT POPULATION

History

When deciding on the surgical approach, it is important to take a good medical history. Systemic medical conditions, patient anxiety, or patient positioning factors that prohibit longer procedures or higher anesthesia may make certain longer cases, such as transscleral suturing, more difficult and thereby may affect planning.

Anticoagulant therapy may increase risk for intraoperative hemorrhages with transscleral or iris-sutured fixation.

For younger patients, uveitic patients, glaucoma patients, and trauma patients, anterior-chamber intraocular lenses (ACIOLs) are generally avoided for risk for future long-term endothelial damage, inflammation, or glaucoma.

EYE EXAMINATION

It is important to perform a careful eye examination to rule out other ocular pathology that could limit visual potential and to discuss these findings with the patient. Prior surgeries such as previous glaucoma procedures and presence of conjunctival scarring may affect IOL placement and scleral fixation. Examination of the anterior segment should focus particular attention on:

- Location of IOL
- Type of IOL (one-piece, three-piece, etc.)
- Capsular remains (if any)
- Zonular integrity
- Corneal scarring or edema
- Vitreous in the anterior chamber
- Iris anatomy

SURGICAL TECHNIQUES

IOL Exchange for Power or Type with Intact Capsular Bag

Opening the Capsular Bag

When planning to exchange an in-the-bag IOL, often the most difficult obstacle is reopening the capsular bag and/or removal of the existing IOL, especially if the IOL has been implanted more than 6 weeks before removal. This can result in significant fibrosis and the capsule can become adherent to the IOL haptics, particularly to haptic features such as terminal bulbs or eyelets.

Some pearls in opening the capsular bag include the following:

- Use a combination of viscodissection, blunt dissection, and sharp dissection.
- Start in the area in which the anterior capsule appears to be the least strongly adherent, usually at the optic-haptic junction.
- Attempt to use a Palay cannula or a 27-G needle on an optical variable device (OVD) syringe to help open the capsule initially. Bending the needle tip slightly toward the bevel allows the surgeon to use the smooth back side of the needle to lift the continuous curvilinear capsulotomy, reducing the likelihood of damaging, reducing the likelihood of damaging the anterior capsule.
- If focal areas of fibrosis are present, it may be possible to extend the anterior capsulotomy peripherally around areas of focal adhesions by making a tiny snip in the capsulorrhexis margin at the site of adhesion and peeling the capsule around it. There are also reports of using femtosecond laser to assist in creating a new capsulorrhexis to assist in opening the bag.[5]
- If a haptic is entrapped within a strongly adherent capsular bag, it may be necessary to amputate the haptic and leave it in place to avoid zonular damage.

Extraction of Existing IOL

The primary goal of IOL removal is to use the least invasive means to avoid damage to surrounding structures.

- Once the IOL is free from the capsular bag, lift the IOL into the anterior chamber.
- The IOL should be lifted using a Sinskey hook (or similar) instead of rotated to avoid stressing the zonules.
- Copious OVD should be placed above and below the lens.
- The two primary techniques of extraction are "folding" and the "cutting."
- There are several techniques to fold the IOL.
  - Taco fold: The surgeon may first place a spatula through a paracentesis wound 180 degrees away from the main wound so that it is laying across the optic. Using IOL insertion forceps through the main wound, one can fold the IOL over the spatula and remove the IOL from the eye. For this technique, the main incision may need to be enlarged slightly.
  - Twist and Out.[6] One haptic is first externalized through a 2.2- mm corneal incision. A spatula is inserted through a paracentesis and placed over the IOL in a position to protect the corneal endothelium. A straight tying forceps is used through the main wound to grasp the proximal optic haptic junction. The lens is then twisted and rolled out of the main incision. (see Video 41.1: Twist and Out IOL Exchange).
- To cut the lens, hold the IOL in place with intraocular forceps to stabilize and prevent rotation. Use intraocular scissors to cut the lens completely or partially in half and pull the halves through the main wound. (see Video 41.2: IOL Exchange). A partial cut most of the way across the optic will allow a one piece removal with the second half hinged to the first. Cutting into more than two pieces is also acceptable.
  - There are also reports of using femtosecond laser to transect acrylic foldable IOLs.[7]
  - Complications may include vitreous loss if the posterior capsule was violated either during IOL removal or preoperatively (previous capsular rupture or previous yttrium-aluminum-garnet capsulotomy), damage to iris, zonular fibers, or corneal endothelium.
- An anterior chamber maintainer can be beneficial in many of these cases.
- In cases of capsular phimosis, the anterior capsular opening may need to be enlarged with sharp dissection or even with a femtosecond laser. (see Video 41.3: IOL Exchange with Capsular Phimosis).
- In some cases, an IOL will be removed in one piece in its planar orientation.
  - Implants that are made of polymethyl methacrylate (PMMA) are rigid and cannot be folded. The wound will need to be as large as the IOL optic diameter.
  - If one is planning to place a PMMA implant, it will require a larger wound, irrespective, thus no need to fold or cut the *in-situ* implant in this instance.
- It is important to be prepared for anterior or pars plana vitrectomy.

Placement of Secondary Intraocular Lens

The surgeon has four potential options for fixation of secondary IOLs (Fig. 41.1).

- Capsule fixated options:
  - In-the-bag if the bag, anterior capsulorrhexis, posterior capsule, or posterior capsulorrhexis are intact (or could be made to be circular and contiguous)
  - Sulcus placement with optic capture through an intact anterior capsulorrhexis, posterior capsulorrhexis, or both
  - Passive sulcus fixation
- Scleral fixation:
  - Sutured
  - "Glued" (intrascleral haptic fixation in tunnels)
  - "Yamane" flanged intrascleral haptic fixation
- Iris fixation
- ACIOLs

CAPSULE OR SULCUS-SUPPORTED INTRAOCULAR LENS

- Passive sulcus fixation requires an intact anterior capsule plane and complete 360-degree zonular support.
- Optic capture through either an existing or recreated anterior or posterior capsulorrhexis should be performed whenever possible to increase IOL stability, decrease risk vitreous prolapse, and decrease myopic shift to improve refractive outcome.[8]
- If optic capture is achievable, IOL power should be unchanged from an in-the-bag IOL.
- If optic capture cannot be accomplished for a sulcus IOL, the IOL power may need to be reduced by 0.5 to 1 D compared with in-the-bag power depending on the power of the lens. The magnitude of this adjustment in power increases with IOL power.
- Single-piece flexible IOLs are unsuitable for the sulcus and have been associated with higher incidences of complications including iris defects, IOL decentration, and UGH syndrome.[9]
- Single-piece PMMA posterior chamber IOLs with large optics and long haptic-to-haptic lengths are ideal for sulcus stability, but require larger wounds for insertion.

SCLERAL-FIXATED INTRAOCULAR LENS

Scleral-fixated IOLs can be divided into sutured and sutureless techniques. Most of these techniques require a thorough anterior vitrectomy. An anterior chamber maintainer is required to maintain intraocular pressure during surgery. A pars plana infusion also can work. There are times that the infusion should be halted to allow for lens insertion and to avoid iris prolapse when the wounds are open.

SCLERAL-SUTURE FIXATED INTRAOCULAR LENSES

Scleral-sutured lenses can be sutured from inside the eye *(ab interno)* or by passing either needles or forceps from the outside of the eye to inside *(ab externo)*. Malbran et al. first introduced an *ab interno* technique for creating two suture loops within the eye to which each IOL haptic is hitched through a corneal incision or during an "open sky" procedure. Each suture loop is secured and tied 2 mm posterior to the limbus.[10] In the 1990s Lewis described an *ab externo* approach by using a straight needle carrying a 10-0 polypropylene suture.[11]

- Torque vs. tilt
  - Torque refers to a vector force acting on an object, in this instance, an IOL, which induces rotation of that object around an axis. IOL tilt refers to the implant being oriented at an angle to the pupil rather than planar. Torque is a force that can induce tilt.
- Torque and sutures
  - Two-point versus four-point fixation: when a suture is affixed to an implant haptic at one point on each haptic, that is considered "two-point fixation." If there are two points on each side of the lens where the sutures are affixed to the haptic, this is considered "four-point fixation."
  - If there are two horizontally oriented openings in the scleral wall for the suture but the suture is passed directly through an eyelet or around the haptic, then one arm of the suture will be

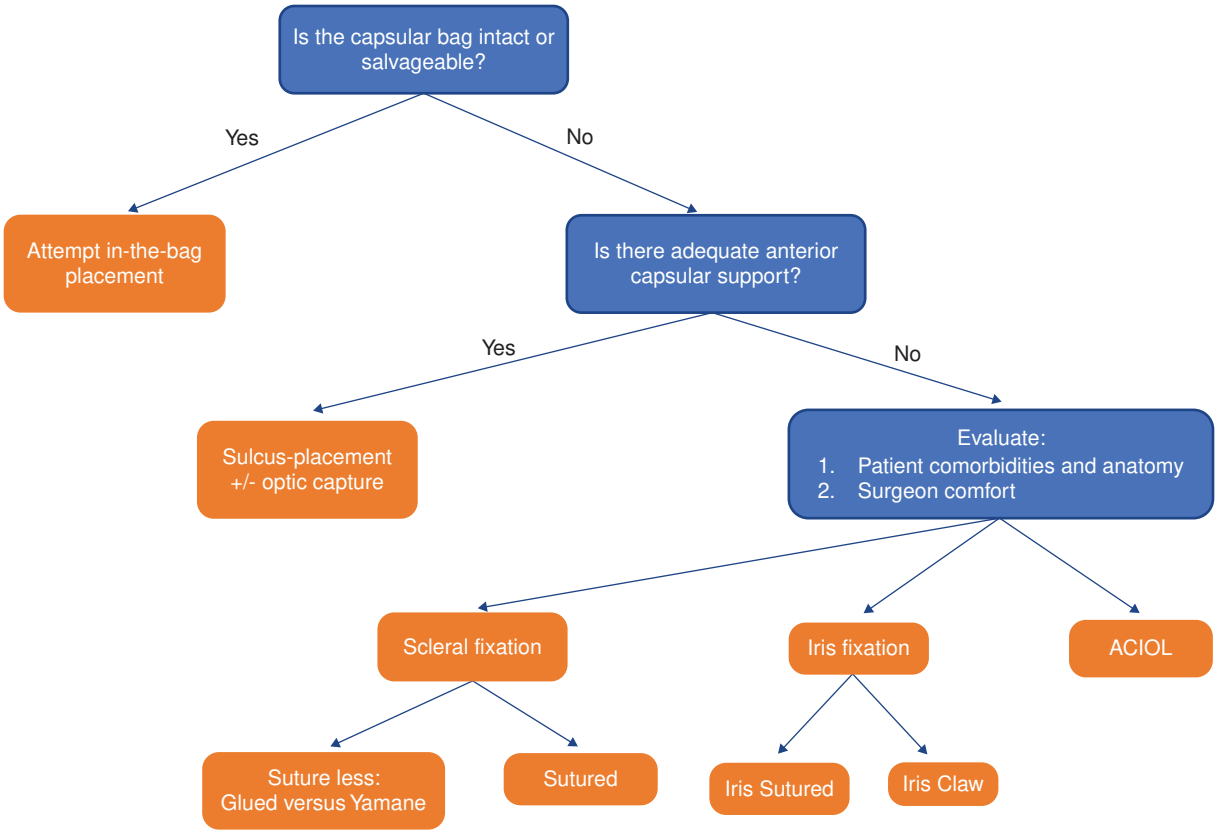

Fig. 41.1 An algorithm to guide decision making on placement of secondary IOLs. The most stable placement is generally in-the-bag placement with intact capsular bag. If the posterior capsule is compromised, an intact anterior capsule can still allow for sulcus IOL placement with (preferred) or without optic capture. If no capsular support is available, the decision must be made to fixate an IOL to sclera or iris or to place an ACIOL. Patient factors such as health of iris, conjunctiva, scleral, and corneal endothelium and risk for hemorrhage should be considered, as well as surgeon experience. The authors prefer the Yamane sutureless scleral fixation when capsular support is unavailable.

above the haptic and the other below. As the suture is tightened, it induces torque on that haptic. If the opposing haptic is affixed in the same way, torque will occur there as well. With this orientation, tilt will occur unless the torque on each haptic is exactly equal and opposite. Two-point fixation has the risk for IOL tilt with some studies finding a two fold increase in mean IOL tilt angle compared with in-the-bag IOLs.[12]

- If both arms of a horizontally oriented suture loop are on the same side of the IOL haptic (both above or both below), then there will be no torque applied, and if the scleral openings are the same distance from the limbus, the IOL will be planar.
- Several suture patterns can result in a "no torque" configuration. (Fig. 41.2). Using the suture configuration shown in Fig. 41.2B, Ogawa and colleagues have demonstrated in two large single-surgeon, single-technique studies (one using 9-0 polypropylene and the other using CV-8 polytetrafluoroethylene [ePTFE]) no tilt in over 400 sequential cases using the same technique. The study on the 9-0 polypropylene group had an average 10.8 years of follow-up.[13,14]

- Suture material
  - Nonabsorbable and with acceptable tensile strength.
  - Transscleral 10-0 polypropylene has been shown to degrade.
    - 0% to 27% occurring from 3 to 9 years postimplantation.[15–17]
    - 9-0 or 8-0 polypropylene may have a longer functional "lifespan."
  - CV-8 expanded polytetrafluoroethylene (Gore-Tex, W. L. Gore & Co., Newark, DE, USA).
    - High tensile strength
    - Does not degrade
    - Off label for ophthalmic use
- Lens material/design
- No IOLs are Food and Drug Administration (FDA) approved for sulcus fixation.
  - PMMA
    - Alcon CZ70BD, one-piece PMMA with eyelets ("positioning holes") at the apex of each haptic
    - Rigid, stable
    - Large, 7.0- mm optic
    - Requires 7- mm scleral tunnel wound
  - Hydrophilic acrylic
    - Akreos AO60
    - Four "haptics" with apertures through which sutures can be passed
    - Can be placed through a small corneal incision
    - Can opacify with intravitreal or anterior chamber gas/air bubbles[18]
    - Shorter than sulcus so is "suspended" by scleral sutures
      - Can ballotte if sutures are too loose
      - If sutures are tight, can induce lenticular cylinder

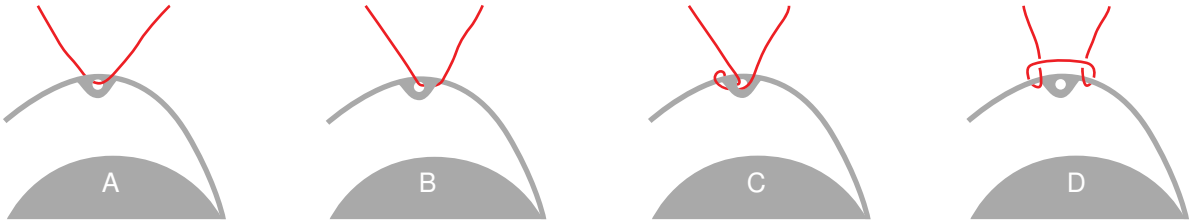

Fig. 41.2 (A) Simple suture passed through an eyelet around a haptic with one arm above and the other below (two-point fixation, induces torque). (B) Suture through eyelet, but both arms of the suture are above the haptic and cross in separate areas (four-point fixation, no torque). (C) Suture loop passed through eyelet and then looped over the end of the haptic, but both arms of the suture are above the haptic and cross in separate areas (four-point fixation, no torque). (D) Suture loop is folded over itself and slipped over the haptic with a "cow hitch." Both arms of the suture are above the haptic, are spaced apart by the eyelet, and cross in separate areas (four-point fixation, no torque).

  - Hydrophobic acrylic
    - The Bausch & Lomb enVista MX60
    - Has a single aperture at each haptic optic junction
    - Recent reports of eyelet fracture intraoperatively and postoperatively[19,20]
- Four-point scleral fixation technique: general principles (see Video 41.4: Scleral-Sutured IOL and Video 41.5: Scleral-Sutured IOL, Snyder variation 2 with suture placement before fixated to IOL).
  - Use of an anterior chamber maintainer or pars plana infusion line decreases the risk for intraoperative hypotony and increases procedure facility.
  - Wound
    - 7- mm scleral tunnel for rigid PMMA IOL
    - Corneal wound for foldable IOL
  - Sclerotomies to sulcus level
    - Two pairs of openings 180 degrees apart
      - Full-thickness sclera
      - Sclera with a groove between the openings
      - Under a scleral flap
    - Limiting or avoiding cautery in area of sclerotomies may reduce late suture exposures.
  - For four-point, tilt less, centration-adjustable technique, sutures are retrieved first with suture loops left out of the wound.[21]
  - Suture loops affixed to haptics.
    - Cow hitch
    - Passed through aperture
  - For passing sutures through apertures, suture retrieval follows affixing the suture to the IOL.
  - The sutures are tightened fully for PMMA IOL; tension titrated to centration for foldable, shorter IOLs.
  - The sutures are then tied off and knots are either rotated into the sclerotomies or buried in the sclera under a flap.[22]
    - If knot is buried inside the scleral wall, place through counterclockwise sclerotomy at each paired site.
    - For centration adjustable technique, the suture can be slid back and forth to fine-tune centration.
- Scleral flaps, grooves, or Hoffman pockets
  - Some surgeons prefer to make sclerotomies directly and have the suture rest on the episcleral surface between the two paired sclerotomies.
  - Some surgeons prefer to place sutures under a scleral flap.
  - Anecdotally, avoidance of cautery in the area of external suture placement may reduce the incidence of suture erosions.
  - A "Hoffman pocket" in which a limbal groove is created and a tunnel is performed going mid-thickness from limbus into scleral wall allows a knot to be placed and tied within the pocket, thus avoiding a surface knot and avoiding conjunctival dissection.[23] However, there are reported cases of Gore-Tex suture erosion through the roof of Hoffman pockets.

SUTURELESS SCLERAL FIXATION

Sutureless haptic fixation has been gaining popularity because of the absence of complicated intraocular suture manipulation and suture-related breakage or erosion. These sutureless techniques involve embedding the haptics of a three-piece IOL within the sclera.[24] There are currently two main methods of intrascleral fixation: flanged and "glued" techniques in which the haptic is slid into a 26-G "Sharrioth" scleral passageway and the overlying scleral flap is closed with fibrin glue.

With any scleral-fixated IOLs, placing a peripheral iridotomy can decrease the risk for pupillary block and pupil capture.[25]

Flanged Technique

In the flanged technique, which was first described by Yamane in 2017, the ends of the haptics of a three-piece IOL are bought through the sclera, and the tips are cauterized. This creates an end-bulb flange to fixate just inside the sclera.[25,26] This technique has gained popularity recently because of its relative ease (after the initial learning curve), quick visual recovery, and excellent outcomes. This is the author's technique of choice for secondary IOL fixation and is illustrated in Fig. 41.3. (see Video 41.6: Double Needle).

To perform this technique:

- Two transconjunctival sclerotomies are made 2.5 mm from the limbus in an average eye, exactly 180 degrees from each other, generally at 1:00 and 7:00, using a bent, half inch, thin-walled, 30- G needle.
- Each haptic is grasped with intraocular microforceps from within the anterior chamber and fed carefully into the lumen of each of the needles.
- The haptics are then externalized.
- The tips of the haptics are cauterized with low-temperature cautery to create the flanges to prevent dislocation of the haptics back into the eye.
- The IOL haptic is then pushed to embed the tip in the sclera.

The intrascleral portion of the haptic pass might be long or short and the path may be difficult to accurately orient in one plane, so IOL

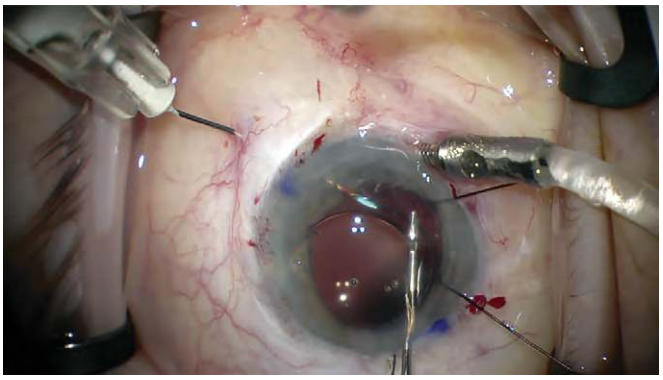

Fig. 41.3 Sutureless scleral fixation with Yamane technique. The three-piece IOL has been inserted into the anterior chamber. The cornea has been marked with two blue marks exactly 180 degrees apart. A 25-G forceps (Alcon MAXGrip) is used to grasp the haptic, which is fed into a 30-G thin-walled needle. The placement of the needle is 2.5 mm peripheral to the limbus at one blue corneal mark. The first haptic should not be externalized until the second haptic has been captured by a second 30-G needle. Note that an anterior chamber maintainer is placed inferotemporally (for right eyes) to maintain firm intraocular pressure. Iris hooks were used in this patient for a prior dislocated IOL removal.

tilt can be a problem, even if the optic is centered. Because few, if any, three-piece IOLs are planar, there is torque at each haptic. The torque must be equal and opposite to ensure the absence of tilt. Postoperative tilt can be detected and estimated by simple alignment of the Purkinje 1, 3, and 4 reflexes using a muscle light or quantified with anterior segment OCT or ultrasound biomicroscopy.[27–29] In Yamane's original paper, reported average IOL tilt was 3.4 degrees +/− 2.5 degrees in 96 patients.[26] Intraoperatively, if IOL centration is poor or the IOL is found to be tilted, it is most likely a result of uneven haptic length, tunnel length, or tunnel location:

- First, it is important that the two needle sclerostomies must be exactly 180 degrees apart where they enter the eye internally.
- The fixation points should be the same radial distance from the limbus.
- Scleral pathways must be consistent in both length and direction.[25,30] In one case series, Kurimori found that, in two patients with IOL tilt of 25.3 and 38.1 degrees, shortening the haptics by 2 mm and 3 mm decreased tilt to 7.7 and 5.7 degrees, respectively.[27]
- In a study of 488 eyes in a single surgeon case series by Abbey:
  - Dislocation of the IOL occurred in 6.6% of 189 eyes undergoing flanged intrascleral haptic fixation.
  - Six eyes (1.2%) had scleral erosion with haptic exposure.
  - Two of those six eyes (0.4% of the total) developed endophthalmitis as a result of exposure.[31]
- Lens material/design:
  - The ideal IOL for the flanged technique is an IOL with PVDF haptics that have a high flexibility and high memory (i.e., Zeiss CT Lucia)
- Extruded PMMA haptics may also work but are not as durable and have a higher probability of kinking the haptic intraoperatively.
  - Polyamide haptics may degrade and crumble when affixed in intrascleral tunnels.
  - Optics with a sharp anterior edge should be avoided because they can result in significant pigment dispersion and photophobia. Even smooth-edged optics can cause pigment dispersion.

"Glued" Sharioth Pocket Technique

First published in 2008 by Gabor Sharioth.[32]

- A peritomy at the site of exit of the IOL haptics is first performed.
- Partial-thickness scleral flaps are made exactly 180 degrees apart.
- A 20-G needle is used to create a sclerotomy 1 mm from the limbus under the scleral flap, and the needle is directed toward the center of the globe.
- One haptic of a three-piece IOL is injected into the AC and grasped at the tip with a 23-G forceps inserted through the sclerostomy site.
- As the three-piece IOL is injected into the AC, the injector is slowly withdrawn so that the trailing haptic is released outside of the eye.
- The first haptic is externalized and the trailing haptic is subsequently grasped at the tip and externalized.
- A bent 26-G needle is used to create scleral tunnels at the edge of the flaps parallel to the limbus.
- The haptics are "tucked" into these pockets. The IOL is held in place by the friction in the pocket.
- The area is dried and fibrin glue applied under the scleral flap. The glue keeps the flap down and seals the 20-G sclerotomy to reduce hypotony.[33,34] (The glue does not actually secure the IOL, as the fibrin is rapidly degraded.)

IRIS-FIXATED POSTERIOR-CHAMBER INTRAOCULAR LENS

Iris fixation is becoming less common as scleral-fixated IOL placement becomes more popular. However, iris fixation is still a useful tool to have accessible, especially if the three-piece lens is in the sulcus and dislocated or the conjunctiva needs to be spared. We recommend it only if there several clock hours of remaining capsule, which will serve to prevent excessive pseudophakodonesis.

Most commonly, iris fixation is performed by fixation of the haptics of a PC-IOL to peripheral iris with a technique known as *McCannel suturing*, eponymically named for Malcolm McCannel. The McCannel suture uses a long straight or curved needle to pass through the iris around the IOL elements and back through the cornea. The Siepser knot may then be performed, retrieving a loop of suture by partially externalizing the distal arm of the suture and tying a slipknot, which is tightened within the eye.[35] In the Weikert modification, the two arms of the suture are first crossed before externalizing the suture loop.[36] This creates a square knot when finally tightened. (see Video 41.7: Iris-Sutured IOL).

Most surgeons prefer a 9-0 or 10-0 polypropylene. The key to good iris fixation is taking as small and as peripheral bites of iris as possible. Long bites close to the pupillary margin distort pupil shape and reactivity. Constricting the pupil is helpful for this reason.[35,37] Thin, round haptics are required for cosnsideration of iris suturing.

Iris "claw" IOLs have also been used as secondary IOLs for both phakic and aphakic patients. These IOLs can be placed anterior or posterior to the iris plane and are secured to the iris via enclavation in which the IOL "claws" entrap small snips of midperipheral iris tissue.[38,39] The Artisan iris claw IOL has demonstrated safety and efficacy in Europe; however, it is not currently available in the United States (except for minus lenses for treatment of myopia) and is still actively undergoing investigation.[37,40]

Iris fixation of IOLs, either by suture or by claw enclavation, can result in pressure necrosis and other "field effects" causing iris atrophy at and around the fixation point. This can result in late dislocations of the implant. Of course, IOLs with a square anterior edge should be eschewed for iris fixation.

ANTERIOR-CHAMBER INTRAOCULAR LENSES

ACIOLs have fallen out of favor because of their higher risk for chronic postoperative inflammation and risk for both corneal endothelial cell loss and damage to the trabeculum. They also require a larger wound

of around 6.0 mm.[41,42] Modern-day flexible open loop ACIOLs have less risk than their closed-loop ancestors.[43,44] They can be an acceptable option in the right patient, especially if the surgeon has no experience with iris or scleral fixation.

Selecting the correct sizing of the ACIOL is essential for decreasing complication rates. Lenses that are too small may lead to increased IOL movement, leading to endothelial damage, corneal edema, and CME. Lenses that are too large may lead to chaffing of anterior angle structures, iris damage with pupil ovalization, and resultant secondary glaucoma. The optimal sizing is thought to be 0.5 to 1 mm larger than the horizontal white-to-white measurement; however, these are surrogate measurements, and the sizing can still be off, even when following these guidelines.[43]

The surgical technique for insertion requires a 6-mm corneal or limbal incision because no available ACIOL is foldable. (see Video 41.8: Anterior Chamber IOL). A lens glide can be used to ease insertion. The pupil is constricted to open up the angle, and a peripheral iridotomy needs to be performed to decrease risk for pupillary block. The surgeon should check for roundness of the pupil post implantation. Any peaked or oval pupil may indicate iris incarceration, leading to higher rates of postoperative complications.[45] Intraoperative gonioscopy (after wound closure) to confirm the absence of iris tuck can be helpful.

ACIOLs should be used with additional caution or avoided in younger patients and those with decreased endothelial cell counts, chronic ocular inflammatory disease, abnormal irides, shallow chambers, glaucoma, or compromised angle structures.

COMPLICATIONS OF SECONDARY INTRAOCULAR LENSES

Studies evaluating the outcomes of secondary IOLs are limited by diverse confounding factors and heterogeneous preoperative pathology. Furthermore, studies of new techniques developed within the past half-decade are limited in their follow-up time. The advantages and disadvantages of different methods of IOL stabilization are outlined in Table 41.1.

INTRAOCULAR LENS MALPOSITION AND TILT

- IOL positioning and stability is highly dependent on technique and surgeon experience.
- IOL tilt can cause induced lenticular astigmatism, loss of best-corrected visual acuity from coma, and/or glare postoperatively.
  - Clinically significant IOL tilt in 10-0 polypropylene scleral-sutured IOLs ranges from 0% to 10.4%.
  - Significant IOL tilt has been reported less frequently in sutureless scleral-fixated IOLs from 0% to 1%; however, follow-up time for sutureless techniques is also shorter given their recent development.
  - IOL tilt can increase risk for pupillary capture, which ranges from 0% to 9.6% for scleral-fixated IOLs, sutureless-PC-IOLs, iris claw, and ACIOLs.[46]
- Pupil capture can occur with a perfectly positioned scleral-fixated PC-IOL from posterior bowing of the iris. Peripheral iridotomy(ies) can help mitigate that risk.

TABLE 41.1 Advantages and Disadvantages of Different Options for Secondary Intraocular Lenses

Technique		Advantages	Disadvantages
Scleral-fixated	Scleral sutured IOL	• Does not require capsular/iris support • Minimizes uveal contact • Can attempt four-point fixation to decrease IOL tilt • No haptic-related complications	• Risk for suture exposure and erosion, especially if thin scleral flap • Risk for decentration and dislocation • More technically difficult • Increased operating time • Suture-related endophthalmitis • Risk for CME and glaucoma
	Sutureless scleral-fixated	• Does not require capsular/iris support • Minimizes uveal contact • No suture-related complications • Short surgical time	• Only short-term data available • Only option of two-point fixation • Requires precision to decrease IOL tilt and decentration • Risk for haptic erosion/extrusion • Risk for haptic intrusion • Haptic-related endophthalmitis • Risk for CME and glaucoma
Iris-fixated	Iris sutured	• Requires minimal capsular support • Short surgical time • No manipulation of vitreous base	• Increased risk for chronic uveitis and pigment dispersion • Limited pupillary dilation and risk for pupillary distortion • Requires intact iris tissue • Risk for CME and glaucoma
	Iris claw	• No suture-related complications • Shorter surgical time	• Not yet approved by the U.S. Food and Drug Administration • Late decentrations • Iris atrophy at and around enclavation sites • Risk for CME and glaucoma
Open loop anterior-chamber IOL		• Newer designs have decreased risk for endothelial cell loss than closed loop ACIOLs • Less surgical dexterity required	• Requires intact iris tissue • Higher risk for corneal decompensation, and uveitis • Not appropriate for shallow chambers, compromised angle structures, or younger patients • Risk for CME and glaucoma

Optimal placement of secondary IOLs will depend on patient anatomy, such as iris/capsule support, narrow angles, and thickness of sclera. Patients with intact capsules or iris will ultimately have the most options for IOL placement. Patients with certain comorbidities such has history of uveitis or glaucoma may not be the best candidates for certain techniques.

- IOL dislocation:
  - 10-0 polypropylene sutured IOLs have the highest reported rates of OL dislocation, between 0% to 28% with a mean dislocation time of 50 +/− 28 months.[15,46]
  - Suture breakage is the most common cause of IOL dislocation.
  - Kinking or overhandling of suture may increase the rate of suture breakage.
  - Using 9-0 polypropylene suture may delay suture breakage.
  - Breakage of CV-8 ePTFE suture used for IOL fixation has never been reported.
  - For sutureless scleral-fixated IOLs, reported rates of haptic dislocation range from 0% to 5.7%.[46]

POSTOPERATIVE UVEITIS

Iris manipulation and suturing can increase risk for chronic uveitis.

- Most studies report rates of postoperative uveitis of less than 5% in secondary IOLs.
- Iris claw IOLs shows slightly higher rates of postoperative uveitis.
- CME rates were highest in iris-fixated IOLs in one study compared with scleral-sutured IOLs, sulcus IOLs, or ACIOLs. However, other older studies showed that scleral-sutured IOLs had higher rates of CME than iris-fixated lenses in patients undergoing concurrent penetrating keratoplasty, which adds a confounding factor.[42,46,47]
- Inflammatory sequelae are likely technique, IOL design, and comorbid pathology dependent.

IRIS CHAFE

Loss of iris pigment can occur because of the IOL edge rubbing against the posterior iris surface if a sharp-edged IOL is used. Sometimes this can be bad enough to stimulate pigment dispersion glaucoma or create photic symptoms severe enough to precipitate need for an iris prosthesis placement (Fig. 41.4).

SUPRACHOROIDAL HEMORRHAGE

Suprachoroidal hemorrhage is a devastating potential complication.

- The incidence is extremely rare.
- Highest rates reported in scleral-sutured IOLs (3.3%–4.2%), although these numbers are at least ten fold higher than the editors have found in their own clinical cohorts.
- Risk factors include prolonged intraoperative hypotony.[46] This can be obviated by use of an anterior chamber maintainer or pars plana infusion line.
- There have been no studies to provide insight on the incidence of suprachoroidal hemorrhage with ACIOL, iris-fixated IOLs, or sutureless scleral-fixated IOLs.

POSTOPERATIVE ENDOPHTHALMITIS

Postsurgical acute endophthalmitis generally occurs on average 9 days after cataract surgery.[48] Larger wounds required for rigid IOLs may theoretically increase the risk for acute endophthalmitis; however, reported rates are still quite low (0%–2.6%). Delayed endophthalmitis (defined as >6 weeks postoperatively) may present related to late suture exposure after scleralsutured IOLs. Scleral thinning, shallowly placed knots, and larger knots may predispose to knot erosion and exposure. Reported rates of suture erosion range from 0% to 8%.[46] Ogawa and colleagues in their two studies, both of which tucked knots internal to the eye wall, had zero suture exposures in 422 combined total patients with up to 16 years follow-up.[14] Additionally, some surgeons have recommended leaving the ends of sutures long, so that they lie flatter within a flap; however, the efficacy of this has not been evaluated. Haptic erosion through the sclera has also been reported to occur in scleral-glued IOLs as well.

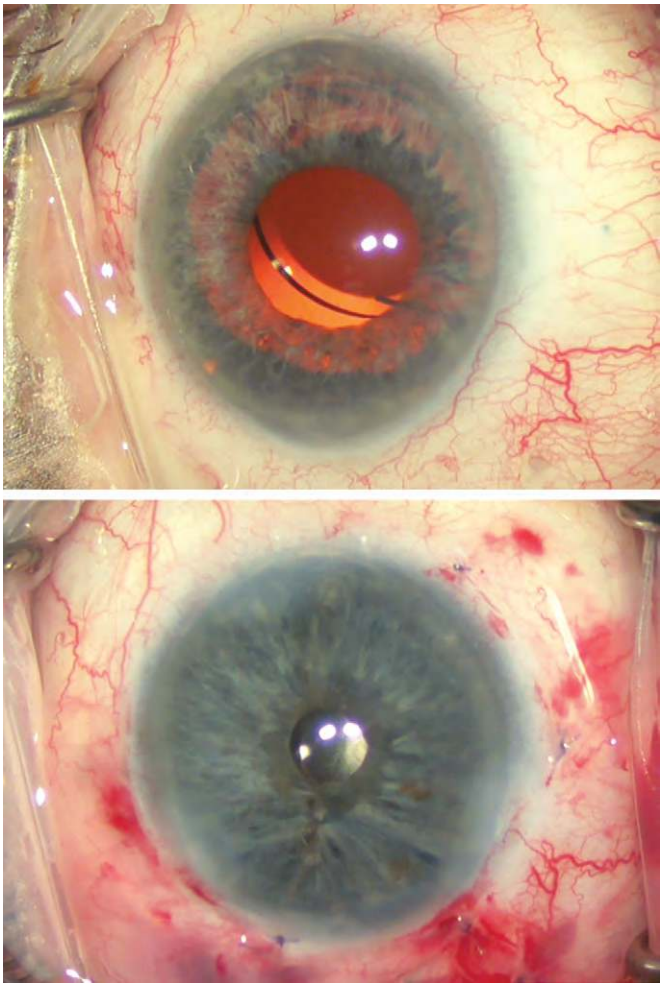

Fig. 41.4 Top, Severe iris pigment epithelial loss from chafe of the IOL edge against the posterior iris surface. The uniformity of the pigment loss and the significant retroplacement of the lens currently suggests that the damage occurred when the lens was in a central and planar position. Prophylactic iridotomies (not present here) reduce iridodonesis and thereby reduce the risk for pigment loss. The IOL had subluxated due to intrusion of one haptic. The other haptic tip is seen in the scleral wall on the right side of the image, superiorly. Bottom Same eye after IOL exchange and implantation of black custom, flexible iris prosthesis (CustomFlex ArtificialIris, HumanOptics AG, St. Augustine, Germany.) Case of Michael Snyder, MD.

RETINAL DETACHMENT

Retinal detachment rates are always increased during complex cataract surgery if the vitreous face is disrupted. Furthermore, passing sutures near the vitreous base may also increase the risk for retinal breaks and vitreous traction. Reported rates of retinal detachment were highest in studies evaluating 10-0 polypropylene sutured lenses (4.2%–8.2%) and lowest for iris claw, ACIOL, and sutureless intrascleral-fixated IOLs (0%–1%).[46]

REFRACTIVE OUTCOME

Refractive outcome may be best with capsule-fixated sulcus IOLs with optic capture. Refractive outcome after ACIOLs, scleral-sutured IOLs, scleral-haptic fixated IOLs, and iris-fixated IOLs have been shown to be satisfactory and not significantly different.[47,49]

SUMMARY

- The key to IOL exchange is removal of the existing IOL without damage to capsular bag.
- There are many different options for patients who require secondary IOLs.
- Although in-the-bag capsular-fixated IOLs remain ideal followed by sulcus IOL placement with optic capture, patients can still achieve anatomic and refractive success in the absence of capsular support.
- IOL tilt is the most common difficulty after scleral-fixated IOLs, especially in two-point fixation, and can be decreased with careful technique.
- For sutured IOLs, the haptic-suture orientation is critical in preventing tilt.
- Maintaining globe pressure with an infusion line through either an anterior chamber maintainer or pars plana infusion reduces hypotony associated risks and makes the procedure's execution more facile.
- Polypropylene suture material degrades over time, although ePTFE does not.
- For scleral sutured techniques, erosions are rare if knots are tucked internally.
- There is still a need for further research on the long-term outcomes of many secondary IOLs, particularly for newer techniques such as sutureless intrascleral-fixated IOLs, as IOL subluxation and haptic exposure seem to occur in a nontrivial number in the short to intermediate-term and long-term results are as yet unknown.

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Video 41.1 Twist and Out IOL Exchange, Uday Devgan, MD. Dr. Uday Devgan demonstrates the "Twist and Out" technique of IOL removal in which a spatula is used to protect the corneal endothelium and the IOL is grasped by intraocular forceps and then twisted and removed from the eye through a 2.4- mm incision.

Video 41.2 IOL Exchange, Zaina Al-Mohtaseb, MD. Dr. Zaina Al-Mohtaseb demonstrates an IOL exchange in which the IOL is freed from the capsule, prolapsed into the anterior chamber, bisected using intraocular scissors, and removed from the eye.

Video 41.3 IOL Exchange with Capsular Phimosis, Douglas Koch, MD. Dr. Douglas Koch demonstrates two cases of IOL exchange in patients with capsular phimosis. In one case the anterior capsular opening is enlarged with intraocular forceps. In the second case the anterior capsular opening is first enlarged with femtosecond laser. The haptics are found to be adherent to the capsular bag and are cut from the optic and left in place.

Video 41.4 Scleral-Sutured IOL, Zaina Al-Mohtaseb, MD. Dr. Zaina Al-Mohtaseb demonstrates scleral-sutured IOL placement with four-point fixation using Gore-Tex suture with a cow-hitch knot.

Video 41.5 Scleral-sutured IOL, Michael Snyder, demonstrating another method using girth-hitch knots.

Video 41.6 Double Needle, Zaina Al-Mohtaseb, MD. Dr. Zaina Al-Mohtaseb demonstrates sutureless sclera fixation of a three-piece IOL in a patient with no capsular support. The haptics of the IOL are withdrawn through the sclera using two 30-G needles placed exactly 180 degrees apart. Heat is used at the end of the haptics to create a flange to permit intrascleral fixation.

Video 41.7 Iris-Sutured IOL, Douglas Koch, MD. Dr. Douglas Koch demonstrates an iris-sutured IOL in a patient with no capsular support. A three-piece IOL is sutured to the iris with 9-0 polypropylene suture using a Siepser knot with Weikert modification. Pupillary distortion is minimized using peripheral iris bites.

Video 41.8 Anterior Chamber IOL, Douglas Koch, MD. Dr. Douglas Koch demonstrates placement of an anterior chamber IOL in which the corneal diameter is measured for the appropriate IOL size, and IOL is placed into the anterior chamber through a large limbal corneal incision.

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Traumatic Cataract

Mauricio A. Perez Velasquez, Mahshad Darvish, and Michael E. Snyder

CONTENTS

KEY POINTS

- Traumatic cataracts are caused by either blunt or penetrating ocular trauma, causing varying degrees of lenticular opacity.
- They can be associated with damage to adjacent structures such as the iris, the trabecular meshwork, and the zonular apparatus.
- The management of a traumatic cataract includes different areas of anterior segment reconstruction, such as iris repair, zonular weakness management, and secondary intraocular lens fixation techniques.

INTRODUCTION

The surgical approach to a traumatic cataract will likely involve most topics in anterior segment reconstruction. Its presentation varies widely, from a very mild and focal, clinically insignificant lenticular opacity to a complete destruction of the crystalline lens, and it can result both from blunt and open ocular trauma (Fig. 42.1). It is the surgeon's responsibility to try to anticipate all possible scenarios and to be prepared, both logistically and technically, with diverse surgical techniques.

This chapter attempts to provide a complete algorithm to deal with the traumatic cataract patient, from the initial clinical exam to its surgical resolution and eventual final reconstruction.

CAUSES

Traumatic cataracts can be the result of diverse injuries ranging from mild blunt trauma, which can result in a focal asymptomatic lenticular opacity, to severe penetrating lesions caused by a sharp object, which can result in total destruction of the crystalline lens and surrounding structures.

- Special attention is required when the mechanism of injury involves metal-on-metal activities, because a foreign intraocular object could inadvertently be missed.
- Ideally, imaging is recommended to rule out this complication if any areas are hidden to examination.
- The same level of attentiveness applies while dealing with pediatric cases, in which a traumatic cataract requires the ophthalmologist to at least suspect and rule out child abuse.

Preoperative Clinical Exam

The initial exam includes each step of a standard cataract exam but also adds important features to search for or rule out.

Vitreous Prolapse

- The presence of vitreous in the anterior chamber is a common feature in traumatic cataract cases, and its extent will vary depending on the severity of the ocular trauma and consequent zonular damage.
- Location and number of clock hours involved need to be documented.

In some cases, vitreous will not be evident during the initial clinical exam; therefore we strongly suggest "staining" it intraoperatively using diluted triamcinolone to facilitate its visualization during surgery[1] (Fig. 42.2 and Video 42.1).

Iris Status

Iris damage is commonly associated with traumatic cataracts. Trauma patients should first be examined at the slit lamp before dilation to ensure that mydriasis or sphincter tear is not overlooked. Common defects can be subdivided into structural or functional.

Structural Iris Damage

Structural lesions can be highly variable and should be noted as to both presence and extent.

- Iridodialysis
- Tissue loss (focal through subtotal)

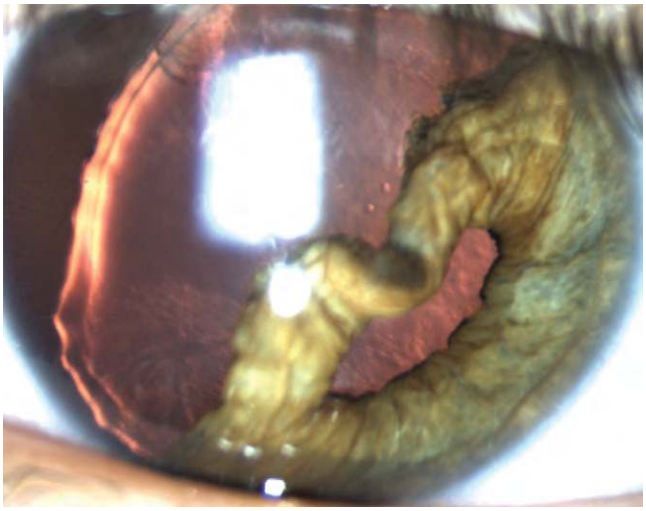

Fig 42.1 Traumatic cataract demonstrating lens opacity, zonulopathy, and a large iridodialysis. Also note the misshapen nature of the lens, confirming the younger age at which the trauma occurred.

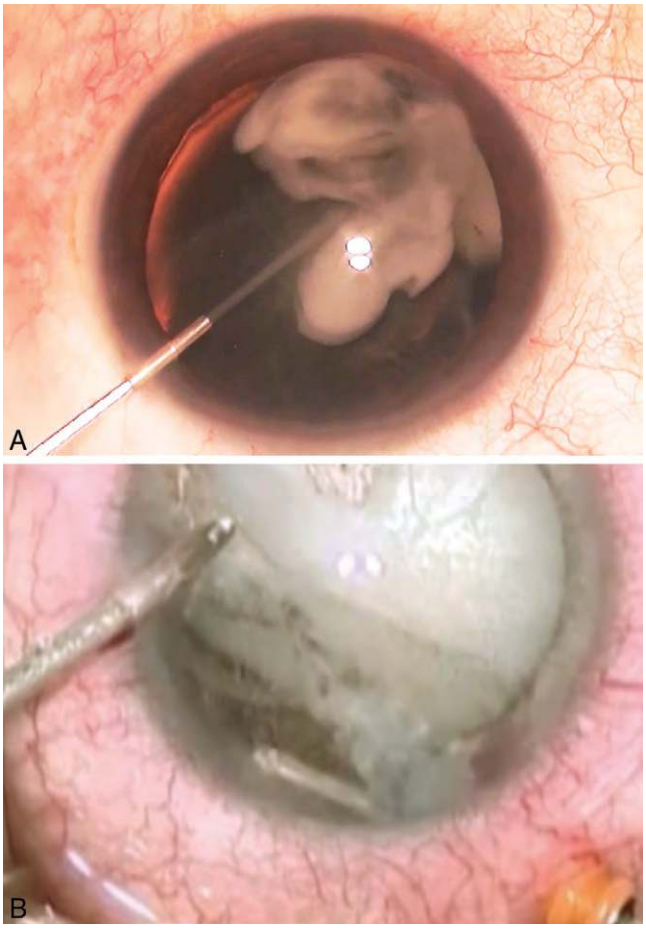

Fig. 42.2 Triamcinolone staining of vitreous prolapse seen with a stream of diluted triamcinolone entering the anterior chamber (A) and the particles suspended with vitreous gel prolapsing around the equator (B).

As a rule of thumb, an area of less than 3 clock hours of iris tissue loss is susceptible to primary reconstruction, depending on the "stretchability" of the tissue. Larger iris defects will require an iris prosthesis for an adequate functional and cosmetic result. This topic is covered in detail in Chapter 43.

Functional Iris Damage

Functional damage can be either from pigment loss or sphincter damage (or both).

- Iris pigment epithelial loss can be assessed by retroillumination (Fig. 42.3).
  - Stromal repair may restore cosmesis.
  - If there is inadequate iris pigment epithelium, photic symptoms are likely. In such cases, we recommend including healthy full thickness iris tissue over the translucent area of repair,[2] including intact iris pigment epithelium.
  - If there is inadequate tissue to close, an iris prosthesis may be considered.
- Mydriasis.
  - In isolated mydriasis, a cerclage suture is usually suitable.

If mydriasis is resulting from inflammatory disease, if the stroma is thinned, or if there is missing iris pigment epithelium, a prosthesis may be a better choice.

Zonular Weakness

After the initial slit lamp evaluation, a full *dilated* slit lamp exam is imperative:

- Define the extent of zonular impairment in clock hours and location.
- Identify different degrees of lens phacodonesis or subluxation; however, phacodonesis is sometimes less apparent after dilation as the zonules are put on stretch.
  - Look for areas with evident absence of zonules, under full pupillary dilation (Fig. 42.4).
  - Have the patient look off to one side, then rapidly look straight to see if the lens wiggles.
  - Another technique is to gently tap the globe through the lid from the side with your index finger.
  - Identify any:
    - Displacement of the lens?
    - Misshapen geometry?

Fig. 42.3 Iris pigment epithelium defect seen by retroillumination involving all of the temporal iris and much of the nasal iris. The misshapen cataract can be seen easily through the temporal iris tissue that has no remaining pigment epithelium.

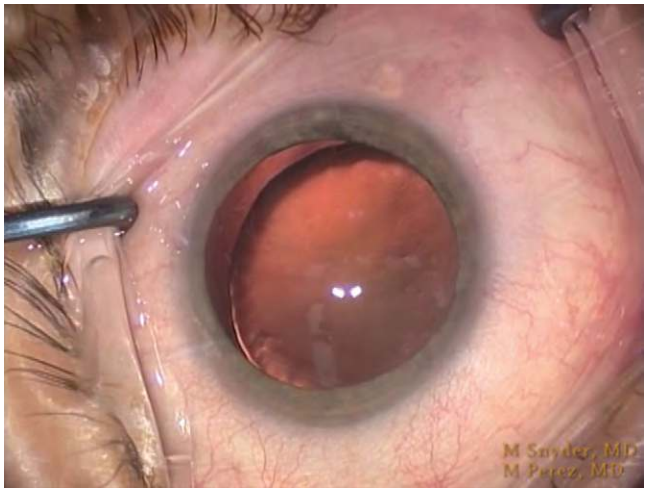

Fig. 42.4 Subluxated traumatic cataract with the equatorial edge visible through the dilated pupil and mild subluxation of the lens. The zonulopathy may have been missed without a full dilation.

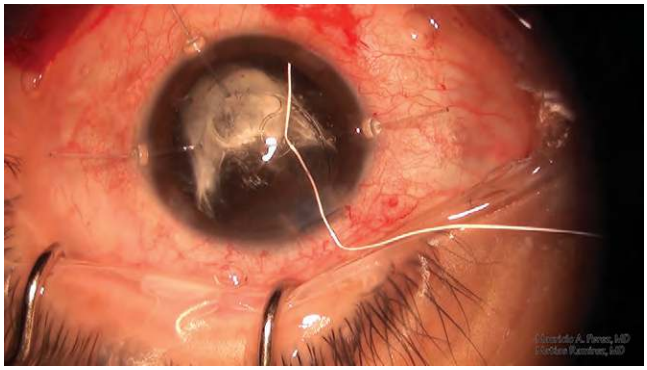

Fig. 42.5 Capsular tension segment threaded with ePTFE (Gore-tex) just before it is tucked into the capsule fornix.

Extent of Zonulopathy

The extent of zonular damage will determine which intraocular devices will most likely be required during surgery and will allow proper planning to ensure that the proper supplies are available in the OR. Use of devices is covered in the later section on surgical execution.

- Usually, with less than 3 hours of predicted zonular weakness, a standard capsular tension ring should be able to maintain long-term capsular bag stability.
- A device that can be sclerally fixated is likely advisable if:
  - There are more than 3 hours of zonular impairment.
  - There is lens displacement.
- D Options include:
  - "Cionni ring," also called a Modified CTR or MCTR. (Morcher GMBH, Stuttgart, Germany)
  - Capsular tension segment (or segments), commonly known as "Ahmed segment," [Morcher GMBH]) (Fig. 42.5).
  - AssiAnchor (Hanita Lenses, Kibutz Hanita, Israel) are also available outside the United States. An advantage of the AssiAnchor is that its fixation element is centrifugal to the peripheral capsule, so it does not induce torque, as occurs with an Ahmed segment, with the occasional very frustrating rotation of the segment out of the bag when the suture is tightened against fibrotic countertraction 180 degrees away. See Chapter 34 for more information and a video.
  - Suture material: For scleral fixation, for years, 10-0 polypropylene suture filled that role in anterior segment reconstruction, but its life span was limited to roughly 10 years on average[3]. Lately, expanded polytetrafluoroethylene (ePTFE) or CV-8 Gore-tex (Gore Medical, Newark, DE, USA) has surged as the leading (off-label) alternative because of its long-term fixation capabilities and decreased likelihood of intraoperative breakage during surgical manipulation.

Temporary disposable capsule hooks and iris hooks should be readily available in the operating room whenever zonulopathy cases are planned.

CAPSULAR STATUS

The capsular bag must be examined to determine both anterior and posterior capsular status, areas of tears and their extent, areas of fibrosis (Fig. 42.6), posterior iris synechia, and whether enough tissue remains to provide sufficient capsular support for intraocular lens implantation or whether the damaged capsular tissue remnants can be repaired to fulfill this role.

Intraoperatively, vital dyes, especially trypan blue,[4] are key to improve capsular visualization. They aid not only in the creation of a reliable capsulorrhexis but also in every cataract extraction step, especially to determine the location of any required intraocular devices related to the capsular bag (whether it was implanted in the sulcus or in the bag).

Trypan blue not only helps with visualization but also has been shown to interact with the capsular biomechanical characteristics, thereby reducing its elasticity.[5] This can be very helpful in counteracting the lack of zonular countertraction while dealing with a complex rhexis, specifically in younger patients where the elasticity is even higher. This biomechanical change can create some concerns, however, because decreasing elasticity also translates into increased fragility. In cases where capsular fragility could be an issue, a very useful alternative to trypan blue would be indocyanine green dye[6], which has similar dying capabilities with no biomechanical interactions. For cases in which the capsule is incarcerated in a corneal scar, special dissection techniques will be required to free the adhesions.[7]

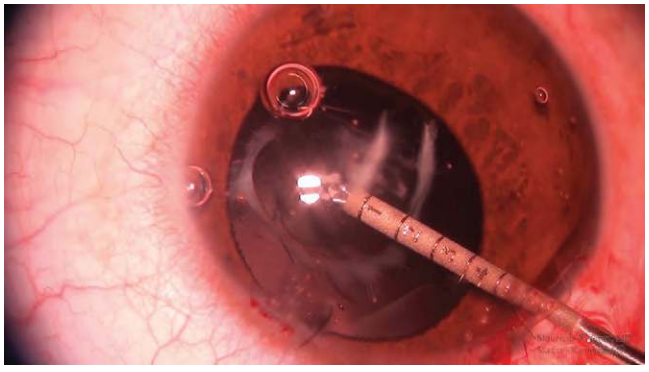

Fig. 42.6 Fibrotic capsule remnants.

ANGLE STATUS

Gonioscopic examination is recommended in every patient with ocular trauma to determine the status of the trabecular meshwork, the presence or absence of anterior synechia, angle recession, or a cyclodialysis cleft. Gonioscopy could be delayed in cases of concomitant hyphema because it could potentially stimulate a rebleeding.

IMAGING

- **B-Scan:** Retinal examination can be difficult to perform because of media opacity typical of any cataract, which can be significant in traumatic cases. Because the retinal status needs to be determined to predict the visual prognosis, B-scan ultrasonography can be helpful to at least recognize major landmarks (Fig. 42.7).
- **UBM and Anterior Segment OCT:** These two different technologies can be helpful in determining posterior capsular status. This is a key piece of information when planning the surgical steps required to face a particular case of traumatic cataract, and to anticipate the likelihood of cataract material prolapsing into the vitreous cavity (Fig. 42.8).

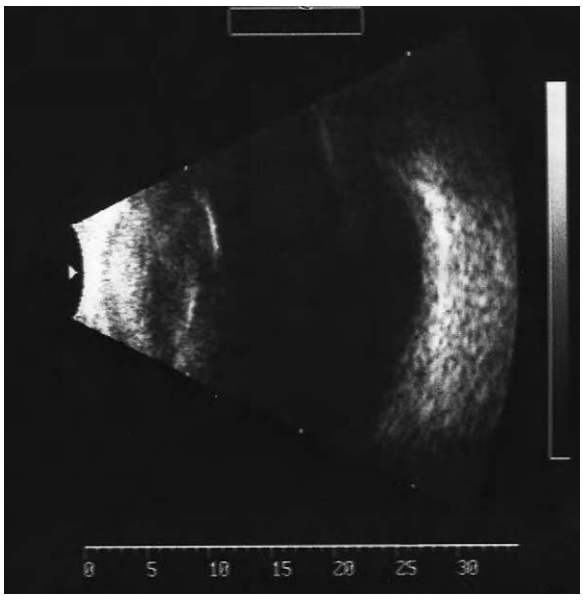

Fig. 42.7 B-scan image in a mature white cataract showing a discontinuity of the posterior surface of the lens, confirming that the trauma included the posterior capsule.

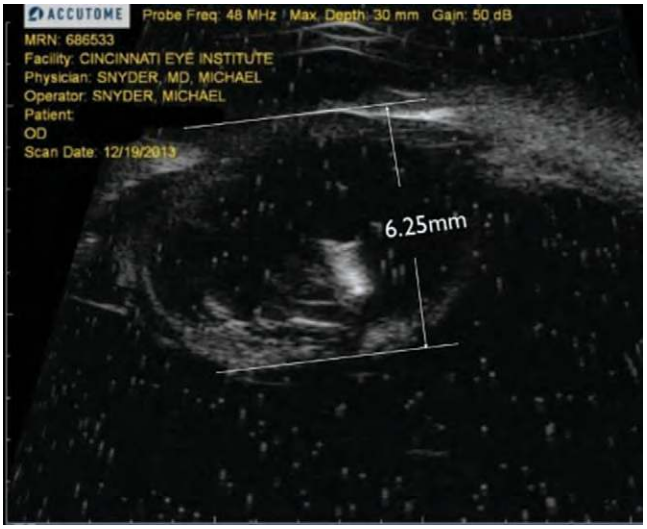

Fig. 42.8 UBM demonstrating a thick, intumescent lens with an obvious intralenticular foreign body.

Surgical Procedure

Timing

There are no strict rules in this regard, but as a general guideline, cataract surgery can be delayed in traumatic cases as long as there is no free crystalline cortical material in the anterior chamber and no anterior capsule tears are present. Furthermore, poor visualization caused by corneal edema or the presence of central corneal sutures caused by penetrating trauma repair can also force a delayed cataract extraction.

ANESTHESIA ALTERNATIVES

Different approaches can be taken in this regard, depending on the severity of the case. Generally, open trauma is better suited for general anesthesia to prevent potential consequences from posterior pressure. Secondary cataract extraction could potentially be performed under any type of anesthesia, but we would strongly recommend doing these cases under at least a sub-Tenon's approach, avoiding topical anesthesia. The reasoning behind this is the uncertainty of surgical steps that will be necessary to complete the surgery because unplanned anterior vitrectomy, iris manipulation, and even scleral incisions could be required to complete the case. For pediatric patients or highly complex cases that are expected to be overly prolonged, general anesthesia is usually prudent.

VITAL DYES

Different types of dyes can be used for different purposes during a traumatic cataract surgery. The main categories would be vitreous staining, in which triamcinolone is the dye of choice, and anterior capsule staining, with trypan blue being the most commonly used (indocyanine green is also an alternative, especially in cases in which changes in capsular elasticity are not wanted).

- **Triamcinolone:** Diluted triamcinolone is the tool of choice to delineate areas of vitreous prolapse, or to at least ascertain the absence of it. For ideal results, we emphasize the need of using this vital dye in the absence of viscoelastics because the staining of OVD could mimic vitreous prolapse, potentially leading to confusion.
- **Trypan Blue:** As previously stated, trypan blue stain is excellent at improving capsular visualization and providing the ability to decrease capsular elasticity, which can be crucial to counteract the frequent areas of focal or diffuse zonular weakness that are commonly present in traumatic cases.
- **Indocyanine Green (ICG):** This dye works well for capsule staining, but is "off-label" for this purpose in the United States.
  - Dissolving and dilution is required. The precipitate is mixed with 0.5 cc of sterile water until dissolved, then 4.5 cc of BSS is added to make it acceptably isotonic.

ANTERIOR VITRECTOMY

Although dealing with traumatic cases, an anterior vitrectomy must at least be anticipated by the anterior segment surgeon. Traditionally, two main approaches are available, the anterior (via a paracentesis) or the pars plana approach.

- Pars Plana: We strongly encourage the pars plana approach using a trocar and cannula system because it provides several conceptual advantages:
  - Vitreous follows pressure gradients; therefore a pars plana approach with an anterior infusion pulls vitreous back into the vitreous cavity.
  - Less risk of damage to existing capsule and iris structures.
  - High safety profile.[8]
  - 23 G, 25 G, or 27 G systems
  - The use of a trocar and cannula also allows separation between the vitreous cutter tip and the vitreous base, which potentially reduces the likelihood of a retinal tear.
  - Technique:
    - Secure wounds.
    - Pressurize globe.
    - Measure 3 mm posterior to the limbus.
    - Displace conjunctiva anteriorly and laterally.
    - Place trocar and valved cannula through the scleral wall at an angle in a plane 3 mm behind and parallel to the limbus, flush to the hub.
    - Visualize the tip of the trocar in the AC.
    - Remove the trocar, leaving the cannula in place.
    - Anterior infusion, using either a 23 G anterior chamber maintainer or 21 G butterfly through a paracentesis.
- Limbal Vitrectomy:
  - Pulls vitreous from the posterior segment into the anterior chamber, which maximizes traction at the vitreous base.
  - Vitrector through a paracentesis will not seal the paracentesis, so the likelihood of vitreous strands getting caught into the wound is higher.
  - Difficult access to subincisional vitreous.
  - Higher chance of damage to residual capsule or iris, based on both flow and proximity.
  - Always split infusion. Never use coaxial irrigation.
  - Never place vitrector through the main incision.
  - Technique:
    - Secure wounds.
    - Pressure globe.
    - Anterior infusion, using either a 23 G anterior chamber maintainer or 21 G butterfly through a paracentesis.
    - Create an ergonomically comfortable paracentesis (for cutter access) at least 2 clock hours from the area for intended cutting.
- Settings/Cutting:
  - It is of most importance to use the "Anterior Vitrectomy" (Irrigation/Cut/Aspiration) mode and avoid the "I/A Cut" (Irrigation/Aspiration/Cut) because aspirating vitreous without cutting it could lead to a giant retinal tear with ominous consequences.
  - Highest cut rate possible.
  - Aspiration and vacuum set at just high enough to move fluid and OVD through tubing.
  - Watch for movement of surround structures, indicating that vitreous is still present.
  - When one believes the offensive gel has been removed, diluted 1:10 triamcinolone can be irrigated into the AC to check for residual gel or strands.

Viscoelastics/Ocular Viscosurgical Devices (OVDs)

Two main categories of OVDs, or a combination thereof, are useful in these types of cases, with specific indications for each of them.[9]

- **Dispersive OVDs** such as Viscoat (Alcon, Fort Worth, TX, USA), which is a mixture of sodium chondroitin sulfate and sodium hyaluronate, or Endocoat (Johnson & Johnson, Santa Ana, CA, USA), which is a sodium hyaluronate dispersive), could be used to prevent corneal endothelial damage and/or to compartmentalize different areas within the eye. The latter is useful while dealing with a posterior capsule break or an area of vitreous prolapse because it creates a plug effect between the two chambers, preventing further unwanted extension of the prolapse by tamponade. This technique can be applied to allow the use of trypan blue in the anterior chamber, even in the presence of a focal vitreous prolapse, as long as the area with the prolapse is coated by a dispersive viscoelastic plug.
- **Cohesive OVDs** (Healon [Johnson & Johnson, Santa Ana, CA, USA] or Provisc [Alcon], both sodium hyaluronate):
  - Have the ability to better maintain space compared with their dispersive counterparts. They can be very useful to maintain anterior chamber depth during anterior segment reconstruction and iris manipulation, and they are key to maintaining an open capsular bag during PCIOL insertion.
- OVDs with mixed properties:
  - Discovisc (Alcon) is a mixture of both chondroitin sulfate and hyaluronate in a way that shares advantages of both types of viscoelastics. It maintains spaces at least as well as the cohesive agents and coats surfaces almost as well as the strictly dispersive agents.
  - Healon5 (Johnsons & Johnson Vision) is a condensed version of mostly hyaluronate that has "viscoadaptive" properties, namely, it behaves more like a dispersive agent at low vacuum settings and more like a cohesive agent at higher flow or vacuum settings, though with turbulence it exhibits a high shear and fragments into smaller bits, retaining some dispersive qualities.
- Mixing OVDs: In some trauma cases, it may be prudent to use more than one type of OVD:
  - Very low endothelial cell counts: It may be useful to place a dispersive agent in the dome, then use a cohesive agent to fill the chamber, pressurizing the dispersive agent against the endothelium in a "soft shell" technique[10] for extra endothelial protection.
  - When the hyaloid face is exposed, a highly retentive dispersive agent can be placed over the vitreous as a "plug" or "tamponade" with a more cohesive agent used to deepen the anterior chamber.
  - There are numerous possible combinations that may be used based on surgeon preference and facility inventory.

OVD Category	Best Uses
Dispersive	• Endothelial protection • Vitreous tamponade • Soft "stent" of capsule fornix in zonulopathy
Cohesive	• Space maintenance • Pressurization
Mixed Property Combined	• Almost as good as dispersive for endothelial protection • Almost as good as dispersive for vitreous tamponade • As good as cohesive at space maintenance • Better than cohesive for pressurization
Mixed Property Viscoadaptive	• Outstanding at maintaining space • Outstanding at pressurization • Better than cohesive agents for endothelial protection at low vacuum and high shear.

Small Pupil Management

- Most cases of small pupil secondary to ocular trauma are caused by posterior synechiae, fibrin in the anterior chamber, or even iridocorneal adhesions. (Additional details on small pupil management can be found in Chapter 35).

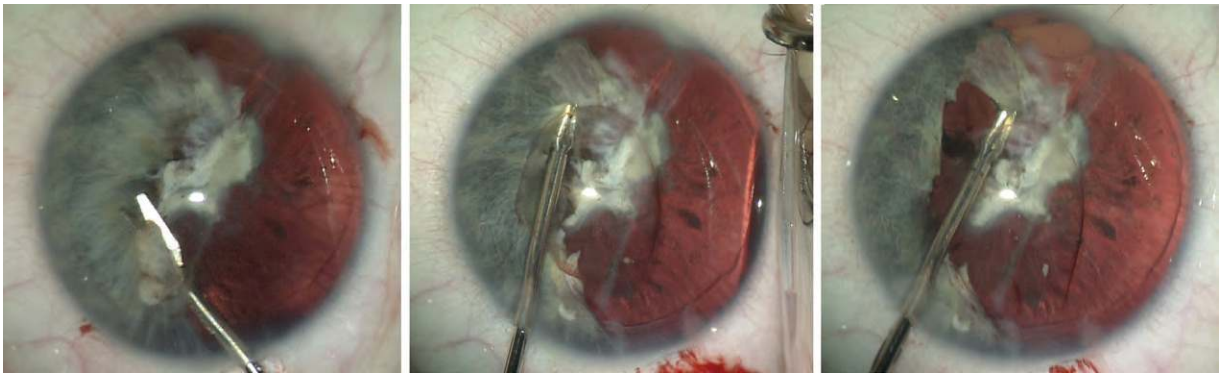

Fig. 42.9 Sequential appearance (left to right) during dissection of the iris margin fibrotically incarcerated into a penetrating injury of the lens.

- Pharmacologic dilation
  - Routine mydriatics.
  - Intracameral diluted epinephrine (1:100,000), usually combined with 2% preservative-free lidocaine. Although worth the exercise, the effect in trauma cases is usually tepid.
    - Mechanical synechiolysis.
      - Can be done sometimes bluntly
        - Viscodissection
        - Lysis with Kuglen hook (or the like)
        - Direct grasping and synechiae separation with microforceps (i.e., Micrograsper, MicroSurgical Technology, Redmond, WA, USA), or disposable units (Maxgrip®, Grieshaber® [Alcon]).
  - Sharp dissection: Sometimes the synechia to the lens can be quite strong at the pupil margin. OVD can usually separate the iris peripheral to this, then a microscissor can be used to severe the more robust adhesions (Fig. 42.9).
- If these initial steps do not achieve an adequate degree of mydriasis, a pupil dilating device might be required. Several devices are available:
  - Iris hooks: Grieshaber (Alcon) (or similar) are preferred for areas with focal miosis or irregular pupils because the effect can be titrated in a given meridian.
  - Dilating rings: There are a wide variety of pupil dilating rings. The Malyugin Ring[11] (MicroSurgical Technology) when the lack of dilation is diffuse. The Malyugin ring is available in two different sizes, 6.25 mm in diameter and 7.0 mm in diameter, with the 6.25 mm ring being our preferred size. It has been updated with a second version, which provides increased space in the scroll gaps, is considerably more flexible and can be inserted through a smaller incision compared with its predecessor. A variety of other vendors for dilating rings of differing geometries are available.

Capsulorrhexis

Capsulorrhexis in the setting of a traumatic cataract can present a wide variety of challenges depending on the severity of the case. The surgeon needs to anticipate areas of focal or diffuse zonular weakness, anterior capsule tears that can potentially extend to the equator or around into the posterior capsule, and areas of anterior capsule fibrosis.

- Surgical equipment needed:
  - Coaxial capsulorrhexis microforceps
  - Microscissors
  - Cystotome
  - Two "short" 0.5-inch, 30 g needles.

Central capsule tears need to ideally be included inside of the continuous capsulotomy. If they extend beyond the intended edge of the capsulorrhexis, efforts need to be made to transform the tear into a continuous curved edge, with any sharp tags or angles pointing inward.[12] The goal is to transform one high stress point (located at the tear itself) into infinite ones,[13] even if that maneuver involves sacrificing the perfectly circular shape of the capsulorhexis.[14] If attempts at a continuous tear are unsuccessful, the high stress point at the outward-pointing edge of the tear itself will persist for the duration of the case, with the likelihood of its extension to the equator, and perhaps even into the posterior capsule at any step of the surgery.

Although some may advocate the use of the femtosecond laser, the authors of this chapter prefer the flexibility and control of the manual approach, especially in these unpredictable cases with altered anatomy.

Puncturing the capsule: Zonular weakness can create a major hurdle while trying to create a reliable capsulorrhexis because of the lack of zonular countertraction that normally opposes the inherent capsular elasticity.

- If this weakness is significant, the lack of countertraction will become evident by the "pincushion effect" seen while trying to create the initial capsular tear (Fig. 42.10). This is exacerbated in young patients with more elastic capsules.

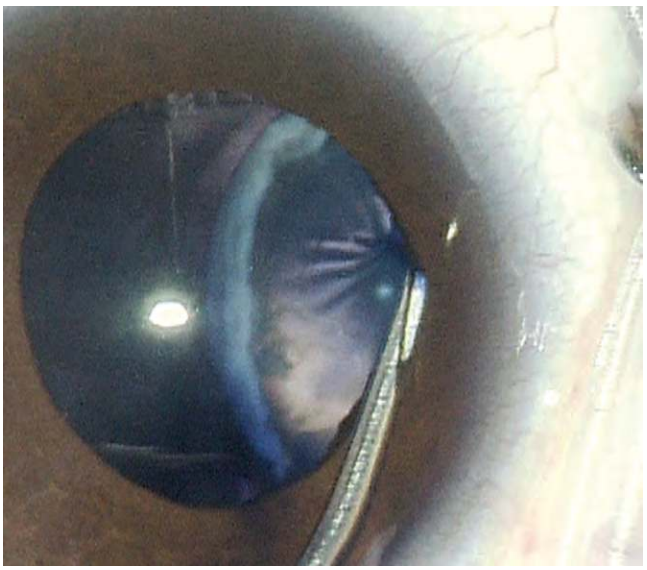

Fig. 42.10 Note that, even with extreme indentation with the cystotome tip, the capsule will not puncture.

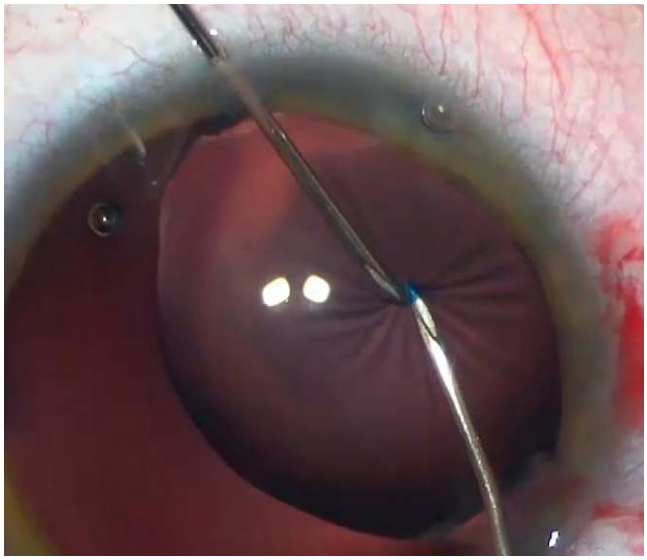

Fig. 42.11 Two opposing 30-gauge needles pinch the capsule between their tips, and one will always pierce; in this instance, it would be the lower needle's tip.

- Our maneuver of choice to overcome this difficulty involves two opposing 30-g needle entering the anterior chamber via opposing paracentesis[15] (Fig. 42.11). These two needle tips are used to create a central "pinch" or fold in the anterior capsule, and then eventually one of the needles will perforate the anterior capsule at the desired location, initiating the tear.
- The lack of zonular countertraction will also modify the direction of the force vectors during the propagation of the capsulorrhexis.

- Vector forces may need to be more centripetal than in cases with normal zonules.
- In some instances, flexible iris hooks to the capsule margin might be required to artificially create countertraction. "Capsule hooks" are bulkier and hard to place safely before the capsulorrhexis is completed. This is covered in additional detail in Chapter 34 on zonulopathy.
- Some surgeons will use another microforceps to stabilize the edge in a bimanual tearing approach, a maneuver that requires extraordinary surgical dexterity.
- In some cases, there will be an anterior capsular plaque or fibrosis through which a continuous tear cannot be propagated.
  - In such cases, a scissors can be used to snip through the fibrotic area.
  - It is crucial that the initiation of the first snip begins in normal capsule, extends slightly centrifugal to where the continuous tear hits the fibrosis, and ends within the fibrosis.
  - It is equally important that the snip that exits the area of fibrosis goes far enough into normal capsule that it can be grabbed by a forceps to continue propagation as another continuous tear.
  - Zonular weakness can also impact the desired capsulorrhexis size and shape; therefore the surgeon must pay extra attention to any focal flattening on the edge of the lens at the equator caused by longstanding lack of zonular countertraction.
- In a misshapen lens, the capsulorrhexis should mimic the shape of the periphery of the lens in that area because after cataract extraction, the capsular tension ring will round up the peripheral edge of the lens, which will also round up the edge of the rhexis that was intentionally created flat around its contour.[16]
  - In a smaller lens, the surgeon may need to make the capsulorrhexis smaller as well. If too small of a capsular rim is left, the bag may not hold the capsular tension ring reliably and the ring might pop out.

HYDRO/VISCODISSECTION

Very gentle hydrodissection should be performed in traumatic cases because in some instances the posterior capsule status will remain unknown until the cataract has been removed. This hydrodissection should be complemented with careful viscodissection of the cortex with a dispersive agent in cases in which a capsular tension device (either ring or segment) might will be implanted before a complete removal of the cataract cortex. This extra step will facilitate cortex removal in this setting, which could otherwise become entrapped behind the ring in the periphery of the bag, adding stress into the already weakened zonules. The viscodissection also lifts the capsulorrhexis margin off the cortex, facilitating hook placement, if needed.

LENS REMOVAL

Several mechanisms can be envisioned in the removal of the traumatic cataract.

- Most traumatic cataracts will be removed by phacoemulsification. There are no strict rules in terms of which technique is ideal for traumatic cataract extraction. We prefer techniques that will avoid zonular stress, therefore prioritizing the use of chopping versus groove-creating techniques when possible.
- For an extraordinarily dense, black lens with normal zonules, one may consider small incision extracapsular cataract surgery (SICS). This is covered in Chapter 21.
- When the lens has been macerated by the injury and no useful capsular material remains, or if the lens is fully luxated into the vitreous cavity, vitrectomy with pars plana lensectomy may be most suitable.
- In young patients in whom the lens material is very soft, the lens can be evacuated manually using Bob Osher's "dry aspiration" technique.
  - The anterior chamber is filled with OVD.
  - A 3-cc syringe is filled halfway with BSS, ensuring that there are no air bubbles. A 27 cannula is attached.
  - The cannula is placed through a paracentesis into lens material and the soft lens is aspirated. As lens volume is removed, additional OVD is placed to maintain a positive anterior chamber pressure.
  - This is an especially sensitive technique when a posterior capsular break is already suspected and vitreous may be admixed within the lens material.

ZONULAR WEAKNESS MANAGEMENT

Zonular support devices can be divided into intraoperative use and long-term support.

Intraoperative Zonular Support

- These devices are designed to provide temporary zonular support to achieve adequate lens centration and countertraction to allow for the completion of each surgical step.
  - As noted above, iris hooks can be used to stabilize the capsule during capsulorrhexis. They are less effective during phaco because they support only the edge of the capsule margin and

can become inadvertently disengaged. Also, the equatorial bag can still migrate centrally in their presence, even when fully engaged.
  - Flexible capsule retractors support the bag by means of the rounded end placed into the capsular bag fornix, thus more robust support. Different brands and types are available, but our devices of choice for this setting are the MST capsule retractors (MicroSurgical Technology).
    - The newest version has a rounded end with a small aperture that is too small to catch a CTR during insertion.
    - They can be placed through a paracentesis.
    - Multiple devices can be placed depending on the degree of zonulopathy.
  - Placement of an Ahmed segment early in the case and securing it with an iris hook is also a viable alternative.

Long-Term Support

- The type of device required for long-term zonular support will be mostly defined by the extent of zonular weakness in clock hours.
  - For less than 3 clock hours of damage and no lens decentration, a "standard" CTR is likely sufficient.
  - A scleral-fixated device is required if:
    - More than 3 clock hours of damage are measured.
    - Displacement of the bag/lens is present.
    - Diffuse zonulopathy results in "donesis" of the evacuated bag complex once temporary supports have been removed.
- Fixatable capsule devices:
  - The Cionni modified capsular tension ring (M-CTR) (Morcher, GMBH, Stuttgart, Germany) and the Malyugin variant have a fixation element that is fused to the ring's backbone and course anteriorly around the capsulorrhexis. A suture can be affixed to the eyelet on this element and can be sutured to the scleral wall.
    - Timing of the placement of a CTR is best described by the maxim from Ken Rosenthal: "It should be placed as late as you can, but as soon as you must." Ideally, placement is best when the capsular bag has been fully evacuated, but this is not always practical.
  - The Ahmed capsular tension segment (CTS) (Morcher) is a 120-degree arc of a Cionni ring. It can be placed more easily through a smaller incision but is more vulnerable to torque, which can cause migration out the bag. (Video 42.1).
  - The AssiAnchor (Hanita, Kibbutz Hanita, Israel) functions like a small, flat paper clip that can be clipped on the anterior capsule and supports the bag both at the capsule margin and the equator.
    - Version 1 requires a 2.5 mm opening.
    - Version 2 can be placed through a paracentesis.
    - Can be placed at any time throughout the procedure.
  - As previously mentioned in this chapter, our suture of choice for long-term fixation is the CV-8 ePTFE (expanded polytetrafluoroethylene, Gore-tex®, W. L. Gore & Company, Newark, Delaware, USA).

Additional detailed discussions of zonular dialysis management and device insertion are presented in Chapter 34.

PCIOL Choice

- Most cataract extractions during acute (generally open) ocular trauma result in aphakia with varying degrees of remaining capsular support because, in most cases, a reliable IOL calculation is not available or cannot be completed because of the severity of the trauma. For this reason, it is not uncommon to leave the cataract for a secondary surgery, unless there is evidence of free cortical material in the anterior chamber or a compromised anterior capsule.
- In some cases, the IOL power selection may be based on the fellow eye's biometry.
- The intraocular lens type of choice is no different than that for a standard cataract, especially in cases where the capsular bag can be spared.
  - A one-piece lens may be more facile to place in an intact capsular bag with fixation devices in situ.
  - If the bag is not intact or its anatomy is unsure, we recommend having a 3-piece PCIOL or single-piece PMMA IOL available, in case sulcus fixation is needed, either by optic capture or scleral fixation[17] (Video 42.2).
  - We are not enthusiastic about the use of anterior chamber IOLs in traumatic cases.

Aphakia Management/Preparedness

In traumatic cataract cases, the surgeon always needs to have a plan B for when things do not go as planned in terms of salvaging adequate capsular support for IOL implantation. Several surgical alternatives for managing aphakia are available, depending on the surgeon's choice, logistics, and geographic availability. We will briefly describe our techniques of choice in these aphakic cases. More details on aphakic correction techniques can be found in Chapter 41.

- 4-point, tiltless, centration adjustable, Gore-tex fixation of a CZ70BD PMMA Lens (Alcon Laboratories, Fort Worth, TX, USA)[18]
  - This technique involves the insertion of a PMMA lens through a 7-mm incision, using CV-8 ePTFE (expanded polytetrafluoroethylene, Gore-tex, W. L. Gore & Company [off-label use]) to trap the fixation eyelets located on each lens haptic using a cow-hitch to create 2 points of fixation on each side. The 4 fixation points allow for a tiltless result and, because the fixation eyelets are trapped, it allows for centration fine-tuning at the end of the case by manipulating the Gore-tex suture ab-externo based on the Purkinje reflexes (Video 42.3). A critical feature of any suture fixation technique is ensuring that both arms of the suture are on the same side of the haptic.
- Gore-tex prethreaded hydrophobic acrylic lens injection of a Micropure 1.2.3 lens (PhysIOL, Liège, Belgium) with 4-point fixation:
  - This technique uses a foldable 6-mm optic hydrophobic acrylic lens whit haptics prethreaded with CV-8 ePTFE and inserted into a standard cataract surgery cartridge, which allows its insertion through a 2.4 mm incision after the leading ePTFE sutures have been retrieved from the distal set of previously created sclerotomies at the sulcus level (Video 42.4). It also provides 4 points of fixation and allows for centration fine-tuning.
- Flanged intrascleral IOL fixation with double-needle technique (Yamane technique)[19]:
  - This technique uses a 3-piece lens inserted into the anterior chamber through a 2.75-mm incision.
  - A toric marker is then used to mark two points 180 degrees apart (at 12 and 6 o'clock for a temporal approach), and calipers are used to place another mark 2 mm posterior to the limbus at both 12 and 6.
  - A thin-walled 30 G (TSK Ultra thin) needle is bent with the bevel facing outward and it is tunneled through the sclera at the previously placed marks. (A standard 27 g needle can be used as well.)
  - The most facile lens for this technique has deformable polyvinylidene fluoride (PVDF) haptics, which have a strong memory

(Zeiss CT Lucia 602). However, both the Johnson and Johnson AR40E and the Alcon MA60AC lenses have been used. Although the AR40e IOL has a rounded anterior edge, the square edge of the MA60AC has a sharp anterior edge, which creates a higher risk of iris chafe.
  - The haptics are then docked into the needle using intraocular microforceps and externalized.
  - The haptics can either be docked and externalized one at a time, or both haptics can be docked and then externalized simultaneously (Video 42.5). Cautery is then used to deform the end of each haptic into a mushroom-like flange.

Iris Reconstruction (see Chapter 43 for more detailed information)

- As mentioned above, defects compromising less than 2 to 3 clock hours are potential candidates for primary repair, depending on the quality and "stretchability" of the residual iris tissue. Conversely, lesions larger than 3 clock hours more commonly require the surgeon to at least consider the need for an iris prosthesis.[20]
- For primary repair, we suggest using a 10-0 polypropylene suture to reconstruct the remaining native iris by a combination of single sutures using the Siepser knot[21] (or any of its modifications), cerclage, or peripheral iris reinsertion, depending on the anatomy of the original injury.
- For injuries greater than 3 clock hours, our iris prosthesis of choice is the custom, flexible iris prosthesis (Custom*Flex*® Artificial*Iris*®, HumanOptics AG, Erlangen, Germany) (Fig. 42.12), a foldable silicone iris prosthesis that is custom made based on an image of the fellow, uninjured eye. It provides both excellent functional and cosmetic results. This device can be:
  - Inserted into the capsular bag
  - Placed passively in the sulcus (if enough native peripheral iris issue is present)
  - Sclerally fixated using ePTFE sutures (Video 42.6)
  - Sclerally fixated with a "Canabrava" flange approach[22]

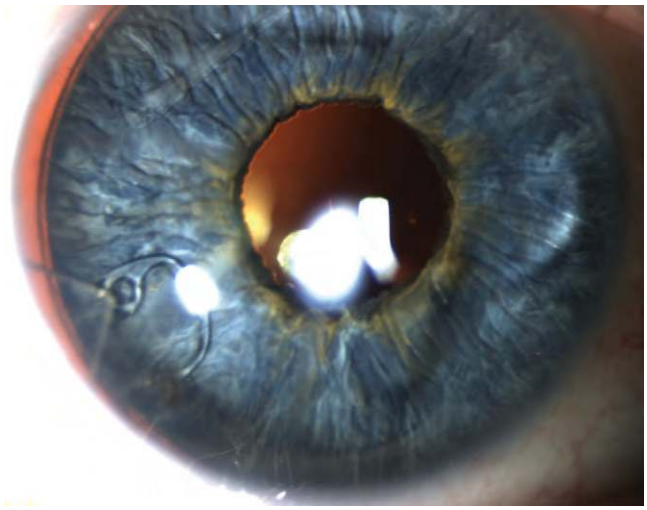

Fig. 42.12 This patient had total iris loss with traumatic cataract. After the cataract was removed, a Cionni ring was placed and both the implant lens and custom iris prosthesis were placed within the capsular bag. The fixation element of the Cionni ring can be seen temporally with the ePTFE fixation suture. The circumferential portion of the ring can be seen in retroillumination just peripheral to the iris prosthesis's outer edge.

POTENTIAL COMPLICATIONS

Although all of the traditional potential risks of cataract surgery exist for traumatic cataracts, there are some that are unique to traumatic cases:

- Glaucoma
  - Phacolytic and/or phacoanaphylactic glaucoma.
  - Resulting mostly from direct trauma to the trabecular meshwork.
- Vitreous prolapse around a zonular dialysis.
  - Perhaps higher retinal tear/detachment or CME risk caused by complex surgical maneuvers including vitreous manipulation, sclerotomies, iris manipulation, and intraocular devices fixation.
  - We recommend frequent dilated fundus exams on the postoperative care to prevent or preemptively detect this complication.
- Late capsular bag/lens complex subluxation, resulting from inadvertent zonular weakness at the time of surgery or insufficient long-term capsular support.
  - We usually recommend to at least use a standard capsular tension ring whenever some degree of zonular weakness is suspected because, apart from distributing the capsular forces among the functional remaining zonules, it facilitates a secondary capsular bag reposition in the potential case of a late subluxation.
- Higher incidence of suprachoroidal hemorrhage in trauma, thus increased attentiveness is required.
- Loss of lens material into the vitreous cavity, either through a posterior capsular break or around a zonular dialysis.
  - Need to frequently refill the AC with dispersive OVD to act as a plug and remain attentive to loose pieces.
  - Chopping off one piece of nucleus at a time minimizes the number of free fragments and the chance that one will migrate posteriorly.
- Endophthalmitis is at an increased risk, especially if the environment in which the trauma occurred involves organic material.
  - Intravitreal antibiotic injection may be wise if there is a:
    - "Dirty" penetrating wound
    - Suspicion for a retained intraocular foreign body
    - Suspected sequestered "lenticulitis" in the setting of an intralenticular foreign body

POSTOPERATIVE MANAGEMENT

Postoperative follow-up for these cases occurs more frequently than standard cataract surgery, with special attention on pressure control, lens centration, degree of tilt, suture exposure, and retinal status, all of which are tailored to the unique cases involved.

SUMMARY

Traumatic cataract surgery can involve every aspect of anterior segment reconstruction and could be defined as a surgical "box of surprises," requiring a high degree of expertise in different techniques available to tackle unanticipated situations.

- The "Surgeon's Toolbox" should include:
  - A flexible mind.
  - Facility with complex phaco techniques and willingness to tailor technique to the unique lens.
    - Zonulopathy management with CTRs, MCTRs, and other specialized devices.

    - Manual "dry aspiration" of soft lens material.
  - Facility with limbal and pars-plana approaches to anterior vitrectomy.
  - Facility with iris repair and/or prostheses.
- The "OR Toolbox" should include:
  - A variety of dispersive, cohesive, and mixed-property OVDs.
  - A variety of hooks, implants, and devices.
    - Iris hooks
    - Capsule hooks
    - CTRs, MCTRs, CTSs
    - Anchors (OUS)
  - Sutures
    - CV-8 ePTFE (Gore-tex, off-label), TTc9 needle
    - 10-0 nylon
    - 8-0 vicryl
    - 10-0 polypropylene (CTC 6-L needle)
    - 5-0 polypropylene (Canabrava flange)
  - Microinstrumentation
    - 23 and 25 G forceps
    - Ruler capsulorrhexis forceps (Seibel forceps, MST)
    - 23 G scissors
- Trypan blue
  - Stains the capsule for visualization.
  - Reduces elasticity in young capsules and/or zonulopathy.
- 1-piece and 3-piece IOL options, at least one with a rounded anterior edge.
- Iris prosthesis (access to).
- Step-by-step approach.
- Plan for the most likely scenarios anticipated in the exam room, but alter the plan and/or change the order of the steps as the cases evolves.

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Video 42.1 Traumatic cataract with zonular weakness and vitreous prolapse treated by Kenalog-staining, pars plana anterior vitrectomy, phacoemulsification with iris hooks for capsule support, capsular tension ring, and segment placement, fixated with Gore-tex® (ePTFE) scleral fixation suture (off-label use).

Video 42.2 Capsular support repair by scleral fixation and optic capture of a 3-piece lens.

Video 42.3 Adjustable, tilt-free technique for 4-point Gore-tex (ePTFE) fixation of a PMMA IOL.

Video 42.4 Technique for 4-point Gore-tex (ePTFE) fixation of a hydrophobic acrylic injected lens.

Video 42.5 The Yamane technique of PCIOL fixation with intrascleral haptics.

Video 42.6 Step-by-step scleral fixation of a custom flexible iris prosthesis and an intraocular lens in an aphakic and aniridic eye after trauma.

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Iris Repair and Iris Prosthesis

Gregory S.H. Ogawa and Michael E. Snyder

CONTENTS

KEY POINTS

- The globe needs to be pressurized during iris repair and iris prosthesis surgery.
- Congenital iris coloboma requires effective repair at the time of cataract surgery.
- Iris diathermy is an excellent tool for pupil shaping and centration.
- An iris cerclage suture should be used only in the setting of 360-degrees of absent sphincter function.
- Intraocular knots should be cinched inside the eye at the location of the suture and knot.
- Iris prostheses are a good option for when native iris tissue is inadequate.
- Iris prostheses can be placed in the capsular bag, passively in the ciliary sulcus, or suture fixated to the sclera.

INTRODUCTION

The causes for damaged or malformed irides are legion. Regardless of cause, patients are often vexed by:

- Photophobia
- Poor vision
- Dysphotopsia
- Altered body image

The improvement in quality of life from iris repair or prostheses can be quite profound, making skill development in iris repair and prosthesis use a worthy pursuit.

IRIS REPAIR VS. IRIS PROSTHESIS

Many techniques can repair iris abnormalities, but in some cases, there is just not enough iris available to make an adequate repair. If the iris is pulled too tightly during a repair, then the iris may tear at the suture, iris root, or elsewhere. An overtightened iris suture can also cause chronic inflammation. A useful guide for tension is that if more than two wraps with a single throw in 10-0 polypropylene suture is required to hold the iris tissues in a particular position, then the iris may be pulled too tightly. This may be modulated by refraining from tightening sutures all the way to tissue approximation using bridging sutures. However, in other situations an iris prosthesis may be required. An iris prosthesis may function as an adjunct to direct iris repair or as a complete treatment, depending on the type of prosthesis being used: segmental or 360 degree. Choosing between repair and prosthesis depends on the following:

- The quantity of tissue available
- The quality of tissue available (stretchability)
- The surgeon's skill set with iris repair
- The surgeon's skill set with iris prosthesis placement

PREPARATIONS FOR IRIS REPAIR

Globe Pressurization

During iris repair, the globe needs to be pressurized to minimize bleeding and maintain normal anatomic relationships.

- Intact lens capsule diaphragm: OVD may be used.
- Open lens capsule diaphragm: infusion should be used.
  - A 23-g high-flow *limbal* infusion cannula maintains a small incision yet allows good fluid flow.
  - Avoid pars plana infusions, which create an unfavorable posterior-to-anterior flow gradient.
  - Infusion mechanism:
    - Active pump system: may push fluid too aggressively out of a wound.
    - Gravity feed is more forgiving.
  - For either type of infusion system, the intraocular pressure only needs to be at, or a little above, physiological pressures. High infusion pressures should be avoided for iris work because it can cause damage to iris caught in fluid flow out through an incision.

OVD TYPE	PRIMARY COMPOSITION	PROPERTIES	COMMERCIAL EXAMPLE
Dispersive	Low-molecular weight hyaluronic acid ± chondroitin sulfate	• Effectively holds iris tissue in place • Harder to remove	Viscoat® Endocoat®
Cohesive	Hyaluronic acid	• Does not hold iris tissue well • Easier to remove	Healon® Provisc® Amvisc plus®
Cohesive-dispersive combination OVD	Chondroitin sulfate and hyaluronic acid	• Effectively holds iris tissue in place • Relatively facile to remove	DisCoVisc®
Viscoadaptive	Condensed hyaluronic acid	• Effectively holds iris tissue in place • Relatively facile to remove	Healon5®

OVD, Optical variable device.

Sutures and Needles

- The standard suture material for iris repair is 10-0 polypropylene.
  - Excellent combination of strength and flexibility. In the anterior chamber, it degrades extremely slowly over many decades. In sclera, degradation is between 7 and 20 years.
  - If the transscleral 10-0 polypropylene passed through sclera for iris repair does degrade and break, it can be resutured. This rarely occurs, possibly because of the low tensile stress from the iris.
- Long curved transchamber needles (at least 13 mm long) are most commonly used.
  - The curve makes it easier to get from the limbus, down to the iris, and then back up to the opposite limbus.
  - A fine spatula side-cutting needle (e.g., Ethicon CTC-6L) makes the smallest orifice when passed through iris tissue; however, it is flimsy and so more difficult for some to control inside the eye.
  - A similar curved taper cut needle (e.g., Ethicon CIF-4) is typically more rigid, making it easier to control; but because of its continuous taper, it tends to drag on iris tissue and also make a larger orifice in the iris.
  - The authors generally prefer the fine spatula needle (e.g., Ethicon CTC-6L) because of the much greater flexibility in entry-exit locations and the low drag coefficient on iris tissue.
- Straight transchamber needles may also be used for iris suturing, but, for the needle to exit the eye, the entire needle must come anterior to the limbus plane, which automatically elevates the iris to that same plane, thereby stressing and deforming the iris enough that a tear at the iris root or suture site may occur.

Instrumentation

- An appropriate needle holder is essential for iris suturing.
  - A fine-tipped needle holder is needed, but because of how long the needles are, a stout hinge section is beneficial for a solid grip on the needle (e.g., Osher needle holder, Storz E3807 WO). One should avoid locking needle holders.
  - Titanium needle holders grasp stainless steel needles with greater friction on the stainless steel needles; however, design is more important than material.
- 23- or 25-gauge coaxial scissors is necessary to cut the suture tails on the knot in situ rather than dragging the knot, suture, and iris toward a limbal incision.
- Paracentesis blades of several types can be used. We advise making the paracenteses parallel to the iris.
- An iris support instrument can be useful during needle passage. Sometimes no support is required, but in other situations a coaxial intraocular forceps, iris reconstruction hook, intraocular lens (IOL) manipulator, or similar instrument will stabilize the iris and avoid putting undue stress on stromal tissue and the delicate iris root.
- Intraocular forceps with a curved shaft and 23- or 25-g size are required for tying certain intraocular knots. Reusable and disposable forceps are available from several manufacturers. Disposable 25-g vitreoretinal forceps may manually be bent at the shaft to make them useable in the anterior chamber.
- 23-, 25-, or 27-gauge bipolar diathermy probes can be extremely useful for adjusting pupil location and shape by contracting iris stroma. Disposable versions can be bent for improved ergonomics and iris access.

Vitreous Removal

If vitreous is near or around the iris that is in need of repair, then it should be removed before commencing iris surgery.

- Limited vitreous can be adequately removed through a limbal paracentesis with a guillotine cutter.
- With more vitreous, a single-port pars plana approach may be necessary. The pars plana is preferably accessed with a trocar and cannula system.

Pharmacologic Agents

- If pupil work is planned, then avoiding either preoperative dilating or constricting drops is advisable (unless combined cataract or IOL procedure is planned).
- For iridodialysis or oversew techniques, preoperative pilocarpine puts the tissue on stretch and makes repair more facile.
- Having an intraocular miotic available during surgery is often useful.
  - Acetylcholine works more quickly and avoids excessively strong constriction of the sphincter muscle. Instillation may be repeated, if need be.
  - Carbachol will also achieve constriction but should be used sparingly because of the tendency to produce exaggerated pupil constriction. Excessive sphincter contraction from carbachol may make it more difficult for the surgeon to intraoperatively assess the adequacy of iris repairs.

Clear Crystalline Lens

Iris repair in the presence of a noncataractous crystalline lens is a high-stakes undertaking. Even subtle bumps to the lens may cause a cataract to form.

- A dispersive OVD has an increased chance of causing a feathery subanterior capsular cataract, even during the case. This tendency is less with hyaluronate.
- Very experienced iris surgeons sometimes (but rarely) offer iris reconstruction in young patients with disabling photic symptoms.

Thorough counseling is mandatory because cataract surgery may be needed during the case or soon after. An appropriate IOL should be available.

INTRAOCULAR KNOTS FOR IRIS SUTURING

Many iris repair techniques require tying knots within the anterior chamber, in situ, without dragging the tissue to a limbal wound, which could stretch, tear, or disinsert the tissue and/or cause bleeding.

Just as with other surgical knots, intraocular knots are formed with a plurality of throws, each with some number of suture wraps.[1] Standard shorthand for indicating number of throws and wraps indicates the number of wraps for the first throw, followed by a hyphen, then the number of wraps in the second throw, and so on. Accordingly, a knot with three wraps in the first throw, one wrap in the second throw, and one wrap in the third throw would be indicated as a 3-1-1 knot.

The friction created by a knot is completely reliant on the knot's internal friction if it is not compressing tissue (an iris cerclage knot, for example). There is additional frictional holding power when the knot compresses tissue (i.e., when squeezing iris tissue together). When relying on internal friction alone, for 10-0 polypropylene, the minimum knot configuration should be a 2-1-1 knot.

McCannel described the first knot for iris suturing many decades ago.[2] He pulled the iris to the main wound at the limbus, which displaces and applies tension on the iris. Although in some situations this might still be appropriate, intracameral cinching of knots at or close to the final location of the knot is much less likely to damage or distort the iris. Herein, we detail three knot variations, with macro videos demonstrating each. Video of the Ogawa Knot in the microscopic environment may be seen in multiple surgical videos for this chapter. Macro videos of several other knots in the table are available elsewhere.[3]

Siepser Knot (and Osher, Cionni, Snyder Square Knot Variants)

- In this knot, all of the throws are formed externally and tightened with no instruments inside the eye.
- A long, curved needled is passed through a limbal wound, taking care not to catch any wound fibers.
- The needle is passed through the iris tissue according to the technique employed, and the needle is passed out through the limbus distally.
- A loop of the suture from the distal side of the iris pass is retrieved with a hook through the initial wound.
- The sutures are carefully **oriented** such that:
  - the trailing suture (which has remained outside of that same incision throughout) is on the outside on one side,
  - the strand of the externalized loop from the distal iris pass is in the middle, and
  - the strand of the externalized suture loop coming from the distal exit site from the eye is on the other side.
- The trailing strand is passed *down* through the loop (twice), wrapping it around the middle strand, moving toward the limbus.
- Both suture ends are pulled outside the eye to cinch the throw inside the eye.[4]
- The same sort of loop is hooked out in the same fashion to lock the first throw with a second (or plurality of throws). This creates a granny knot.
- In the Osher et al. variant, the second (or subsequent plurality of) throw is placed by either using the same orientation but passing the trailing strand *up* through the loop. This creates a square knot. Similarly, the second (or subsequent) throws can be created using an orientation in mirror image to the prior throw, also effectuating a square knot[5] (Video 43.1).
- Four-wrap, single-throw knot[6]: This does not have a locking throw at all and relies strictly on the friction within the throw itself. The elegance of this approach is in its simplicity. This is most suitable for very friable tissue in which case retrieving a loop for a second throw may risk damage to the residual iris tissue. Occasionally, the friction within that first four-wrap throw may seem to "lock" before the knot is seated, which can be frustrating. Sometimes, even a three-wrap throw is functional if the thin tissue is on no or little tension.

Ogawa Knot (Throws Formed Externally, Tightened With an Instrument Internally)

- The throws are all formed outside the eye with tying forceps in a conventional fashion; then the two suture arms are held in one forceps while an IOL manipulator functions like a pulley to take one arm into the eye, with the throw following.
  - One needs to make one suture arm loop a little longer outside the eye so that the IOL manipulator can go past the knot location. If the suture arm loops are the same length, then the IOL manipulator will not be able to travel past the knot location, decreasing the ability to properly tighten the throws and increasing the chance that the IOL manipulator knob could get caught in the throw[7] (Video 43.2).
- The IOL manipulator is moved past the knot location to cinch the throw with the tension of the arms at the knot, oriented about 180 degrees apart. By creating the throws with wraps in alternating directions, using the long arm to do the wrapping each time, and alternating which suture arm is pulled into the eye with the IOL manipulator, a flat square knot can be made.

Ahmed Knot (Two Intraocular Forceps)

- This intraocular knot requires two smooth platform intraocular forceps of 23 g or 25 g. These knots are formed and tied just like one would do outside the eye, but it is all done inside the eye.
- After passing the suture through the iris, one arm is left moderately long, and the other should be cut short just outside the globe. The longer suture is held inside the eye with one forceps and wrapped twice around the distal portion of the other forceps before that second forceps grasps the suture inside the eye that was cut at the external surface of the eye. The sutures are then manipulated to tighten down the first throw. t0015
- The forceps holding the longer suture is used to wrap the suture once around the distal portion of the second forceps in the opposite direction of the first wraps. The shorter tail is grasped inside the eye again with the second forceps to tighten down the second throw, pulling the sutures in the opposite direction so that the throw lies down square as it is cinched.
- The first forceps grasps the longer tail again and wraps the suture around the second forceps once in the same direction as for the first throw; then the second forceps grasps the short arm again to form and cinch the final throw before trimming the suture ends[8,9] (Video 43.3).

TABLE OF INTRAOCULAR KNOTS

Siepser Style Knot: Throws Formed and Tightened From Outside the Eye	Ogawa Style Knot: Throws Created Outside the Eye Then Taken Inside the Eye With an Instrument to Tighten the Knot	Ahmed Style Knot: Two Coaxial Forceps Used Inside the Eye to Form and Tighten the Knot
Original Siepser (2-1)[4]	Original Ogawa (2-1-1)[7]	Ahmed (2-1-1)[8, 9]
Osher, Cionni Snyder variant (2-1)[5]	Ahmed variant (2-1-1)[10]	
Condon variant (2-1-1)[11]		
Ahmed variant (3-1-1)[12]		
Schoenberg, Price variant (2-1-1, knot behind iris)[13]		
Narang, Agarwal variant (4 wraps, 1 throw)[6]		

TYPES OF IRIS REPAIR

Iridodialysis Repair

The iris root is the thinnest and weakest part of the iris, prone to tears from external blunt trauma and intraocular surgery. Hyphema often accompanies either. Small tears in the range of 1 clock hour often do not need repair, but as the size increases and traction on the iris toward the pupil from fibrotic surface bands increases, the iridodialysis becomes progressively more optically disabling.

- If cataract surgery is performed and the resulting IOL optic edge is in the iridodialysis space, then glare and other dysphotopsias may occur.
- Because the dilator muscles are in the posterior portion of the iris stroma, the iris edge tends to roll posteriorly along the dialysis, making it harder to engage the iris with needle passes from the anterior surface of the iris.
- A peritomy should be performed in the area of iridodialysis, with cautery to achieve hemostasis on the scleral surface. If the pupil size is moderate to large, some acetylcholine should be injected into the anterior chamber so that the iris is not bunched toward the periphery. Globe pressurization with OVD or infusion should then be achieved.
- Fibrotic surface bands from blood from the time of injury sometimes create a V configuration at the edge of the iridodialysis. Two intraocular forceps might be useful to lightly stretch the iris radially by grasping near the pupil and at the edge of the iridodialysis before gently stretching, using forceps or IOL manipulators (Video 43.4) (Fig. 43.1A-B).
- "Testing" with an IOL manipulator or forceps helps determine the number of fixation points that will be needed for the repair and the location for each. It often requires fewer fixation points for an iridodialysis repair than one might initially imagine.
- The primary way to manage iridodialysis is with horizontal mattress sutures.
  - The double-armed 10-0 polypropylene suture is passed one needle at a time through a paracentesis 4 to 6 clock hours away from the desired suture location and then passed posteriorly through the pupil before catching the far periphery of the iris with the spatula curved transchamber needle. Then the needle is passed out through the sclera at the level of the iris root.
  - The surgeon passes the second needle through the same paracentesis, being certain not to catch corneal tissue, then posteriorly through the pupil and then anteriorly through the far periphery of the iris, adjacent to the first pass, before passing the needle out through the sclera approximately 1.5 to 2 mm to the side of the first suture, again at the level of the iris root (see Fig. 43.1C).
  - When feasible, the sutures may be passed transcamerally over the iris, and the peripheral iris can be engaged from the front surface.
  - The suture arms are trimmed outside the eye, then a two-wrap throw, with or without a half bow on top, will hold the suture and iris in place while the position is assessed. If only one mattress suture is placed, then the suture tension may be adjusted with the emphasis on an adequate closure of the iridodialysis and good pupil contour rather than on complete closure of the iridodialysis.[14]
  - If more than one mattress suture is placed, then each one should usually be temporarily tied until the last is in position, then the tension of each can be adjusted before final tying the 2-1-1 knot, with the knot then buried inside the eye.
  - A Sinskey hook may be useful for helping to push the knot in through the sclera or even for slightly enlarging the tract through the sclera as part of the process to get the knot inside the eye. It is important to get the knot actually inside the eye through the scleral wall to avoid erosion of the knot through the conjunctiva[15] (Video 43.4) (see Fig. 43.1D).
- Sewing machine suturing techniques, including for iridodialysis repair, have been described for iris repair.[16–18]
  - Most of these involve scleral grooves or scleral flaps (with flap closure using other sutures) and hollow bore needles, all with diameters much larger than the 6 mil (0.15 mm) width of the spatula curved transchamber needle described previously. Some of the sewing machine techniques are executed as a running suture and others as interrupted sutures.
  - Because iridodialysis repair does not need continuous peripheral iris support, a running suture is not needed and, in fact, likely decreases the quality of the result because of decreased adjustability once the sutures are placed. There are probably surgeons in whose hands sewing machine techniques works well for iridodialysis repair, but, in the authors' experience, they complicate what is otherwise a straight-forward technique, do not readily allow for passing the needle from posterior to anterior to suture the most peripheral edge of the posteriorly rolled iris, and create more iris tissue damage because of the larger diameter needles.
  - Other fixation techniques for iridodialysis repair continue to emerge, for example large diameter polypropylene sutures,[19] and at some point one or more of them may have enough follow up with good results to become a standard that replaces the mattress technique described previously.

Interrupted Pupil Margin Suture

With focal injury, a simple interrupted suture—one bite on each side of the defect—is all that is needed. For more extensive sphincter damage, one or more multibite interrupted sutures may be required, especially when there is still some contiguous retained, functioning sphincter.

- If there is limited or no sphincter function, then an iris cerclage suture is appropriate, as described later in this chapter.
- Multibite interrupted sphincter sutures yield a nicer result than a single imbricating suture across an extended span of nonfunctioning sphincter in which the intervening iris can readily pooch out

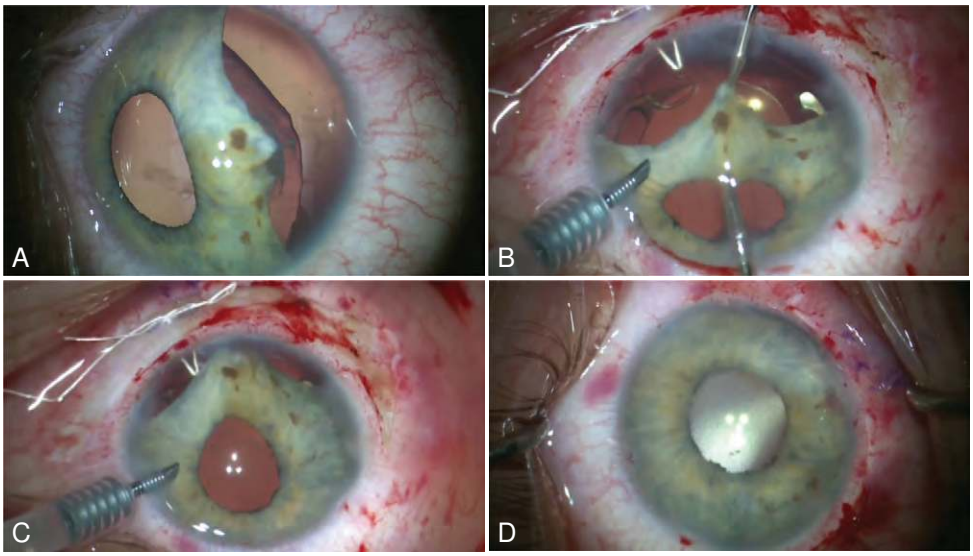

Fig. 43.1 (A) A 21-year-old male with a right-eye large inferior iridodialysis, extensive zonular defect, vitreous prolapse, underdeveloped lens inferiorly, and a cataract from a fishing weight injury 13 years before surgery. (B) Stretching the contracted iris with coaxial forceps before suture repair of the dialysis. Anterior vitrectomy, cataract aspiration, and expanded polytetrafluoroethylene (ePTFE) (Gore-Tex) sutured capsular tension segment with acrylic IOL placement in the bag had already been completed. The ePTFE was tied with a two-wrap throw and a half bow to adjust the bag/IOL position should it be needed after iris repair. A 23-g reusable titanium infusion cannula is shown for maintaining globe pressurization. (C) First mattress suture placed with 10-0 polypropylene double armed with 13 mm × 0.15 mm curved spatula needles in the middle of the iridodialysis defect. Needles were passed through the pupil then anteriorly through the periphery of the iris because the iris usually rolls or curves posteriorly. A small amount of hang back was used to achieve the desired pupil position. Typically, the 10-0 sutures are tied with a two-wrap throw and a half bow to adjust tension before completion, but in this case the knots were finalized as they were placed. (D) Completed repair after placement of three mattress sutures. It is worth noting that, even with an iridodialysis this large, a relatively small number of fixation points can support the iris. The pupil is well centered and did not need iris sphincter sutures. Purkinje images 1, 3, and 4 are well lined up in the center of the cornea, indicating a flat and centered IOL.

peripherally, creating a radial opening in the iris at the location of the suture.

- Acetylcholine can help visualize where the sphincter still functions and where it does not. Analysis of the radiality of the iris stromal cords can also help separate functioning sphincter (radial) from nonfunctioning sphincter (splayed).[3]
- The multibite:
  - The needle on a 10-0 polypropylene suture is passed through the limbus then through the iris near the margin at, or close to, where there is some remaining sphincter function.
  - The needle is then passed up through the iris adjacent to where it was passed posteriorly through the iris.
  - Subsequent passes may continue in this basting stitch pattern, or a whip stitch in which the needle tip wraps around the pupil margin and then passes through the iris from posterior to anterior may be used for all of the subsequent passes.
  - The main advantage of switching to a whip stitch is that it is easier to get the needle passes closer together and decreases the chance of the iris bunching up once the suture is tied.
  - An intraocular knot is tied before trimming the suture tails with coaxial intraocular scissors.[5,7]
  - Having the first multibite interrupted suture completed makes it more obvious to the surgeon where subsequent multibite or two-bite sutures (if needed) should be placed.
  - We target an entrance pupil of about 3.5 to 4 mm in diameter. This simulates a relatively bright light situation and will typically be adequate to control photophobia.
  - Patients with darker fundi (and irides) will often tolerate more light entering the eye, and those with lighter fundi (and irides) generally tolerate less light (Video 43.5).

Iris Gathering/Oversew Suture for Iris Transillumination Defects

During cataract and other surgeries, it is not rare for the iris to prolapse out through the main incision or through a paracentesis. Often, patients have no symptoms from the focal changes, but others have significant dysphotopic symptoms, particularly if the pigment epithelium is absent from that area. If the area of transillumination is large, an iris prosthesis may be required. For more modest defects, bringing healthy iris pigment epithelium closer together with gathering or imbricating sutures is effective.[20]

- The pupil is constricted with either preoperative pilocarpine, intraoperative acetylcholine, or carbachol.
- 10-0 polypropylene on a thin cutting needle is preferred because the iris is typically fragile.
- Suture passes need to start in an area of intact iris and then weave through or over the area of transilluminating iris, ending with a bite in intact iris at the other side of the transillumination.

- When tying the intraocular knot, it is not always necessary to fully compress all the tissue. The suture only needs to compress iris tissue enough to control the transillumination.
- Often two or more of these sutures are needed.
- It is not unusual for the iris sphincter to also be damaged in these situations. If so, the pupil should be repaired first (Video 43.6).

Congenital Iris Coloboma Repair

The congenital iris coloboma is relatively unique among iris defects in that the iris was never normal.

- These individuals were born without closure of the optic fissure during embryogenesis. The anterior segment coloboma can be as subtle as an area of abnormal looking iris stroma inferonasal to the pupil or as dramatic as a radial iris defect going all the way to the periphery that includes the ciliary body with an absence of lens zonules.
- The posterior colobomas that typically accompany the anterior defects can create visual field defects and even have a devastating impact on vision if it involves the fovea.
- Congenital iris colobomas rarely need repair before the time of cataract surgery because the natural lens is roughly 12 mm in diameter; thus the crystalline lens edge is still not exposed. Most IOL optics are about 6 mm in diameter, so cataract surgery without coloboma repair will expose the IOL edge, often producing monocular diplopia, edge glare, decreased contrast sensitivity, coma, and other optical aberrations.
- The coloboma margin typically contains functional pupillary sphincter muscle. In larger iris colobomas, the coloboma sphincter muscle may pull the colobomatous pupil inferonasally toward that fixation point. So one may need to pedunculate or extirpate the muscle at the edges of the coloboma.[21–23]
  - Miotic is injected while observing how the colobomatous and noncolobomatous pupil respond. (Avoid phenylephrine or epinephrine in the infusion bottle during the cataract surgery.)
    - Vitrector trimming:
      - Set the cut rate to about one cut per second with very low vacuum and aspiration flow rate settings. The vitrectomy port is then used to slowly remove the sphincter muscle along the coloboma margin.
      - As the colobomatous sphincter is removed, the surgeon may notice the relaxation of the stroma adjacent to the coloboma as it moves centrally. Start slowly, go slowly, and do not remove excess tissue because that makes it harder to close.
    - A fine microscissor may also be used to trim this tissue.
  - Simple interrupted sutures are placed, the first one bringing together normal pupil sphincter from the nasal and temporal sides. An intraocular knot holds the sides of the pupil margin together. (See intraocular knot tying.) Additional interrupted sutures are sequentially placed, moving from central to the periphery, bringing the two, now stromal sides, of the coloboma together.
  - There is often a very small peripheral triangular defect, of no optical significance, that is best left unsutured to avoid tearing iris tissue.
  - Because the most peripheral sutures have the potential to stress/tear the iris, it is advantageous to use a knot-tying technique that can tie the knot down in the iris plane, rather than needing to lift the iris to the limbus plane to cinch the knots. Those options would include the Ike Ahmed two intraocular forceps technique[8,9] and the Ogawa intraocular knot[7] (Fig. 43.2A–C). Pupil shape and centration may be adjusted as needed by using intraocular diathermy (described later in this chapter) (Video 43.7).

Iris Cerclage for Permanent Mydriasis

Large pupils with no iris sphincter activity at all need extensive iris suturing or an iris prosthesis. Several of the multibite interrupted sutures may be used; however, this tends to put excessive stress on the attenuated iris between the sutures and results in a polygonal shaped pupil, like a square or a pentagon. For the atonic mydriatic pupil, an iris cerclage suture is effective, minimizes stress on the iris tissue, and produces a very good cosmetic and functional result, provided that an acceptable amount of pigment epithelium remains and that the stromal tissue is hearty enough to hold a suture[24] (Fig. 43.3A).

- Using 23-g paracentesis openings around the periphery, each made parallel to the iris, makes it easier to pass needles in and out of the eye. Larger resting pupil diameters are easier to suture with a greater number of limbal access points, with a usual minimum of 4, which can include a cataract surgery incision.

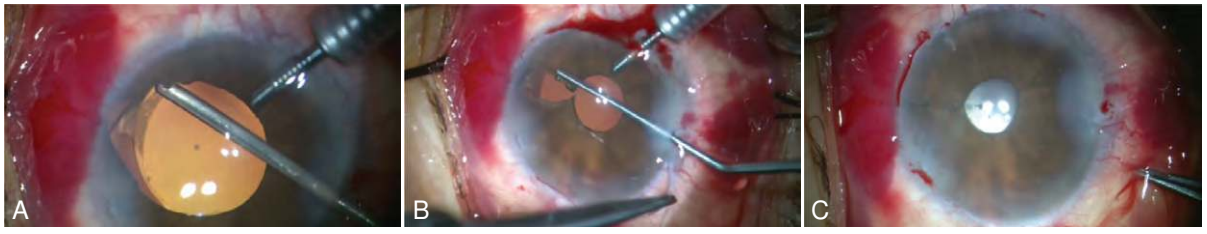

Fig. 43.2 (A) Patient with a left iris coloboma. The vitrector is being used at a rate of one cut per second, low flow, and low aspiration to trim the iris sphincter muscle off the sides of the colobomatous part of the pupil. A 23-g self-retaining limbal infusion cannula keeps the globe formed. Cataract removal with lens implantation had already been performed followed by instillation of acetylcholine to bring down the pupil size and make it clearer where the transition from coloboma to normal pupil occurs. (B) A suture was placed through the nasal and temporal aspects of the normal appearing ends of the pupil. Here the first throw of the first suture is being gradually tightened before the iris edges come together, and the two-wrap throw is cinched. An angled IOL manipulator functions as a pulley to provide tension on the throw 180 degrees away from the paracentesis. (C) At completion of the case, the pupil is centered and Purkinje images verify a well-positioned IOL. The iris stroma, without colobomatous sphincter, has been closed with interrupted 10-0 polypropylene sutures to almost the periphery of the iris.

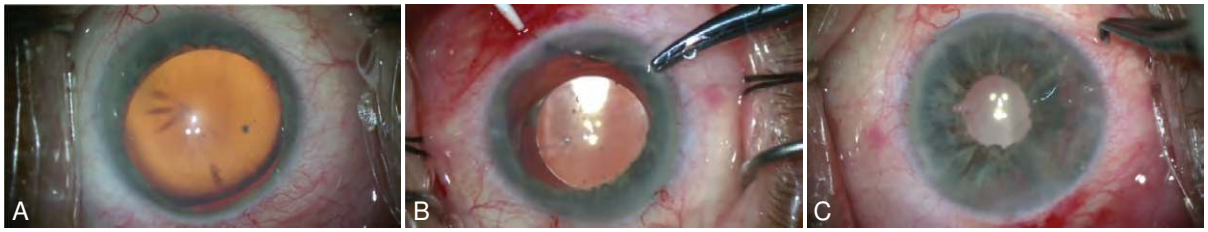

Fig. 43.3 (A) Trauma caused this large unreactive pupil. Essentially 360 degrees of absent pupil sphincter function is the situation in which it is appropriate to place a cerclage suture. The pupil is so large, down, and to the right in this image that one can see around the crystalline lens. (B) The 10-0 polypropylene cerclage suture placement started down and to the left in this image (10 o'clock position for the eye) and progressed in a counterclockwise direction going in through a paracentesis, weaving through the pupil margin, and exiting out the next paracentesis. Here the iris bites can be seen wrapped around the needle in a spiral resulting from whip stitch style suturing. A 24-g plastic IV catheter (angiocath) was used to catch the needle tip inside the eye and guide it out through the paracentesis without catching corneal tissue and not dulling the needle tip. (C) The completed case with a pupil size of about 4 mm as measured externally and optimal Purkinje images indicating excellent IOL position. The small notch in the pupil margin on the left of the image occurred at the most common location, a site where the needle exited the eye and reentered to begin suturing the iris again. It is visible under the microscope, but this size is not particularly visible to the naked eye.

- It is critical to avoid catching corneal tissue when passing the needle in and out of the eye. For exiting the eye, the needle tip should be docked into the tip of a 24-g IV catheter (angiocath) or a 27-g steel cannula. The needle can sometimes penetrate through a wall of the angiocath, creating small challenges, and the needle tip can readily get dulled putting it into a steel cannula. Because none of these maneuvers are perfect, the surgeon should test at every paracentesis to ensure corneal tissue has not been caught (see Fig. 43.3B).
- Double-armed 10-0 polypropylene with long curved spatula needles works well. Keeping it double-armed gives the surgeon an out should something happen that stops progression in the first direction or even for ergonomic convenience.
- The first needle pass must be done through a paracentesis, as described previously, not catching any corneal tissue in the incision. The location where the surgeon sits and the starting place can all be done as works best for the individual surgeon's ergonomic preferences. Some surgeons may choose to change their position during parts of the procedure.
- The (right-handed) authors prefer to start proximally and continue circumferentially in the counterclockwise direction.
- A full-thickness bite is made front to back, then back to front as close together as is practical.
- Additional bites can be made with a similar basting stitch or using a whip stitch in which the needle tip wraps around the iris margin (or the reverse) from back to front.
- This is continued until the ergonomics prevent further degrees of freedom, usually around 3 or 4 clock hours.
- A paracentesis is created near the needle tip (if not already precreated), and the needle is exited, guided by a cannula or angiocath. It is reentered and the process is repeated until 360 degrees have been engaged.
- The more bites taken and the closer the bites are together, the more round the result.
- The knot is tied using the surgeon's preferred mechanism, although at least a 2-1-1 orientation is required. We usually aim for 3.5 to 4 mm (Video 43.8) (see Fig. 43.3C).

CERCLAGE TIPS	BENEFITS
• Bites close together	• Smoother, more round aperture, no gaps
• Numerous bites	• Smoother, more round aperture, no gaps
• Whip stitch	• Smoother, more round aperture, no gaps
• Leave double-armed suture	• If suture gets trapped, can start in other direction
• Start cerclage via a distal paracentesis	• Can use both needles and go part clockwise and part counterclockwise so all suture passes are forehand
• Microforceps to stabilize the iris during suture passage	• Less tension on iris insertion and less risk for iridodialysis, however, may crush iris tissue a bit
• Microforceps to wrap the iris margin around the needle tip	• More ergonomic, especially distally • Can get bites closer together • Less "oar-locking" of the needle at the paracentesis because the needle is stable

Bridging and Coat-Hanger Repair for Large Iris Defects

Sometimes even a maximal, expert repair will still leave a substantial defect. Iris prostheses are ideal in these situations, but they may not be viable for timing or cost reasons. Bridging or suspension sutures may be helpful to mitigate symptoms. If unsuccessful, a prosthesis can be placed at a later date (Fig. 43.4).

- Bridging and coat-hanger sutures work best for large superior iris defects because the upper lid usually covers part of the upper cornea. Often, when a lot of superior iris is missing, a corectopic pupil needs to be lifted superiorly. One may use multiple bridging sutures, but the coat-hanger configuration can sometimes achieve a similar result with a single suture.
  - The coat-hanger suture creates vector forces that are not directly in line with the sutures themselves but rather someplace in between the direction of the sutures. The actual direction of the

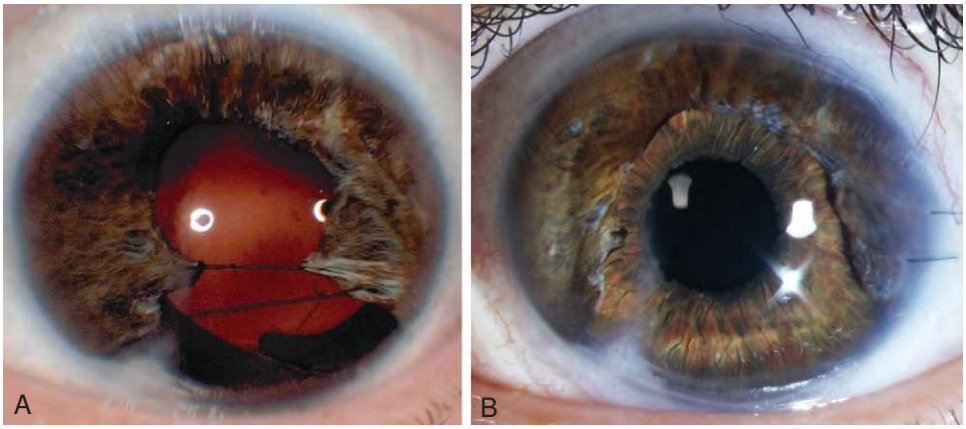

Fig. 43.4 In this eye the fibrotic iris tissue could only be partially stretched, so bridging sutures were used for a partial closure (A). Particularly because this defect was inferiorly positioned, the patient had significant residual photic symptoms. To ameliorate the symptoms, the bridging sutures were removed, and an iris prosthesis was placed in the sulcus and sutured to the sclera (B).

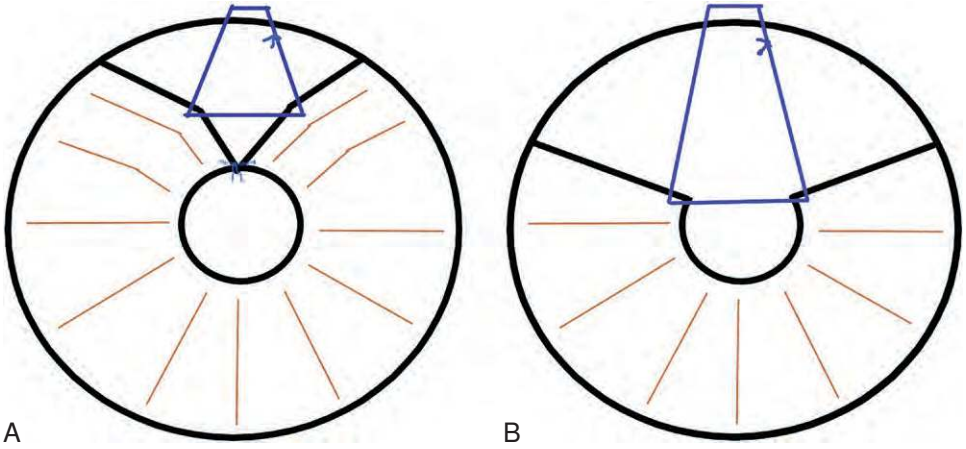

Fig. 43.5 (A) Schematic diagram of a coat-hanger repair in a situation in which it was possible to close the iris superiorly, but a large defect remained. The author (GSHO) calls this a *coat-hanger repair* because of its shape. Where the suture passes through the iris, the vector force is between the two sides of the suture, and hence it both lifts the iris and brings the two sides together. The iris' resistance to stretching in any particular direction has an impact on how much and in which direction the iris actually moves. The 10-0 polypropylene knot is pushed into the eye with a Sinskey hook or pulled into the eye using coaxial forceps to grasp the suture inside the eye. (B) Schematic diagram of a coat-hanger repair with superior pupil margin and a large area of superior iris missing. Without the suture, the iris would drape down inferiorly, covering only about the lower third of the corneal area. Although this repair is far from providing complete closure, it creates a much more manageable situation, especially when superior like this because the patient may use the upper eyelid to help block some of the light that would otherwise go in through the upper section of absent iris.

iris movement depends not only on the direction that the suture sides are pulling, but also on the focal "stretchiness" of the iris stroma (Fig. 43.5A–B).

- Creating a coat-hanger suture starts with double-armed suture needles that are sequentially passed through a single paracentesis incision about 180 degrees away from the defect.
  - After the first needle passes through the paracentesis, it needs to go through the particular part of the iris that will benefit from being pulled toward the midline and superiorly. Testing with a microforceps before passing the suture is helpful for determining the best site to penetrate the iris. Next, the needle tip exits the eye wall at the plane of the iris root, out through sclera at a point that will create the proper vector force for iris positioning.
  - The second needle enters the eye through the same paracentesis and then passes through the analogous iris material and sclera on the other side of the eye.
  - First the externalized suture arms are tied externally with a two-wrap throw, then the suture tension is adjusted to maximize the desired iris position, and then, finally, two single-wrap throws are placed to lock the knot. The tails are trimmed, and the knot is placed internally, either pushing it in with a Sinskey hook or by using a smooth-jawed intraocular forceps to grasp the suture internally and pull the knot into the eye (see Fig. 43.5A–B).

Diathermy Contouring of Pupil Shape and Position

There is a tremendous amount of iris repair that can be accomplished with suturing, but there are times when a bit of additional fine-tuning may be useful. Intraocular diathermy to the iris can provide that refinement. Electrocautery applied to the anterior surface of the iris causes focal shrinking.[9,25,26] One can start with low energy and increase it until the desired effect is seen. Unpublished laboratory work by one of the authors (MES) has found that, in eyebank eyes, even rather high diathermy energy does not cause an iris penetration. Treated areas may darken in eyes that have moderate or lighter colored irides, so one should try to make any color changes look as naturally positioned as possible.

- For shaping the pupil, one applies treatments on the side of the pupil that needs to be pulled peripherally.
  - Treatments closer to the iris margin create more acute shape changes in the pupil margin.
  - Treatments applied a bit further from the pupil margin pull the pupil toward the treatment with a gentler curve.
  - Treatments circumferentially adjacent to each other affect a larger arc of the pupil.
  - Treatments applied radially adjacent to each other tend to have an additive effect along the meridian of the treatments.
- To shift the position of the pupil, the treatments should be performed on the side of the iris in the direction that the surgeon desires the pupil to move. The treatments are often applied in a field or larger area of iris to avoid creating focal irregularities. Even when the intention is to shift the position of the iris, the pupil margin shape may also change from treatments that are closer as opposed to further from the pupil margin.
- A balanced approach between shifting and shaping should be followed when one needs to accomplish both functions, perhaps avoiding getting the pupil shape perfect before centering the pupil because moving the pupil position may change the shape.
- Exercise caution near areas of the iris that have been sutured; additional iris tension may pull open iris defects that appeared closed. Diathermy could create enough tension to strain the suture sites and enlarge suture holes or worse.
- Even though thermal contraction in the cornea regresses over time,[27] iris contraction seems quite stable over time. The operating microscope view exaggerates what the patient or others will see when directly viewing the iris, so it does not need to look perfect under high mag (Video 43.9).

IRIS PROSTHESES

There are some instances in which native iris tissue is either of inadequate quality or quantity for repair techniques to be successful. In these cases, an iris prosthesis can be used to treat unfavorable photic phenomena.

COMMON IRIS SUTURING & KNOT–TYING PITFALLS	PROBLEM	PREVENTION/REMEDIATION
Siepser suture forms a twist instead of a throw	The sutures are inadvertently oriented with the strand from the distal iris on the outside or if the wraps are effectuated moving away from the limbus.	Orient the sutures so that the strand coming from the distal iris pass is between the trailing strand (attached to the proximal iris pass) and the leading strand (which exits the eye distally).
Catching corneal or limbal fibers with needle tip when entering a wound	If you catch collagen fibers at a wound, sliding knot–type techniques will be ineffective as the iris will be dragged to the wound.	For entering the eye, a cyclodialysis spatula, or one side of a tying forceps, can gape the paracentesis while the needle tip is slid down the side of the instrument. Move the needle tip a few millimeters into the eye when it is first placed, then slide the shaft side to side. If no corneal tissue was caught, then the needle shaft will move the full width of the incision. If corneal tissue has been caught, then the shaft will pivot/catch with the tissue perforation site, acting as a fulcrum, and the pass can be redone. If this is not discovered until much work has been done (as in a cerclage), some extra slack can be pulled into the eye and an Ahmed intracameral typing technique can be applied. Alternatively, the trapped collagen fibrils can be lysed with the tip of a 25-g needle, although this risks breaking the suture.

PATHOLOGIES COMMON IN EYES NEEDING IRIS PROSTHESIS PLACEMENT			
Inadequate *Quantity* of Iris Tissue		Inadequate *Quality* of Iris Tissue	
Acquired	**Congenital**	**Inadequate Stroma**	**Inadequate Pigment Epithelium**
Trauma	Aniridia syndrome	Uveitides	Uveitic atrophy
Surgical excision (i.e., iridocyclectomy for melanoma)	Rieger's syndrome	Iridoschisis	Medication-related atrophy
Iatrogenesis		Very high intraocular pressure from angle closure episode(s)	Iatrogenesis
ICE syndrome			UGH syndrome
Uveitides			Ocular albinism

ICE, Icthyosis-cheek-eyebrow; *UGH*, uveitis-glaucoma-hyphema.

IRIS DEFECTS THAT MAY NOT BE AMENABLE TO REPAIR

When the iris is of inadequate quality or quantity for repair, iris prostheses are an excellent alternative. The pathologic conditions that make up this group of patients are legion and may be either congenital or acquired.

SLIT LAMP EXAMINATION FOR CONSIDERATION OF IRIS PROSTHESIS

It is crucial to examine all patients with known or suspected iris defects with a careful slit lamp examination *before* pharmacologic dilation. The slit lamp examination should be complete and specifically should include the following:

- Assessment of the iris color and comparison to the fellow eye's iris color
  - Photographic documentation of color should be performed before dilation if a custom iris prosthesis is considered.
- Assessment of the pupil size, shape, and function
- Assessment of the stromal surface
- Determination if any synechiae are present
- Assessment of the pigment epithelium by retroillumination

It is equally important to repeat the slit lamp examination after pharmacologic dilation to reassess the iris tissue in a different state, to determine the degree of muscle function present, and to determine the underlying lens and zonular status because zonulopathies, cataracts, and malpositioned IOLs are often comorbid findings in these patients.

DEVICE SELECTION

Peter Choyce reported the first iris prosthesis, marketed in England in the mid 1960s.[28] Although a variety of iris prostheses have been marketed world-wide over the last two decades, most are no longer available. The custom, flexible iris from HumanOptics AG is the only device available in the United States. Reper NN makes a colored acrylic device in Russia, marketed outside the United States. The authors do not have any clinical experience with that device and so will restrict implantation details to the unit available in the United States.

DEVICE ORDERING

The HumanOptics custom, flexible iris is manufactured uniquely for each patient and is based on an index photo taken of an injured eye.

- The photo is printed on hard copy paper, and both the physician and patient sign off on the acceptability of the match to the patient's uninjured eye.
- Congenital aniridics can select an eye photo of their choice.
  - We advise ordering both devices at the same time for bilateral cases so that the match is as close as possible between the two eyes.
- For albino patients or those with normal iris stroma but epithelial loss of iris pigment, a black device can be specified.
  - Albino patients may have residual photophobia because stray light can also enter the eye through the eye wall because of an absence of retinal pigmented epithelium (RPE) and choroidal pigmentation.
- The template photograph hard copy is sent to the custom manufacturer.
- The color matches are usually quite good, although there can be some mild variation in relative color or lightness. This can vary subtly depending on the ambient light source.
- We instruct patients that the matches are usually "cocktail party good," meaning that at cocktail party distance and cocktail party lighting, it will look very close to the other eye.
- It takes a few months for manufacturing and shipping.
- Because there cannot be any custom devices in inventory, urgent implantation is not viable.
- The devices can be ordered made entirely of silicone ("fiber free") or with an embedded polyester mesh. The "fiber-free" devices are more easily manipulated and can also be sutured if needed. The devices with fiber can become slightly distorted if they are passed through a nonvalidated injector system. We tend to order the devices "with fiber" meshwork only when we will be suturing a device through a larger corneoscleral wound.

IMPLANTATION TECHNIQUES

The custom, flexible iris is versatile and can be placed in several different ways.

- **In-the-bag placement:** If there is an intact capsular bag, placing the device within is our strong preference, as the device is thereby sequestered and not in contact with any vascular tissue (Video 43.10).
  - Because the iris implant can push the IOL slightly more posteriorly in the bag, the effectivity changes, and one should plan to aim roughly 0.75 D more myopic than usual. Refractive results are slightly less accurate than in normal eyes.
  - In-the-bag devices must be accompanied by a capsular tension ring (CTR) to reduce the risk for buckling.
  - The device needs to be trephinated to the proper size. We measure the diameter between the internal edges of the CTR using a 23-g intraocular ruler and subtract 0.5 mm for the trephination diameter.
    - The trephination can be "freehand" against a flat surface or with a trephine-centering guide (Video 43.11).
  - In-the-bag placement is most facile when done at the same time as cataract surgery.
  - Making a capsulorrhexis slightly larger than usual makes placement easier.
  - Capsule staining is critical because the red reflex disappears as the device enters the eye.
    - Trypan blue dye works well in most cases.
    - Indocyanine green dye is preferred for congenital aniridics because the capsules are one-third thickness and trypan blue reduces the elasticity, making the capsules even more fragile.[29]
  - Placing the device into the bag through the capsulorrhexis, which is necessarily smaller than the device diameter, requires injection and some awkward manipulation.
    - The trephinated implant is folded in a trifold fashion with the colored side outward and placed into the barrel of a Silver Series injection cartridge (Johnson & Johnson®).
    - The device is injected into the bag under the distal capsulorrhexis margin.
    - Unfold the two lateral wings of the device into the bag with crossed hooks (of any type).
    - Placing the subincisional part into the bag is the hardest. Using a 23-g serrated forceps from a distal paracentesis to grasp the subincision, pseudopupil margin allows the device to be overfolded, reducing the outer diameter; then it can be tucked under the capsule margin and allowed to unfold to a planer configuration.

IRIS PROSTHESIS	INVENTOR/ CHAMPION(S)	DEBUT	PROPERTIES	AVAILABILITY
Rayner Mark V, England	Peter Choyce	1964	• Rigid anterior implant • Blue, green, and brown	Defunct
Morcher, Germany	R. Sundmacher	1991	• Rigid, black PMMA diaphragms • With or without an optic	Defunct
Morcher 67s et al., Germany	Volker Rasch, Ken Rosenthal, Bob Osher, Kevin Miller, Sam Masket	1996	• CTR-based black PMMA fins • Implantable into the bag in pluralities	Defunct
Ophtec 311, Netherlands	Jan Worst	?	• Rigid Perspex® diaphragm • Blue, green, or brown • With or without an optic	Defunct
Ophtec IPS, Netherlands	Otto Hermeking	?	• Multipiece rigid Perspex® • Blue, green, or brown element for in-the-bag placement	Defunct
Morcher 30-B, Germany	?	?	• Clear PMMA diaphragm • Opaque overlay of colored, simulated iris images • Made in 48 colors with an optic	Defunct
HumanOptics CustomFlex® Artifical*Iris*, Germany	Hans Reinhard Koch	2005 ?	• Flexible silicone device • Custom-matched to an index photo • Can be trimmed to fit in the capsular bag, sulcus, or suture fixated • With or without embedded fiber mesh	Worldwide, including United States
Reper, Russia	Nadia Pozdeyeva	?	• Foldable acrylic matrix • Simulated iris colors surrounded by acrylic • With or without an optic • Available in a variety of geometries	CE Mark countries, Russia

CE, Cataract extraction; *CTR*, capsular tension ring; *PMMA*, polymethyl methacrylate.

  - The periphery should be inspected to make sure the IOL haptics are not "caught" by the device edge. If so, they can be tucked gently under using a Kuglen-like hook inside the capsular bag.
  - In-the-bag placement is still viable when a sutured CTR or segmental fixation is required (Fig. 43.6).
- **Passive sulcus placement:** If the posterior capsule or capsulorrhexis is no longer intact, but the zonules are intact and an IOL is secure in the bag, then the implant can be placed passively in the sulcus. Passive fixation requires no more than 4 clock hours of contiguous gap in the peripheral iris tissue to prevent the device from riding anteriorly to the trabeculum or endothelium.
  - For most average sized eyes, the device can be used at full size (12.8 mm).
  - We like to measure the sulcus internally using an ultrasound biomicroscopy (UBM) preoperatively or an intraoperative microruler (Micro Surgical Technologies, Redmond, WA, USA).
  - For passive sulcus fixation, the device should be snug but not tight. If it too loose, movement and inflammation may ensue.
- **Scleral suture fixated:** When the zonular integrity is absent, compromised, or unsure, then scleral fixation is required. When in doubt, it is better to fixate (Video 43.12).
  - We prefer CV-8 ePTFE (Gore-tex) suture using a TTc-9 needle for this purpose.
  - The device should ideally be sized to leave a 1-mm clear gap between the outer edge of the implant and the inner edge of the eye wall when it is suspended in place. The sulcus can be measured by intraocular ruler or UBM. Often, the device can be used full size, but it may require trephination in some eyes.
  - We use two opposing horizontal mattress sutures placed into the periphery of the device for a 1.5-mm bite tangential to the edge

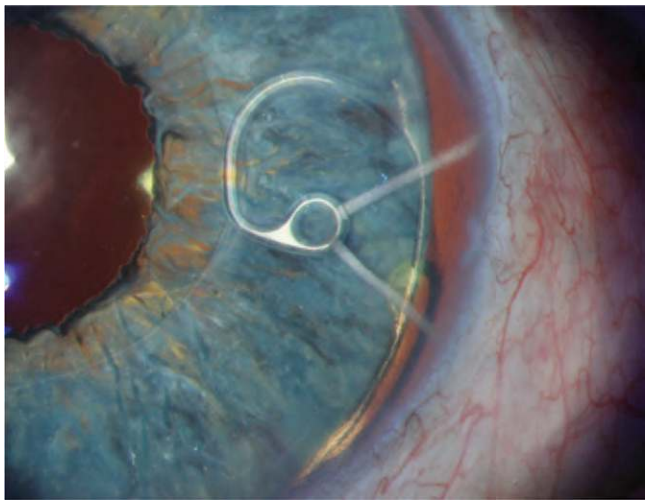

Fig. 43.6 A custom iris device is seen within the capsular bag with a suture-fixated (Cionni) capsular tension ring in the bag's equator. The fixation element is visible, coursing anteriorly around the capsulorrhexis. Note that the IOL haptic was captured by the edge of the device during unfolding and inadvertently was not noticed intraoperatively so as to reposition it.

about 1.5 mm in from the edge. Each end is trimmed to roughly 1.5 to 2.0 cm.
- A peritomy is performed in the areas of planned suture placement. For congenital aniridics, a limbus-based flap is preferred to avoid any manipulation of the limbal stem cells.
- Four sclerotomies are created at the level of the ciliary sulcus, two pairs (about 4–5 mm apart for each pair) roughly 180 degrees away from each other.
- Forceps insertion:
  - When the device is placed in the eye with forceps, the suture ends that correspond to the two most distal sclerotomies should be placed in the eye and retrieved from the sclerotomies before placing the implant into the anterior segment.
  - The device is folded 60/40 and placed into the OVD-filled chamber.
  - The sutures are pulled, unfolding the device.
  - The two trailing sutures can then be placed into the anterior chamber and retrieved with microforceps placed through the sclerotomies.
- Injector insertion: the implant is folded in a trifold with the colored side outward and the sutures all directed toward what will be the tail end of the Silver Series cartridge (Video 43.13).
  - The device is tucked into the barrel of the cartridge and the four trailing suture ends through the hollow tail, making sure they do not get trapped as the cartridges butterfly wings are closed.
  - The device is injected into the distal ciliary sulcus and manually unfolded.
  - The device's edges are all manipulated into the ciliary sulcus and the device rotated so that the suture sites are corresponding to the sclerotomies.
  - The sutures are retrieved form the sclerotomies.
- The globe is pressurized.
- The sutures are snugged externally to maximize centration, and the knots are tied in a 3-1-1-1-1, trimmed with 0.5-mm tags, and rotated internal to the eye wall.
- The suture can be slid along its tract until centration is ideal. Fine-tuning can be performed by sliding the device along the suture using a serrated microforceps to grasp the device inside the eye.

We usually find it faster and easier to secure IOLs separately from the iris implant, although one can attach the implant to the IOL with either sutures or haptics placed through sleeves made in the artificial iris, then secure either the IOL to the scleral wall or secure the iris implant to the scleral wall as a unit.

The conjunctiva and Tenon's fascia should be securely sutured to the limbus to ensure good coverage over the transscleral sutures.

PITFALLS/COMPLICATIONS OF IRIS PROSTHESES

Eyes that need iris prostheses tend to have several comorbid pathologies. We restrict our discussions to complications and pitfalls that occur related to the device, rather than a comprehensive review of complication management.

- ***Iris device is too big***.
  - If the device is trephinated too large for either the bag or the sulcus, it can either buckle or bow forward or backward. This requires that the device be explanted and either retrephinated to a smaller size or, if the device is damaged during explantation, the back-up device can be trephinated to a more appropriate size.
  - If a device bows modestly within the bag, it will also cause a more hyperopic result than expected.
- ***Iris device is too small***.
  - If an iris device is made too small and placed within the bag, the pupil will decenter inferiorly. This is primarily cosmetic but could be annoying to some patients, especially if the implant is a lighter color. Removal and placement of the back-up device in a more appropriate size can be performed.
  - A passively placed iris device that is too small can cause movement within the sulcus space, and this may result in inflammation or hyphema. This can be ameliorated by placing scleral fixation sutures in situ (Video 43.14).
- ***Capsule contraction*** can cause buckling or bowing of an in-the-bag device. This is extremely rare with a CTR in the bag but rather common (over one-third of cases) if a CTR is not placed.[29] The best management for this problem is prevention by placing a CTR. If bowing occurs, the device can either be migrated into the sulcus and suture fixated or replaced with the back-up device (if it is still available by then).
- ***Capsulorrhexis break*** can occur during implantation of the device. This is very uncommon overall but slightly more likely in congenital aniridics whose capsules are much more fragile. In a large series of custom iris placement during congenital aniridic cataract surgery, capsulorrhexis break occurred in 11%.[29] If the device were to decenter or subluxate, it could be suture fixated to the scleral wall.
- ***IOL haptic capture*** can occur not uncommonly as the device is unfolding in the capsular bag. This may decenter the lens a bit. This is easily reduced by stabilizing the iris device with a serrated microforceps on the pseudopupil, pulling it slightly centripetally, and tucking the haptic underneath the implant with a Kuglen (or similar) hook placed into the capsular bag.
- ***Aniridia fibrosis syndrome*** is a serious vexing problem that can occur idiosyncratically in congenital aniridia in which fibrous tissue can grow throughout the anterior segment and possibly onto the ciliary body or retina. This occurs in less than 5% of congenital aniridia eyes. The rate is not appreciably different whether an iris prosthesis is placed or not (4.5% in the landmark description without iris prostheses,[30] 3.1% of 98 eyes with custom, flexible iris prosthesis placement[29]).

SUMMARY

- Some iris defects may be repaired directly, whereas others require an iris prosthesis; a decision is needed on this preoperatively.
- Globe pressurization is a critical part of iris repair surgery.
- Adjust the sutures of an iridodialysis repair with attention to the pupil shape/position and not necessarily to complete closure of the dialysis.
- Cataract surgery in a patient with congenital iris coloboma requires coloboma repair to achieve a good result from the cataract surgery.
- Iris cerclage surgery is only appropriate for eyes with absent iris sphincter function but reasonably normal stroma and iris pigment epithelium.
- Intraocular knots for iris sutures should be tightened inside the eye at the appropriate location to avoid damage to and distortion of the iris.
- Iris prostheses are an excellent solution to reduce photic symptoms and restore body image when iris repair is not possible.
- Iris prosthesis placement in the capsular bag is preferred when possible.

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Video 43.1 Macro model demonstrating the Osher, Snyder, and Cionni variants of Siepser sliding knot. The bicolored strings in this model along with the narration make it easy for one to see the steps to successfully create this knot. A loop is hooked out of the eye from the distal side of the iris three times to create the three throws, with wraps in alternating directions, before cinching the throws inside the eye with tension on the sutures outside of the eye. A 2-1-1 example.

Video 43.2 Macro model demonstrating the Ogawa intraocular knot. The bicolored strings in this model along with the narration make it easy for one to see the steps to successfully create this knot. The three throws are formed outside the eye, then an angled IOL manipulator is used to pull each throw inside the eye and cinch them at the location desired for the knot. A 2-1-1 example.

Video 43.3 Macro model demonstrating the Ahmed two forceps intraocular knot. The bicolored strings in this model along with the narration make it easy for one to see the steps to successfully create this knot. The three throws are formed and cinched inside the eye using two coaxial smooth jawed forceps. A 2-1-1 example.

Video 43.4 Repair of large traumatic iridodialysis using three mattress sutures of 10-0 polypropylene on 13 mm × 0.15 mm spatula curved needles. The mattress suture tension is focused on optimizing pupil position and shape as opposed to fully closing the iridodialysis defect. Cataract surgery and anterior vitrectomy were performed before the iridodialysis repair.

Video 43.5 Sutures of 10-0 polypropylene on a long, curved, transchamber needle to place a multibite interrupted suture for iris sphincter repair. The iris is supported by an iris reconstruction hook during passes of the needle. The knot was tied using the Ahmed two intraocular forceps technique.

Video 43.6 Iris-gathering sutures are placed for treatment of a focal iris transillumination defect. Interrupted 10-0 polypropylene sutures on a single 13 mm × 0.15 mm curved spatula needle are passed through the intact iris at the edge of the transillumination defect, then woven through the radial iris strands of the defect until intact iris is reached on the other side of the defect. The two arms are then tied with an intraocular knot to gather the iris, thereby decreasing light passage through the area. In this situation a second pass of the same sort is needed more peripherally to achieve the desired result.

Video 43.7 Congenital iris coloboma almost always needs to be addressed at the time of cataract surgery but rarely needs attention before cataract surgery. After cataract surgery, this video shows an effective repair of the coloboma by removing the sphincter muscle from the sides of the coloboma. The closure of what is effectively an iris stromal defect is accomplished with interrupted sutures.

Video 43.8 Iris cerclage suture for permanent mydriasis. This technique is reserved for situations in which there is essentially no sphincter function remaining. The long, curved transchamber needle on 10-0 polypropylene enters through a paracentesis without catching iris tissue, weaves through the iris near the pupil margin, and then exits through the next paracentesis, again without engaging iris tissue. Whip stitch pattern of iris suturing allows for closer bites and hence a smoother resulting pupil margin. An Ogawa intraocular knot is used in this example to tie the suture with a pupil size of about 4 mm measured externally.

Video 43.9 Intraocular diathermy works well for contouring and shifting the pupil. In this case the IOL is exchanged, and a large iris defect is closed with interrupted sutures before using a 25-g diathermy probe to shrink iris tissue for improving the position of the pupil.

Video 43.10 This video goes through an entire case of phaco with IOL and CTR placement, trephination of an iris prosthesis, and placement of the device in the capsular bag using the overfold technique. At the end of the case, a trapped haptic end is reduced.

Video 43.11 This video demonstrates the use of a centering device for concentric trephination of a custom, flexible iris prosthesis.

Video 43.12 Step-by-step scleral fixation with ePTFE (Gore-Tex) suture of a custom flexible iris prosthesis and an intraocular lens in an aniridic eye with traumatic aphakia.

Video 43.13 In this video a custom, flexible iris device is injected into the anterior chamber and then suture fixated in the ciliary sulcus.

Video 43.14 A passively placed, custom, flexible iris prosthesis was trephinated too small and a few episodes of uveitis-glaucoma-hyphema syndrome ensued. The video demonstrates ePTFE (Gore-Tex) scleral fixation of the device, alleviating the problem. The color match of this device looked much lighter under the high illumination of the operative microscope but was acceptable in normal room light illumination.

44

Surgery in Short and Eyes

Kavitha R. Sivaraman and Michael E. Snyder

CONTENTS

KEY POINTS

- Eyes at the extremes of axial length pose unique challenges for preoperative planning, surgery, and postoperative management.
- Management of cataracts in very short eyes can be complicated by difficulties in IOL selection, intraoperative technical challenges, and postoperative issues such as choroidal effusion.
- When managing cataracts in very long eyes, the surgeon may encounter issues with zonulopathy, lens iris-diaphragm retropulsion syndrome, and a higher risk for vitreoretinal complications.

INTRODUCTION

Although most eyes fall into the center of the normal distribution of axial length, cataract surgery for eyes on either extreme of the bell curve presents unique challenges, both in planning and operative execution. In some referral practices, eyes with extremely long or short axial lengths may be seen several times a week, while in a general cataract practice, these eyes may present only a few times a year. The special considerations for very short eyes and very long eyes differ in many ways, so we will address each separately in the paragraphs that follow.

SHORT EYES

Definitions

- The average axial length of the adult eye is approximately 23.8 mm.[1]
- Microphthalmia refers to an eye with an axial length (AL) that is 2 standard deviations below the mean, or < ~21 mm in adults.[2]
- Simple microphthalmos is a small eye with no ocular abnormalities, a normal anterior chamber depth (ACD), and normal scleral thickness.[2]
- Complex microphthalmos is a small eye with anatomic abnormalities but also a normal scleral thickness.[2]
- Nanophthalmos refers to an eye with thickened sclera, small ACD, and short AL, often reported as <18 mm, although there is a lack of consensus on the upper limit for AL.[1,2]

Comorbidities

Amblyopia

For short eyes in particular, it is important to assess for underlying amblyopia because high hyperopia is obviously the norm in this cohort; and amblyopia, even if subtle, is quite common. Some highly hyperopic patients will be unaware of their own amblyopia diagnosis if not previously treated with patching therapy. Such a history may be elicited by asking the following:

- "At what age did you get your first pair of glasses?"
- "Were you ever 20/20 with glasses?"

This information can be very helpful in setting expectations. Strabismus (and strabismic amblyopia) is also quite common in highly hyperopic, short eyes but may resolve before adulthood and thus not be evident on cross-cover testing. Patients may only be aware that they have one eye that was always "a little stronger" than the other.

Anatomic Narrow Angle

Gonioscopy and careful optic nerve head evaluation is advisable in these short eyes.

PREOPERATIVE MANAGEMENT

Slit Lamp Exam

Examination of short eyes should be particularly attentive to the relative size and depth of the anterior segment, which can vary markedly in this patient subset. Guttae may be more common in these eyes; even in the absence of guttae, the endothelial cell count may be reduced, perhaps by prior intermittent angle closure episodes. In shallower anterior segments, gonioscopy is advisable, especially if there is any hint of angle closure history.

The examiner should be attentive on fundus evaluation to the possible presence of choroidal folds or retinoschisis, both of which are seen more often in these cases than in eyes of normal axial length. Macular OCT can be especially useful to detect subtle choroidal folds or thickening.

IOL Selection

- Notoriously challenging
  - In very short eyes, the relative size of the anterior segment to the posterior segment is highly variable, unlike eyes with "normal" axial lengths.
  - Some of these eyes will have normal-sized anterior segments with normal depth.
  - Others may have exquisitely shallow and/or small chambers.
  - Variability makes effective lens position (ELP) prediction postoperatively difficult.
  - Relative rarity of these eyes yields less normative data from which to draw conclusions.
  - Because the IOL powers tend to be much higher in this subgroup of patients, any error in ELP estimate will have a greater impact on the final refraction than in normal or longer-eyed counterparts.
  - Artificial intelligence-based calculation methods such as the Hill-RBF formula tend to perform better in this subgroup and should continue to improve with each formula iteration as more data is acquired.
- A more detailed discussion of IOL calculation method is included in Chapter 3 of this text.

IOL power availability in commercially marketed lenses does not always go as high as needed for emmetropia in very short eyes.

- The highest IOL power currently available in the United States in a foldable model is 40.0 diopters.
- For eyes that require much higher powers, several strategies are available. One common approach is to select a 40D IOL and have the patient understand that they will remain highly hyperopic postoperatively.
- At the time of this publication, only one European manufacturer still makes ultra-high-powered IOLs:
  - HumanOptics AG (Erlangen, Germany) manufactures hydrophilic acrylic IOLs up to 60.0 diopters.

This high-powered IOL has relatively soft and thin haptic material and is more vulnerable to movement with bag contraction. Accordingly, insertion of a capsular tension ring (CTR) is advisable, even if no zonulopathy is identified.

Because of the risks of iris chafe, pigment dispersion, and uveitis-glaucoma-hyphema syndrome with sulcus IOL placement in short eyes, we strongly discourage the use of piggyback IOLs in this setting.[3]

SURGICAL PROCEDURE

Preoperative Management

Reduction of vitreous, orbital, and choroidal volume can markedly improve the facility of executing these cases. Preoperative intravenous mannitol (provided there is no systemic contraindication) can have a positive effect on all three of these features. General endotracheal anesthesia with paralytics will relax the rectus muscles and thereby reduce posterior pressure, while the inhaled anesthetics, as smooth muscle relaxants, reduce orbital venous volume. Placing the patient's body in the slightly reverse Trendelenburg position will accentuate the reduction in both orbital and choroidal volume. Furthermore, the associated lower systolic blood pressure will reduce the risk for choroidal effusion or hemorrhage. Some surgeons also find the Honan balloon or orbital massage preoperatively to be useful adjuncts.

Tips for Increasing Anterior Chamber Depth	Mechanism
• General endotracheal anesthesia	
• Inhaled anesthetics	Smooth-muscle dilation reduces central venous pressure and thus reduces choroidal and orbital volume.
• Paralytics	Reduces rectus muscle tone and thereby reduces posterior pressure.
• Intravenous mannitol	Dehydrates vitreous, choroid, and orbit, reducing volume.
• Reverse Trendelenburg	Reduces central venous pressure, by gravity, and thus reduces choroidal and orbital volume.
• Honan balloon/orbital massage	Reduces orbital (fluid) volume.
• Pars plana tap (with vitrector)	Mechanically reduces vitreous volume.
• Highly cohesive OVD (i.e., Healon5®)	Mechanically occupies space.

Intraoperative Management

Maintaining a deep anterior chamber during phacoemulsification can be tricky but is mitigated by the above steps taken before entering the eye. Highly cohesive OVDs, such as Healon5 (Johnson & Johnson Vision) will aid capsulorrhexis creation by helping *flatten the usually very convex anterior surface of the lens* in these small eyes. Repeated OVD instillation will likely be required, so having an ample supply in the room at the onset of the case is wise.

In some instances, the anterior chamber may remain too shallow to work in, even despite the above steps. In these cases, a limited "dry" vitreous tap using a vitrector device via a pars plana incision can reduce the vitreous volume enough to create an acceptable working space.

- In nanophthalmic eyes, the pars plana may be very short and the ora serrata more anterior than normal, so hedging a bit more anterior is prudent. Fundus exam by indirect ophthalmoscopy postoperatively is mandatory.
- Add OVD to the anterior chamber with each bit of vitreous removal.
- Avoid overly aggressive removal of vitreous volume to avoid an overly deep chamber.
- We recommend using a pars plana cannula and trocar system.
- We strongly discourage needle aspiration of "liquid" vitreous because it is difficult to determine where a liquid lacuna is (if there is one), and aspiration of gel creates direct vitreoretinal traction.

There is some literature to support a reduction in intermediate and long-term risk for ciliary effusion by creating prophylactic scleral windows. Rajendrababu et al. reported 60 nanophthalmic eyes, 38.7% of which developed effusions without scleral windows versus 17.2% that developed uveal effusions when scleral windows were placed.[4] We have subjectively found lower numbers. Scleral window creation is a skill set that is not widely held by anterior segment surgeons, however, and is not without risk, especially because the sclera tends to be thicker in nanophthalmos. We have found late effusions to be uncommon, but vexing, so have more recently incorporated this into our regimen.

- The scleral window is made by performing a local peritomy in an oblique meridian (we prefer to work in the quadrant toward our dominant hand).
- Cautery is applied and a slow radial cut-down is performed, centered around a point roughly 4 to 5 mm behind the limbus, just until the choroid's outer surface is encountered.
- A Kelley punch is gently slid under either edge, and a few bites are taken from each side (Video 44.1).

- Fine-tipped cautery is applied to the edges to do the following:
  - Minimize oozing of heme.
  - Open the edges a bit wider.
- The conjunctiva and Tenon's fascia are then closed over the top.
- Although we have not encountered significant bleeding during scleral window creation, this is a distinct risk. If encountered, we would specifically not advise closure of the sclera because this would lead to formation of a suprachoroidal hematoma.
  - Instead, we would advise attempting hemostasis with fine cautery to the bleeding choroidal vessels and maintaining a positive, supranormal anterior chamber (intraocular) pressure. Accordingly, OVD removal from the anterior chamber (if not already done) should be deferred until bleeding has stopped.

There is another important point with regards to timing of scleral window placement. Surgeons from the extracapsular cataract extraction era may be accustomed to placing scleral windows before starting the cataract procedure. However, in the era of phacoemulsification with an IOP-compensated infusion, creating scleral windows at the start of the procedure may actually serve to reduce globe stability in the setting of a highly pressurized eye. If scleral windows are to be placed, we recommend that this be undertaken after phacoemulsification, IOL insertion, and watertight wound closure, either from initial wound construction with hydration or by suture placement.

As nanophthalmic eyes have a higher incidence of zonulopathy, we also routinely place a (small-sized) CTR in these cases.

Potential Complications

Aqueous Misdirection

Also known as malignant glaucoma, aqueous misdirection is a condition characterized by elevated intraocular pressure and a diffusely shallow anterior chamber in the presence of a patent iridotomy.[5] Although classically a complication of glaucoma surgery, aqueous misdirection can also occur with cataract surgery, either intraoperatively or postoperatively. The pathophysiology has not been fully elucidated, but the prevailing theory of aqueous diversion into the vitreous cavity because of cilio-lenticular apposition is supported by UBM findings of anterior ciliary body rotation.[5] Intraoperative aqueous misdirection is characterized by a sudden shallowing of the anterior chamber and marked elevation of intraocular pressure ("rock hard eye").[6] Reversal of this condition can sometimes be achieved with an iridozonulohyaloidectomy, but some cases require pars plana vitrectomy. Before attempting such maneuvers, it is of critical importance that the surgeon rule out a suprachoroidal hemorrhage, which can present in a similar fashion.

Choroidal Effusion and Hemorrhage

Choroidal or uveal effusions refer to fluid accumulation in the suprachoroidal space. In pathologically short eyes, choroidal effusions can be present preoperatively and worsen intraoperatively, develop acutely during intraocular surgery, or develop postoperatively.[2,7] Intraoperatively, a dome-shaped peripheral elevation may be seen along with sudden shallowing and hardening of the eye. Effusions may be either serous or hemorrhagic in nature, with a markedly worse prognosis for hemorrhagic choroidals. Especially in the case of a suprachoroidal hemorrhage, early recognition and immediate water-tight closure of all incisions is critical for preventing catastrophic suprachoroidal bleeding and expulsion of intraocular contents. Intraoperative drainage of either serous or hemorrhagic choroidal effusions is a well-described management strategy; however, this is not commonly part of the skill set of anterior segment surgeons and is often not needed in the acute setting as long as the wound is sealed securely.

Postoperative choroidal effusions can present acutely with elevated intraocular pressure and a shallow anterior chamber. The effusions can be appreciated by fundoscopy or B-scan ultrasound. Effusions often then lead to hypotony as partial ciliary body detachment occurs. Interestingly, the anterior chamber is shallow whether the IOP is elevated or hypotonus. In the former, the chamber shallowing is from more volume behind the capsule plane, whereas, in hypotony, the shallowing may also be related to anterior rotation of the ciliary body. See the "Intraoperative Management" section above for more details on scleral window creation for prophylaxis of postoperative choroidal effusions.

Corneal Edema

In eyes with both short AL and shallow ACD, the working distance between the phacoemulsification needle (along with any ultrasound energy it delivers) and the corneal endothelium will be shorter than in a larger-proportioned eye. Despite the obvious spatial limitations in small, crowded eyes, studies are mixed on the precise effect of ACD and AL on endothelial cell loss. Some studies have found short AL to be a significant marker for the risk for endothelial cell loss,[8] while others have not shown correlation between shallow ACD and postoperative corneal edema.[9,10]

Postop Shallowing in Small Eyes	Findings	Pathology	Management
Aqueous misdirection/ malignant glaucoma	• High IOP (though can be low) • Anterior bowing of iris and capsule plane on exam or UBM • No supraciliary effusion on UBM.	• Cilio-lenticular block with trapping of fluid into the posterior segment/vitreous, causing angle narrowing and high IOPs	• UBM must be done to differentiate from ciliary effusion. • Laser iridozonulohyaloidotomy can resolve some cases. • Recalcitrant cases require pars plana vitrectomy and iridectomy, creating a direct communication between the anterior and posterior segments for a unicameral eye.
Ciliary effusion	• Myopic shift in refraction • Low IOP (though can be high) • Anterior bowing of iris and capsule plane on exam or UBM • Supraciliary effusion is present on UBM.	• Accumulation of serous fluid under the ciliary body causing anterior rotation, resulting in: ▪ Myopic shift (from anterior ▪ Displacement of the ▪ Capsular bag complex) ▪ Hypotony (from ▪ hyposecretion) or high pressure (from angle closure)	• UBM is diagnostic and must be done to differentiate from aqueous misdirection. • Cycloplegia (may need chronically) • Steroids (if even minimal cyclitis) • Iridotomy (if angle closure is imminent) • Scleral window (prophylactically or secondarily if recalcitrant to conservative measure)

Other Complications

Although modern phacoemulsification techniques have enhanced safety for eyes of all axial lengths, exceptionally short eyes are at a categorically higher risk for complications. The risk appears to increase with the severity of axial hypermetropia. A study by Day et al. looking at eyes with AL <21.0 mm undergoing phacoemulsification found an overall complication rate of 15.5%.[11] The odds ratio for complications increased with decreasing axial length: eyes <19.00 mm in length showed a 21-fold increased risk for developing a surgery-related complication.[11] Although the intraoperative and postoperative risks can be mitigated as outlined above, extremely short eyes are challenging even for the seasoned anterior segment surgeon and should be approached with appropriate caution and careful planning.

POSTOPERATIVE MANAGEMENT

Options for management in an axial hyperope who is unhappy with the refractive outcome after cataract surgery are similar to those of any other pseudophake, albeit with more complex risk/benefit considerations. Options include corrective eyewear, laser vision correction, and IOL exchange. Intraocular lens exchange may be more challenging in small eyes because of the smaller working space and risks of choroidal effusion and corneal decompensation.[12] Piggyback IOLs, typically placed in the sulcus anterior to an in-the-bag implant, can be problematic in small eyes because of the risks of pupillary block and interlenticular opacification.[13] Pigment dispersion and ultimately uveitis-glaucoma-hyphema (UGH) syndrome may also occur with piggyback IOL placement in the sulcus.[13]

LONG EYES

Definition

High myopia is defined by a refractive spherical equivalent greater than -5.0 D.[14] A proportion of these patients are axial myopes, in which case their myopia is caused by an elongated axial length. The prevalence of high myopia is growing worldwide: by 2050, approximately 10.0% of the world population is projected to be affected compared with 2.2% in the year 2000.[14]

Comorbidities

- Lattice degeneration
- Thinned peripheral retina
- Megalophthalmos
- Zonulopathy
- Stickler Syndrome
- Tilted discs
- Posterior staphyloma
- Open angle glaucoma
- Pigment dispersion syndrome/glaucoma
- Epiretinal membranes

Awareness of prior vitreoretinal pathology, particularly prior vitrectomy, is important for both preoperative counseling and planning. Axial myopes are categorically at a higher lifetime risk for retinal detachment whether or not they undergo cataract surgery, but this risk increases with a history of prior retinal breaks, especially in the absence of a posterior vitreous detachment (PVD).[15,16] Recent studies show the postcataract surgery retinal detachment rate in high myopes over time as just under 3%, though this may be demographic in nature, rather than causative.[17]

Axial myopia can also be a predisposing factor for zonular weakness, which can be further compounded by prior vitrectomy. The surgeon should be prepared for placement of capsular bag reinforcement or fixation devices.

Even in the absence of glaucomatous optic neuropathy, these patients can be prone to postoperative IOP elevations caused by a compromised trabecular meshwork.[18] One should be aware of the rare megalophthalmos cases and should be prepared for unique IOL fixation options if the crystalline lens is very large.

PREOPERATIVE MANAGEMENT

Slit Lamp Exam

Preoperative anterior segment examination in extreme axial myopes should give special attention to the following:

- Peripheral transillumination defects
- Krukenberg spindles
- Dense trabecular meshwork pigment
- Relative size of the anterior segment, cornea, and crystalline lens
- Presence or absence of a LASIK flap
- Topography with either oblate, prolate, or hyperprolate pattern
- Presence or absence of an ICL. Be extra alert if:
  - High axial length with low refractive error or, especially, if
  - High axial length and hyper-prolate topography because this is not an uncommon finding after ICL placement and hyperopic outcome, resulting in hyperopic LVC
- Anterior chamber depth
- Phacodonesis

The horizontal white-to-white measurement is also important to note in case sulcus fixation of an IOL becomes necessary. Most commonly used 3-piece IOLs have a haptic-to-haptic diameter of ~13 mm. In very large anterior chambers, a lens of standard haptic-to-haptic diameter may not reach the ciliary sulcus at either end, resulting in pseudophakodonesis, pigment dispersion, UGH syndrome, or subluxation of the implant. In these situations, an appropriately sized continuous curvilinear capsulorrhexis that allows for optic capture of a 3-piece IOL placed in the sulcus (if necessary) is of utmost importance.

Occasionally, patients may neglect to mention a history of laser vision correction. Some LASIK flaps can be exceedingly difficult to appreciate on slit lamp examination and eyes with prior PRK may provide no clues whatsoever on slit lamp exam. If this history is not recognized before IOL selection, a significant refractive surprise may occur. Unusually flat keratometry measurements should raise suspicions.

Topographies in High Myopes	Interpretation
• Overly flat corneas	Possible prior myopic LVC
• Oblate cornea (flatter center than periphery)	Likely prior myopic LVC
• Irregular astigmatism	Possible decentered ablation
• Inferior steepening	Keratoconus or post-LASIK ectasia
• Hyperprolate cornea (much flatter in periphery than center)	May indicate prior ICL placement with hyperopic outcome and subsequent LVC "touch-up"

Findings consistent with zonular weakness include an anterior chamber that is asymmetric in depth to the fellow eye. Zonulopathy can result in the "gap sign," wherein the iris does not directly and uniformly contact the anterior capsular surface. In more advanced

cases, phacodonesis or even subluxation of the crystalline lens can occur. However, even in the absence of these slit lamp findings, severe zonulopathy is sometimes discovered intraoperatively. Surgeons should therefore be prepared to reinforce or fixate the capsular complex to allow safe removal of the cataract and/or facilitate placement of an IOL.

Posterior Segment Exam

Extreme axial myopes are at an increased lifetime risk for retinal detachment.[19] Cataract surgery can increase this risk particularly in younger patients and/or those who have not yet developed a posterior vitreous detachment. These patients should have a meticulous dilated retinal examination preoperatively to assess for the following:

- Presence or absence of a posterior vitreous detachment (PVD)
- Presence or absence or an ERM
- Lattice degeneration
- Holes (operculated or atrophic)
- Tears: if present, are they surrounded by pigment or laser? Fully or partially?
- Posterior staphylomata (tears are more common at edges)
- Vitreoretinal tufts

Consider vitreoretinal consultation for prophylactic laser barricade in patients with asymptomatic breaks and/or other peripheral retinal pathology. Macular OCT can be useful in identifying epiretinal membrane, which is not uncommon in axial myopes, especially if there have been prior retinal tears.

IOL Selection

IOL power selection for high axial myopes is much more accurate than in very short eyes and most fourth-generation calculation formulae methods yield excellent results. Part of the reason for this is that the lower the IOL power, the lesser the impact of any error in the ELP. Imagine, for example, a zero powered (plano) IOL. Does it really matter where it sits within the posterior chamber? Of course not! The details of IOL formula/method choice are covered in more detail in Chapter 3. For eyes in which there is an indwelling ICL, the implant can be virtually ignored, but depending on the biometer used, one should make sure than the anterior chamber depth recorded is to the true anterior surface of the lens, rather than the ICL's anterior surface. The lens thickness should similarly be sought.

Fortunately, there are many commercially available options for low powered IOLs.

- Currently, all very-low-powered IOLs are made in three-piece versions only.
- In the United States, Alcon (Fort Worth, Texas) markets a meniscus IOL with powers as low as -5 D (minus five diopters).
- The low-powered Johnson & Johnson Vision IOL comes in powers as low as -10 D (minus ten diopters). Internationally, other options abound.
- To our knowledge, Humanoptics AG (Erlangen, Germany) markets the lowest power implant at -20D (minus 20 diopters).
- One should take extra care in confirming the low power IOLs, because the model numbers are often the same for the low negative and low positive powers. Inadvertently placing +5D IOL when one had intended a -5D IOL could be devastating. The packaging for the minus power lenses has the small "-" sign, but the plus powers do not carry a "+" sign on the packaging.

With axial myopes, IOL calculations will occasionally indicate a zero (plano) powered implant. Should the patient be left aphakic? The answer to this question is a vehement "no," unless the patient has previously had a complete pars plana vitrectomy. The PCIOL has multiple roles, only one of which is optical.

- First, the sharp edges of the IOL prevent or delay lens epithelial cell migration across the posterior capsule, thereby reducing the risk for posterior capsular opacity (PCO). In the absence of an IOL, PCO is rapid and inevitable.
- More importantly, once PCO occurs, Nd:YAG laser capsulotomy is required. If a plano IOL is in place, the IOL optic functions as a barrier, keeping the vitreous within the posterior segment.
  - In the absence of the IOL, vitreous prolapse will occur after Nd:YAG capsulotomy, and the risks of retinal detachment, aphakic glaucoma, and bullous keratopathy jump markedly, mimicking the miserable data from intracapsular cataract extraction days.[20]
  - Aphakic pupillary block can also occur and lead to acute angle closure.

Therefore even for eyes that do not require a powered IOL for optical correction, it is still prudent to place a 0.0 (plano, zero-powered) PCIOL in most cases.

Very low-powered IOLs do not usually come with toricity; therefore alternate means of astigmatic correction should considered when astigmatic reduction is desired. Other features such as multifocality are also not widely available in extreme spherical powers.

Nonoptical IOL Properties to Consider When Selecting an Implant for an Axial Myope

- Haptic-to-haptic diameter/optic capture
  - Most IOLs are too short for passive sulcus fixation in a large anterior segment. In the event of a posterior capsule rupture, optic capture through an appropriately sized capsulorrhexis would remediate this concern.
  - Optic capture refers to placing the haptics of a 3-piece IOL in the ciliary sulcus while prolapsing the optic posteriorly through a (smaller) anterior capsulorrhexis.
  - The surgeon may elect to create a primary posterior capsulorrhexis and prolapse the optic through both the anterior and posterior capsulotomies into Berger's space.
  - Other configurations of optic capture suffice for when an IOL is already behind the capsular plane.
  - Optimal size of a capsulorrhexis for capture is approximately 1.5 mm smaller in diameter than the optic diameter of the IOL. This is small enough to maintain a capture once achieved, but large enough to make the effectuation of the capture facile.
- IOL material
  - Because retinal detachment is more likely in this cohort, one should consider eschewing silicone-based lenses because one can impede visualization for vitreoretinal surgery from condensation under air. Similarly, if a retinal detachment surgery requires silicone oil placement, the oil can "mar" the silicone IOL (Fig. 44.1).
- IOL optic size
  - Axial myopes have large resting pupils, especially if younger, and axial myopes tend to get cataracts at earlier ages. We took care of one such patient who had a nearly 7 mm resting pupil size and had intolerable halos after implantation of a 6 mm, +4 diopter hydrophobic acrylic PCIOL. His IOL was exchanged for a 7 mm diameter +4D hydrophilic acrylic PCIOL (HumanOptics, AG, used under FDA Compassionate Use Device Exemption), which alleviated this symptom.

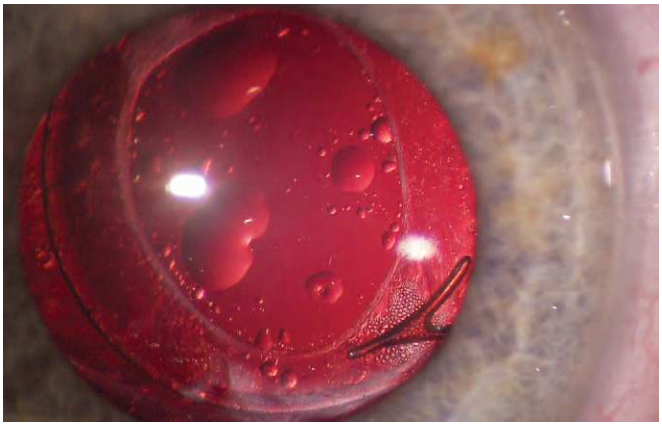

Fig. 44.1 Silicone oil droplets adherent to the surface of a silicone intraocular lens.

SURGICAL PROCEDURE

Anesthesia

Axial myopes are at an increased risk for globe perforation from orbital blocks. Peribulbar blocks, which require less angulation toward the optic nerve, lessen but do not eliminate the risk for globe penetration. A subtenon's block delivered via a blunt cannula obviates this risk but does not reliably provide the same degree of akinesia as a peribulbar or retrobulbar block. Of course, topical anesthesia similarly obviates injection risk. In extreme myopes (or those with significant staphylomata) who are unable to cooperate with topical anesthesia, laryngeal mask, or general endotracheal anesthesia may occasionally be necessary.

Intraoperative Considerations

- Overly Deep Anterior Chambers
  - If the wound is constructed too anteriorly, it can be awkward to access the lens, and the posterior angulation of the phaco can distort the cornea and thus diminish the view. This can be mitigated by attentiveness to a square incision at the (posterior) limbus, beginning just anterior to the conjunctival insertion.
  - Temporal placement of the main incision will also help because the cornea is horizontally ovoid, so a temporal incision will be further from the apex of the corneal dome than a superior incision.
- Lens-Iris Diaphragm Retropulsion Syndrome (LIDRS)
  - High propensity for a hyper-deep anterior chamber during irrigation.[21]
  - Occurs as a result of a mismatch between anterior chamber pressure and posterior chamber pressure. When the anterior chamber is filled with OVD, this creates a relative water seal between the dilated iris and the peripheral lens. The infusion increases the anterior chamber pressure relative to the posterior chamber pressure and causes abrupt hyper-deepening of the anterior chamber and, commonly, patient discomfort.
  - This creates a threefold problem:
    - Access to the cataract at awkward angles
    - Discomfort and thereby less cooperative patient
    - Unnecessary stress on the zonules, which, in axial myopes, are already more likely to be compromised
  - Ameliorated by breaking the relative seal between the iris margin and the capsule, allowing fluid to pass through the zonules and equalize the anterior and posterior chamber pressures (Video 44.2). The lens will come back forward to its native position.
  - This can be effectuated by either using a side-port instrument or the tip of the irrigation-aspiration (I/A) handpiece to gently lift the iris margin, or, alternatively, to gently depress the lens.[21] The latter may seem daunting with an already deep chamber.
  - Patient discomfort from the zonular stretch will be immediately relieved.
  - This LIDRS phenomena may recur repeatedly during the same surgery, typically corresponding to each time irrigation is initiated anew during the procedure.
  - LIDRS can be avoided completely if the peripheral iris is lifted off the lens surface by a side-port instrument or the I/A tip before irrigation is started. (An ounce of prevention is worth a pound of cure.)
  - Another preemptive approach is to actively instill BSS under the iris margin with a 27-gauge cannula to pressurize the posterior segment just before placing the I/A or phaco handpiece into the eye.

Potential Complications

Zonulopathy can be present more commonly in axial myopes than average eyes. Surgeons should be attentive to the possible need for zonular-friendly techniques, capsular tension rings (CTRs), and zonular fixation devices, covered in more detail in Chapter 34. The zonulopathy can present in a delayed fashion, with late capsular bag subluxation, especially if the eye has had (or may have in the future) a pars plana vitrectomy or if other predisposing factors for progressive zonulopathy such as pseudoexfoliation, retinitis pigmentosa, or Marfan's syndrome are present. Many surgeons, including an author of this chapter, will place a CTR proactively in such cases, recognizing that it does not have any prophylactic benefit but does make repositioning of the complex much easier, should that be required in the future.

Suprachoroidal hemorrhage (SCH) is a dreaded complication of any intraocular procedure. Axial myopia is a known risk factor,[22] but many patients undergoing cataract surgery are of advanced age and more likely to have other SCH risk factors including atherosclerosis and hypertension.[22,23] Glaucoma is yet another SCH risk factor that is more common in eyes with extreme myopia. Although the absolute risk for a SCH is very small for phacoemulsification surgery, most surgeons will experience this complication at some point in their career and should remain vigilant, particularly in patients with multiple risk factors. A full review of SCH management is beyond the scope of this chapter, but, especially when operating on extreme myopes, it is prudent to avoid intraoperative hypotony and be prepared to quickly close all surgical incisions as soon as an SCH is suspected. Consider safety suture placement particularly in cases of planned extracapsular cataract extraction, intraoperative conversion to extracapsular surgery, or extension of an incision to facilitate IOL placement.

Vitreoretinal complications of cataract surgery are more common in axial myopes than in eyes with normal axial lengths. A dilated fundus exam with careful attention to the retinal periphery should be performed postoperatively and if the patient develops new onset photopsias, floaters, or other symptoms consistent with vitreoretinal traction or a retinal break.

POSTOPERATIVE MANAGEMENT

Recovery from routine cataract surgery is typically uneventful, even in extreme axial myopes. As detailed above, patients should be counseled on warning signs of a vitreoretinal complication and the ongoing need for at least a yearly dilated exam. We do not typically alter our standard follow-up schedule or postoperative medication regimen for this demographic.

SUMMARY

- Iridozonulohyaloidotomy (IZH) can create a unicameral eye and reduce the risk for ciliary effusion in short eyes.
- Prophylactic scleral windows are another perhaps more effective prophylactic technique in short eyes.
- Aqueous misdirection and ciliary effusion are both more common in short eyes. UBM is an important, perhaps critical determinator.
- General anesthesia, mannitol, reverse Trendelenburg, and pars plana vitreous tap are all mechanisms to increase anterior chamber depth.
- Topography is an important diagnostic study, especially in high myopes.
- A careful peripheral retinal exam is required preoperatively in axial myopes.
- Laser focal wall-off prophylaxis may be required.
- LIDRS is the single most challenging factor in cataract surgery on long eyes and can be alleviated by pressure equalization.
- LMA/GET/or topical anesthesia may be wiser for long eyes with posterior staphylomata.

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Video 44.1. Technique for making a scleral window in an eye with nanophthalmos.

Video 44.2. Management of lens-iris diaphragm retropulsion syndrome.

PART VII

Intraoperative Complications

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Risk Management in Cataract Surgery

Bryan S. Lee

CONTENTS

KEY POINTS

- Juries and judges understand that complications happen, and ophthalmologists often can defend themselves successfully, as long as the risks were disclosed in the informed consent and any intraoperative and postoperative issues were handled correctly.
- Good communication with patients is an essential part of providing care but also can decrease liability risk both preoperatively during the informed consent and postoperatively in the case of any complications or errors.
- In unclear cases, ophthalmologists should consult with risk management or their malpractice insurer to obtain individualized guidance.

INTRODUCTION

Ophthalmologists perform several million cataract surgeries a year in the United States, so there are multiple opportunities for medicolegal issues to arise despite the high success rate of the procedure. Unfortunately, most ophthalmologists will be sued during their career. The Ophthalmic Mutual Insurance Company (OMIC) estimates that 95% of ophthalmologists will be sued over a 35-year period at an average rate of about 8% per year.[1] Cataract was the most common presenting surgery for claims made against ophthalmologists over a 10-year period in a summary from the Physician Insurers Association of America database of 90,743 claims across all specialties.[2] From 2011 to 2015, 21.4% of cataract surgery claims were paid to close with an average indemnity of $259,522.

Lessons from prior litigation and malpractice insurance companies can help doctors navigate this complex environment more safely.[3] Although official documents such as the American Academy of Ophthalmology's (AAO) Preferred Practice Pattern are careful to state they are not medical standards, they provide a helpful summary of the medical literature and provide good general guidance.[4]

PREOPERATIVE CONSIDERATIONS

Before surgery, ophthalmologists should obtain well-informed consent and document medical necessity. This is also the stage at which regulatory concerns are most prominent. The following concepts will be discussed:

- Informed consent
- Advertising
- Fraud and abuse
- Comanagement and antikickback statute
- Charging for noncovered/refractive services
- Deciding on second-eye surgery
- Stark Law

Informed Consent

A claim of failure to obtain informed consent is common in malpractice cases and sometimes avoids an expert witness requirement, making it cheaper and easier to file a lawsuit. States following the "professional disclosure" standard do require expert testimony to establish what a typical member of the profession's informed consent would contain, but those following a "reasonable person" standard take the patient's lay perspective.[5]

It is important to make sure that the informed consent conversation addresses all aspects of the planned cataract surgery, including issues that could complicate that particular individual's surgery or affect visual potential. For example, one plaintiff who suffered vitreous loss argued that his informed consent was inadequate because he was on tamsulosin.[6] Although that plaintiff lost, the court's reasoning suggests that the outcome might be different now, when tamsulosin's role in intraoperative floppy iris syndrome is better established than in 2005. Relatedly, risk for iris damage should be disclosed, as OMIC has reported lawsuits over iris injury during cataract surgery.[7]

A signed informed consent is an important document to have, but mere paperwork is not a sufficient defense against an informed consent claim, especially if the patient has poor vision, is illiterate, or does not speak English.[8] Surgeons should also obtain informed consent with documentation when patients opt for refractive services that are not medically necessary. Consent obtained before the day of surgery is preferable, and it is necessary to obtain consent before administration of any anesthetic medication.

Malpractice insurers may provide sample informed consent forms for practices. These examples provide useful guidance and also highlight the key points that ophthalmologists may want to raise during their time counseling patients. In Florida, the Boards of Medicine approved a cataract informed consent form endorsed by the Florida Society of Ophthalmology.[9]

Advertising

Appropriate informed consent is essential for all patients, but establishing expectations for refractive cataract surgery is particularly important. For example, physician advertisements have been used to allege inadequate informed consent or violations of consumer protection laws.[10] Physician advertising is governed by the Food and Drug Administration, Federal Trade Commission, and the states. In addition to drawing regulatory scrutiny, advertising that focuses on devices' benefits without disclosing risks could be seen as undercutting informed consent.

With the amount of new technology available for cataract surgery, physicians should remember that they are only allowed to promote within a device's labeling and must discuss relevant risk information. For instance, the Food and Drug Administration sent warning letters to four practices warning that their websites did not disclose laser assisted in-situ keratomileusis risks completely. Some malpractice insurers will review proposed advertising for potential compliance issues.

Surgeons must explain the risks and benefits of the technologies offered to patients. In particular, patients may be particularly inclined to believe in the advantages of using a laser to perform cataract surgery. Therefore physicians offering femtosecond laser-assisted cataract surgery need to be careful not to claim superiority of laser-assisted cataract surgery in light[10a] of multiple large studies that to date show only noninferiority to manual cataract surgery.[11,12]

Similarly, discussion of glasses-free outcomes must be balanced with the downsides of presbyopia-correcting IOLs plus the possibility that patients will not be as glasses-free as desired afterward. Plaintiff attorneys often include claims alleging inadequate informed consent or fraud to enable them to ask for punitive damages, which may be much larger in amount and not be covered by malpractice insurance. Using plain language may help patients understand their choices more easily.[13]

OMIC says it is "advisable" to inform patients about IOL options that surgeons may not offer, although it of course remains up to each ophthalmologist to decide which specific IOLs to implant.[10]

Fraud and Abuse

The False Claims Act prohibits knowing presentation of a claim for payment to the government that is false or fraudulent and carries a civil monetary penalty for each false claim.[14] The Department of Health and Human Services Office of Inspector General identified the entire specialty of ophthalmology as an auditing target for 2014, an unusual step.[15] Its 2015 report discussed cataract surgery, noting variability between surgeons in percentage of cataracts billed as complex cases.[16]

Multiple reviews have estimated that only about 2% of the cataract surgeries performed in the U.S. are not medically justified.[17,18] However, lawsuits are often filed alleging fraudulent cataract surgery, so surgeons must document the exam, patient's complaints, and desire for cataract surgery.[19,20] Using a patient visual functioning questionnaire such as the VF-8R, which some insurers endorse, can help document necessity and patient desire for surgery.[21]

Comanagement and Antikickback Statute

The antikickback statute creates criminal and civil penalties for offering anything of value to receive referrals for services paid by a federal healthcare program outside of its safe harbors.[22] There is no safe harbor for cataract comanagement; it may be permissible, including for premium IOLs, but the details of the arrangement are important because the Office of Inspector General will take a case-by-case approach.[23] It is better not to formalize a comanagement financial arrangement between surgeon and referrer in writing because any agreement to send a patient back to the referring provider must be based on patient choice.[24]

The patient should agree in writing to comanagement, and the two providers should have an agreed-upon postoperative care protocol with defined situations in which the referrer will consult the surgeon or send the patient back to handle problems.[25] Otherwise, a plaintiff could argue that the surgeon is vicariously liable if, for instance, an optometrist failed to recognize endophthalmitis. The transfer of care can occur only after the operating ophthalmologist deems the patient stable and ready for transfer, and a trained ophthalmologist must be available if medically necessary.[26] The transfer of care should be documented. Also, the patient should write two checks rather than have the surgeon collect the entire fee and split it.

Charging for Noncovered Refractive Services

Relatedly, doctors should exercise caution and follow guidance for appropriate handling of payment for noncovered services such as toric and presbyopia-correcting intraocular lenses (premium IOLs) and use of the femtosecond laser.[27–29] The surgeon should ensure that the patient understands and signs for the charges and that the femtosecond laser is billed only when used for imaging or astigmatism correction, not for the normal steps of cataract surgery with a standard monofocal IOL. The Office of Inspector General has previously identified noncompliance with assignment rules—trying to get patients to pay more than Medicare's assignment for a service—and excessive billing as enforcement priorities.

Medicare requires an Advanced Beneficiary Notice of Noncoverage (ABN) form when Medicare is unlikely to cover a charge.[30] A formal ABN is not required for premium IOLs because they are never covered by Medicare. An unclear area is coverage of a return to the operating room for a patient who had a premium IOL. In one case, a physician patient sued his ophthalmologist under the False Claims Act whistleblower position, claiming that billing Medicare for rotating a malpositioned toric IOL was fraudulent because this was a refractive procedure.[31] Although the outcome of the litigation is not in the public record, the court dismissed the defendant's summary judgment motion as the plaintiff argued that CMS described the services "required to insert and adjust an astigmatism-correcting IOL" as noncovered.[32]

Deciding on Second-Eye Surgery

The same whistleblower plaintiff argued that billing for the exam after cataract surgery in the first eye and before the second eye was improper. The defendants countered with two other experts who argued that confirmation of the need to proceed with second-eye surgery is a Medicare requirement and that billing of the examination was appropriate; again, the final outcome of this case is not in the published case law.

Ophthalmologists who plan to proceed with cataract surgery in both eyes and then charge for an exam after operating on the first eye should make sure that the examination is thorough and well documented and legitimately supports the decision to perform second-eye surgery.

Stark Law

The Stark Law applies civil penalties to physicians who refer Medicare patients to entities they or an immediate family member have a financial relationship with, regardless of intent. The list of designated health services includes biometry for IOL calculations and B-scans, so physician compensation arrangements should handle revenue for these services separately.[33]

There are exceptions for surgeons whose patients get postoperative optical services from an entity they own and for use of IOLs in ambulatory surgical centers where the surgeon has an ownership interest.[34,35] However, physician ownership of an ambulatory surgery center must

be disclosed in writing.[36] Given the complexity of exceptions for different ownership and compensation arrangements, doctors should contact their attorneys for detailed advice.[37,38]

INTRAOPERATIVE ISSUES

Cataract surgeons should adhere to best practices in managing intraoperative complications, and operative notes should be contemporaneous and accurate. Concerning intraoperative problems include the following:

- Anesthesia complications
- Complications from intracameral medications
- Problems with toric and presbyopia-correcting IOLs
- Wrong eye/wrong IOL

Anesthesia Complications

Most cataract surgeons operate with an anesthesiologist or nonphysician provider. In many states, a certified registered nurse anesthetist must work under the supervision of a physician, so the cataract surgeon may be required to function as the certified registered nurse anesthetist's supervisor. Depending on details of the relationship, complications resulting from a nurse anesthetist's negligence may be viewed as the ophthalmologist's responsibility.[39] Ophthalmologists should verify whether their malpractice insurance covers problems arising out of any supervisory role.

Problems with cases under general anesthesia may primarily implicate the anesthesiologist, as in a case in which a patient became light during the procedure, resulting in loss of vitreous.[40] In that case, the jury found the anesthesiologist but not the ophthalmologist liable. However, surgeons can also be liable if they should have been aware of a deterioration in the patient's condition.[41]

Complications related to regional anesthesia are more common, particularly for retrobulbar anesthesia.[42] Anesthesia risk should be part of the informed consent for cataract surgery. If an ophthalmologist orders the retrobulbar block, but a complication arises when an anesthetist gives it, the former may still be at risk for negligent referral. Ophthalmologists should make sure that the anesthetist has expertise at blocks and should clarify when the anesthetist should defer to them.

The ophthalmologist may still be liable when complications result from patient movement, as one review of closed claims for retained lens fragments showed that the capsulorrhexis was complicated by patient movement in 9% of cases.[43]

Intracameral Medications

Under the doctrine of *respondeat superior*, the ophthalmologist is responsible for medications administered during cataract surgery.[44] In one case, a plaintiff won sanctions in pretrial motions for a lawsuit triggered by alleged use of methylene blue instead of trypan blue.[45]

Compounded medications are another potential risk, with outbreaks often heavily publicized. Although dismissed for procedural reasons, one case alleged improper compounding of triamcinolone because of an endophthalmitis outbreak of 11 patients on 1 day.[46] Physicians may choose to reduce their use of compounded medications and should be careful to choose a compounding pharmacy carefully, being aware of the difference between 503 A and 503B pharmacies.[47] The former compound for individual patient use, while 503B pharmacies must follow Current Good Manufacturing Practices and can make products on a larger scale.

Problems With Toric and Presbyopia-Correcting IOLs

Generally speaking, a known complication during premium IOL surgery is defensible if appropriately managed.[48] An OMIC review in 2011 of 34 premium IOL plaintiffs who filed claims against OMIC-insured surgeons found that informed consent was more important in the defense for these cases than in conventional IOL cases.[49] Therefore part of the increased chair time spent with these patients should include not only a discussion of the benefits of these IOLs but also risks and problems associated with them. These issues include toric IOL rotation and dysphotopsias related to diffractive technology.

Wrong Eye/Wrong IOL

Operating on the wrong eye is the kind of grave error that allows plaintiffs to pursue litigation without needing to resort to an expert witness because of *res ipsa loquitur* ("the thing speaks for itself"). Surgeons should have protocols for preprocedure marking and time outs. It is also important to ensure that there are protocols and clear lines of communication for going "out of order" or for day-of-surgery cancellations and schedule changes.

One of the most common medicolegal problems that arises during cataract surgery is wrong IOL placement, whether from the surgeon's IOL choice or from implantation of an unintended IOL.[50–52] As part of the informed consent, ophthalmologists should identify situations where IOL selection is more difficult.

When circumstances require an intraoperative change, extra care should be taken. Before opening a sulcus or anterior chamber IOL, it is reasonable to make an extra pause to make sure the correct one is being used.[53] Intraoperative aberrometry may also result in a change in the intended IOL, and the results of the aberrometry should be documented in the operative record to explain why the originally chosen IOL was not implanted. Again, it is wise to make a standardized protocol to make sure the appropriate IOL is selected and opened by operating room staff. When a complication occurs, although the desire is natural to rush ahead and catch up, it is important to take extra care to make sure that the operative note is accurate.

Placement of an unintended IOL is difficult to defend in court and can draw public attention.[54] Possible precautions include verifying the correct IOL at multiple timepoints, confirming the IOL against a source document before opening, and allowing only one IOL per case in the room.[55] Every surgeon and facility, whether an ambulatory surgery center or hospital, should have a standardized way to verify IOL type, power, patient, and eye.

POSTOPERATIVE ISSUES

Physicians should take postoperative complaints seriously and ensure that appropriate phone and triage mechanisms are in place to deal with potential postoperative complications. Whenever a patient calls in after hours, it is important to assess for a history of recent ophthalmic surgery or other procedures. Some of the most concerning postoperative issues include the following:

- Endophthalmitis
- Retinal detachment and retained lens fragments
- Toxic anterior segment syndrome
- Discussing complications

Endophthalmitis

Any informed consent for cataract surgery will obviously include the potential risk for infection. Therefore, with a few exceptions, malpractice litigation for postoperative endophthalmitis centers on theories of negligence, especially delayed diagnosis.[56–58] Patients should receive return precautions, and anyone calling with a complaint suggestive of possible endophthalmitis should be seen immediately and, if necessary, referred urgently.

Plaintiffs have argued that the standard of care is to use preoperative and postoperative antibiotic drops although this is not proven to

decrease endophthalmitis, but reliance on the medical literature may be a defense regardless. The literature demonstrating the benefit of intracameral antibiotics continues to grow in strength.[59–61] However, the current lack of a commercially available and FDA-approved formulation is likely to continue to provide a defense for failure to use intracamerals in the U.S.[62,63] Between 2006 to 2010 and 2011 to 2015, endophthalmitis decreased from being the fifth to the tenth most common reason for a liability claim against ophthalmologists, potentially reflecting the increase in use of intracameral antibiotics.[2]

Because of the widespread dissemination of warnings against using vancomycin as an intracameral antibiotic, it could be more difficult to defend against a case of hemorrhagic occlusive retinal vasculitis, although some patients cannot receive moxifloxacin.[64] Surgeons should stay abreast of possible evolution in the standard of care, particularly if an FDA-approved intracameral antibiotic becomes available.

Retinal Detachment and Retained Lens Fragments

Retinal complications and the possible need for additional surgery should be standard informed consent elements, and appropriate management of vitreous loss or retained lens fragments can provide a strong defense. An analysis of 108 closed OMIC claims for retained lens fragments showed 105 of the claims were against the cataract surgeon, with two of 12 trials ending in plaintiff verdicts and 30 cases settled. Risk factors for a negative outcome include excessive manipulation to try to retrieve lens fragments and poor documentation. Close follow-up and quick referral to a retinal specialist in the case of retained lens material are also essential management points.

Toxic Anterior Segment Syndrome

Unlike endophthalmitis, which is infectious, toxic anterior segment syndrome (TASS) is inflammatory in nature and has been traced to multiple potential causes.[65] The FDA estimates that the incidence is greater than one in 1000 cases because of several clusters of "three to 20" cases annually.[66] When TASS is suspected, operating centers and surgeons should analyze possible causes and closely follow patients at risk. Adherence to suggested guidelines to prevent TASS is likely to help with any potential defense, along with appropriate immediate increase in the use of postoperative steroid drops. In one case, the jury found that the plaintiff failed to prove the specific cause of TASS and ruled in favor of the defendant.[67] A cluster of TASS cases probably is more difficult to defend against and can also result in negative publicity.[68] If an outbreak is identified, OMIC recommends counseling at-risk patients so that they monitor themselves appropriately.[69]

Discussing Complications

Transparency is a critical feature of high-quality healthcare and includes disclosure of complications and any errors.[70,71] Of course, not every complication indicates a medical error, which can be defined as "the failure of a planned action to be completed as intended or use of a wrong plan to achieve an aim."[72]

Physicians often avoid error disclosure because of fear of litigation, but empiric evidence demonstrated that a disclosure-restitution program resulted in decreased liability claims and costs.[73,74] The Joint Commission, American Medical Association, and OMIC all have endorsed error disclosure, although physicians should contact their insurer's risk management department before having the conversation.[75] This is sometimes required under policy terms but also gives the doctor an opportunity to receive coaching on best practices for this type of discussion. There is also evidence that patients sometimes sue just to find out what happened after a complication, so disclosure and, if warranted, an apology, may forestall claims from being filed.[76–78]

Ophthalmologists face several unique issues when discussing complications or undesired outcomes. These include their working relationship with optometrists and the height of patient expectations, especially when out-of-pocket payments for refractive cataract surgery are involved.[79] Additionally, many ophthalmologists are in small private practices rather than large organizations with risk management departments and other resources.

Nevertheless, the medical literature provides guidance that can help cataract surgeons. Patients generally prefer full disclosure with use of the term "error" or "mistake" if appropriate, with the doctor taking responsibility.[80] With guidance from risk management or the malpractice insurer, a surgeon may want to offer restitution such as glasses, contact lenses, or corrective surgery.[81] Patients also want reassurance that quality improvement will help prevent similar errors from recurring.

SUMMARY

- Two-thirds of claims against ophthalmologists are dropped, withdrawn, or dismissed, and 90% of cases that receive a verdict end favorably to the ophthalmologist.[2]
- As cataract surgery continues to evolve, so will standards of care and regulatory guidance.
- Staying aware of these shifts and adhering to fundamental principles of documentation, consent, and good communication are helpful in case of a negative outcome or claim and, importantly, are also good medicine.

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Intraoperative Complications

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CONTENTS

KEY POINTS

- Intraoperative complications can occur at any point in cataract surgery.
- Successful outcomes depend on the following:
  - Careful preoperative evaluation
  - Having strategies in mind to handle intraoperative challenges and complications
  - As the situation demands, flexibility to adjust any aspect of the procedure to optimally address any complication that arises

ANESTHESIA

Patient Movement

One primary drawback of local anesthesia is that the patient is still able to move during surgery. Although movement most often occurs from the patient talking, coughing, or simply fidgeting, occasionally a patient will abruptly sit up and try to leave the operating room while the surgeon is still working.

Prevention

Optimal anesthesia requires appropriate preoperative counseling so that the patient's natural fear of eye surgery is minimized. Confirming adequate topical anesthesia before beginning the operation and then reassuring the patient in a gentle, caring voice are worth the time and effort. The authors instruct the patient to inform them if he or she feels anything uncomfortable, emphasizing that any discomfort can be promptly numbed by a few extra eye drops.

Although some surgeons find supplemental intracameral anesthesia to be helpful, the most important factor when using topical anesthesia is appropriate patient selection. To prevent unexpected eye movements, the globe should be stabilized with a fixation ring or by holding or entering the paracentesis with a second instrument during delicate intraocular maneuvers. Finally, repeated verbal reassurance—"vocal local" or "verbal anesthesia"—contributes to the safety and comfort of the patient.

Gentle taping of the forehead to the operating table helps stabilize patients with a head tremor or who are otherwise unable to lie still. This is difficult to do once surgery begins, so assess the patient's level of cooperation and involuntary movement before starting the operation. If a significant head tremor or movement disorder is noted during the preoperative examination, it may be prudent to consider general anesthesia.

Allowing the patient to become overly sedated or to fall asleep also poses risks. The patient may suddenly awaken in a disoriented state and abruptly move their head, resulting in intraocular injury. A periodic reminder may aid the somnolent patient to stay awake. This is a form of verbal anesthesia reminding the patient that surgery is going well and to stay awake. Coughing can also cause sudden head movement and significant positive pressure. We ask the patient to warn us if feeling a cough coming.

Management

The anesthesiologist plays an important role in minimizing excessive patient movement by administering appropriate medications as needed during the procedure. It may occasionally become necessary for the surgeon to be stern with the patient for the sake of surgical safety. With a small, self-sealing incision, the surgeon has the luxury of interrupting surgery at almost any stage to address a problem with excessive patient movement.

RETROBULBAR HEMORRHAGE

Severe retrobulbar hemorrhage after a retrobulbar block should generally prompt cancellation of intraocular surgery.[1,2] High orbital or intraocular pressure (IOP) significantly increases the likelihood of complications, such as iris prolapse, posterior capsule rupture (PCR), and vitreous loss. Anticoagulant therapy increases the risk for a serious retrobulbar hemorrhage, and we routinely ask our patients to check with their internist regarding the safety of discontinuing anticoagulant use before surgery if a local anesthetic injection is planned. For anticoagulated patients, topical anesthesia or a sub-Tenon's block avoids the possibility of retrobulbar hemorrhage.

Whether to proceed with surgery in the setting of a limited retrobulbar hemorrhage is controversial and will depend on many factors, including the surgeon's experience. We have found that phacoemulsification can be performed safely, provided that several criteria are met. First, all bleeding must be stopped by prompt direct orbital pressure. This not only expedites clotting but also limits the volume of blood accumulation behind the globe. The surgeon should next evaluate the extent of the hemorrhage. Surgery can proceed if the globe is soft and easily retropulsed, the lids are loose and mobile, and proptosis is not excessive. If any of these criteria are not met, either digital massage or placement of a mercury bag against the orbit for 5 to 10 minutes may adequately reduce the orbital pressure and IOP enough so that these parameters are fulfilled. It may also be advisable to perform a lateral canthotomy to reduce lid tightness. If after 30 minutes the surgeon remains uncertain about the safety of proceeding, it is advisable to reschedule the surgery rather than risk severe positive pressure intraoperatively.

In rare cases the accumulation of orbital blood may elevate the IOP enough to threaten vision. Although the IOP can be measured quickly using a tonometer, it is more important to confirm retinal perfusion rather than the exact IOP. For this reason, the authors keep an binocular indirect ophthalmoscope and 28-D lens or an Osher panfundus lens (Ocular Instruments) readily available that can be used to quickly view the fundus through the operating microscope. If the central retinal artery is pulsating, its diastolic perfusion pressure has been exceeded and there is risk for infarction.

The combination of progressive proptosis, a tight orbit, central retinal artery pulsation, progressive corneal epithelial edema, and high IOP is an ominous emergency. The surgeon must quickly dissect into the periocular space with a scissors to release an expanding hematoma. If this fails to decompress the globe, the lower and upper lids should be disinserted after an emergency lateral canthotomy and cantholysis. It does not take long to develop an ischemic optic neuropathy.

Although small-incision surgery allows one to deal more easily with the complications associated with a retrobulbar hemorrhage, it does not eliminate them completely. The surgeon who proceeds with surgery in the face of a limited retrobulbar hemorrhage should be comfortable managing an eye with significant positive pressure. It is important for the surgeon to document the IOP, the timetable, and the steps taken to deal with this complication for medico-legal reasons.

WOUND CONSTRUCTION

Incision

Surgeons today have many choices in the design and construction of their phacoemulsification incision. The options include frown, straight or smile scleral tunnel, and near-clear or clear corneal placement.[3–8] Incisions can be located superiorly, temporally, or over the steep axis of corneal astigmatism. Although each variation has its own advantages and disadvantages, the common goal is to achieve a well-sealed incision that is either astigmatically neutral or, in some cases, designed to reduce preexisting astigmatism. A poorly constructed incision will make a routine case difficult. Likewise, a carefully planned and precise incision is an important first step toward achieving success with an extremely difficult case. The following general principles about the cataract incision will help avoid complications.

Placement

An important consideration is the distance from the incision to the central cornea. For any given incision size, the closer the incision is to the central cornea, the greater its tendency will be to alter cylinder along that axis and to increase endothelial cell loss.[7,8] Incision location dictates the tunnel length as well. Clear corneal incisions (CCIs) require a shorter tunnel to avoid working too close to the central cornea, whereas scleral tunnel incisions must have a greater length to avoid premature entry. An incision with too short a tunnel length may not be watertight and self-sealing without sutures because there is less flap surface area for appositional closure. Short CCIs might initially be watertight when the globe is repressurized but may leak with any external pressure applied to the cornea or sclera.[8] To maximize the allowable tunnel length, a CCI should be started as posteriorly as possible. However, a tunnel that is too long can hinder motion of the phaco tip, causing excessive globe movement during phacoemulsification and undesirable corneal distortion. When creating a scleral pocket incision, the surgeon must be careful to avoid excessive bleeding and premature entry. A posterior scleral pocket incision also creates a more difficult, uphill approach for the instruments. Mimicking scleral depression, any excessive instrument pressure on the incision can produce significant positive pressure.

Depth

When a scleral tunnel approach is too deep, the keratome may prematurely enter the chamber angle or even the suprachoroidal space. The former may be associated with iris prolapse, whereas the latter is associated with bleeding and hypotony. If the suprachoroidal space is inadvertently entered, placement of deep sutures may prevent prolonged postoperative hypotony (Fig. 46.1). A guarded blade for performing the initial scleral or near-clear corneal groove (approximately 300 microns) is helpful.

Anterior Chamber Entrance

The width of the entrance into the anterior chamber (AC) must be precise in its dimensions. It must allow easy entry of the phacoemulsification needle. Too large an entrance may result in a leaky incision with constant chamber shallowing throughout the operation and may require a temporary suture (Fig. 46.2). Too tight an incision will constrain maneuvering the phacoemulsification needle, resulting in excessive eye rotation. A tight opening may also constrict irrigation flow, increasing the chance of thermal injury. Finally, trauma to Descemet's membrane is more likely if instruments are forced through a tight incision.

The entrance through Descemet's membrane must be anterior enough to create a self-sealing watertight incision. However, too anterior an entry increases endothelial cell loss and impairs visualization caused by corneal striae developing during phacoemulsification. Moreover, too anterior an entry makes manipulation of the proximal pole of the nucleus and subincisional cortex more difficult. However, too posterior an entrance invites iris prolapse (Fig. 46.3).

INCISION LEAK

If the incision is not watertight at the conclusion of the operation, the surgeon has several options to choose from. First, a 27- or 30-G cannula may be used to inject balanced salt solution (BSS) perpendicularly into the lateral borders of the incision. Hydrating the lateral stroma in this way forces the roof and floor of the tunnel together. Alternatively, one can perform stromal hydration at the roof of the incision. If the incision still leaks, an interrupted 10-0 nylon suture can be passed or a sealant like ReSure can be used.

Finally, if the incision leak is secondary to gaping from thermal injury, special suturing techniques described by Osher may be required. A radial 10-0 nylon suture is passed from the corneal tissue through the floor and tied without incorporating the distal margin (the external lip)

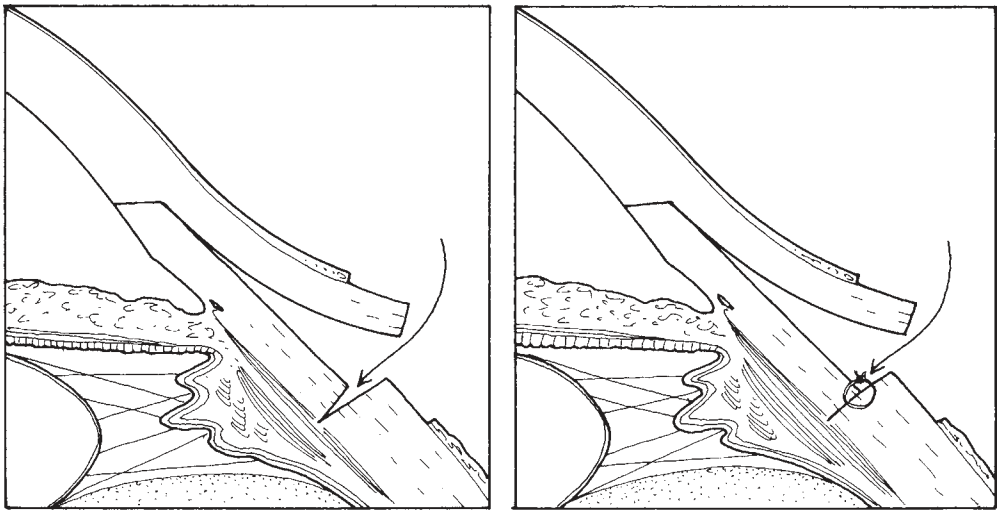

Fig. 46.1 Placement of deep sutures when the scleral groove is too deep.

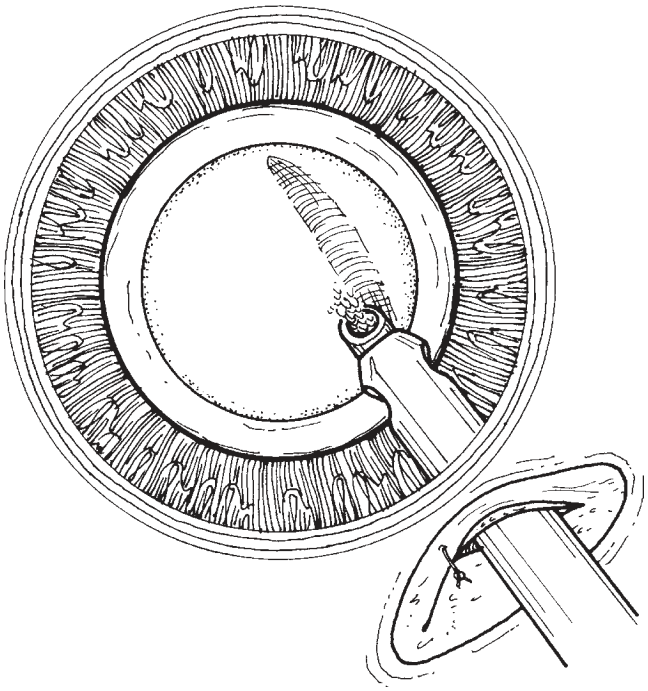

Fig. 46.2 Placement of a temporary radial suture for an oversized phacoemulsification incision.

of the incision. Alternatively, a horizontal 10-0-nylon suture can be passed, compressing the incision roof and floor together. Each of these techniques helps to compensate for tissue shrinkage and to minimize induced cylinder.[9,10]

TEAR OF DESCEMET'S MEMBRANE

Iris Prolapse

Iris prolapse can damage the stroma or sphincter enough to cause postoperative pupil irregularities, iris transillumination defects, peripheral anterior synechiae, or uveal incarceration into the incision. Intraoperatively, acute prostaglandin release may cause constriction of the pupil, whereas rupture of vessels from the minor iris circle may result in intraocular bleeding. Alpha-1a blockers such as tamsulosin (Flomax) have markedly increased the incidence and severity of iris prolapse.[11,12]

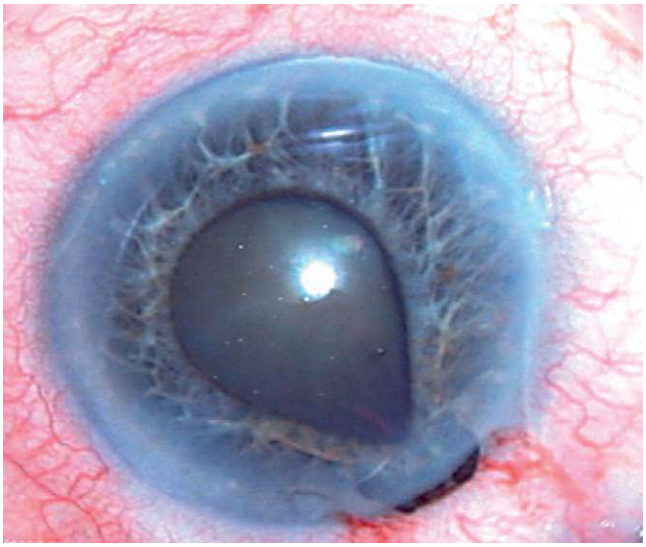

Fig. 46.3 Iris prolapse through a posteriorly placed entrance into the AC.

The cardinal features of intraoperative floppy iris syndrome (IFIS) include iris billowing, suboptimal dilation, progressive constriction of the pupil, and a tendency toward iris prolapse. It appears that the effect on the smooth muscle of the iris dilator is semipermanent so that discontinuing the drug does not prevent IFIS. Moreover, the severity of IFIS is highly variable.[11,12]

Management options include viscomydriasis and mechanical iris retraction with highly retentive optical variable devices (OVDs), iris retractors, pupil expansion devices, and intracameral epinephrine or phenylephrine.[13–15] Trying to enlarge the pupil by bimanual stretching is ineffective and can increase the tendency for iris prolapse.

Management

The surgeon must identify the cause of the iris prolapse to manage the underlying problem properly. If the eye is hard, decompression typically helps; if the eye is soft, then poor wound construction may be

causative. Excessive external pressure on the globe can be caused by improper speculum positioning. A tense and overfilled globe can be softened by aspirating fluid or OVD through a second incision site. If iris prolapse occurs during hydrodissection or viscodissection, neutralizing the pressure gradient between the AC and the posterior chamber (PC) can be accomplished by depressing the nucleus within the capsular bag. The iris can be gently repositioned in most cases with the OVD syringe cannula placed through the paracentesis incision, leaving some OVD on the iris surface. Mild iris prolapse from overfill can be resolved if the pressure is bought down from a paracentesis and the surgeon taps externally at the roof of the incision. Excessive manipulation causes the iris to become increasingly frayed and flaccid. At the end of the case the injection of an intracameral miotic agent, judicious use of an OVD, a peripheral iridotomy, and deeply placed sutures are measures that can be used to reduce the possibility of iris incarceration in the incision. In cases of IFIS, hydrating the incision before removing irrigating instruments and injecting a miotic agent through the side port incision will decrease the risk for iris prolapse at the end of the procedure.

CAPSULORHEXIS

The continuous curvilinear capsulotomy, or capsulorrhexis, is arguably the most important step in modern phacoemulsification surgery. The capsulorrhexis is strong enough to be stretched and resists being torn during nucleus manipulation, cortical removal, and intraocular lens (IOL) implantation.[16–21] An intact rhexis of proper size overlying the IOL optic secures the IOL, improves refractive predictability, and retards posterior capsule opacification.

Osher developed the concept of the "safety rhexis," which provides the surgeon with a "second chance" if the primary capsulorrhexis is faulty.[20,21] A 22-G needle slash results in an anterior capsular tear with two arms. The lower arm is redirected opposite the orientation of the upper arm, which prevents it from running with the primary tear. The upper arm of the tear is then directed clockwise around the anterior capsule until the capsulorrhexis is completed peripheral to the original starting point.[20–22] If a problem occurs with the upper arm, the surgeon may resume the capsulorrhexis by tearing the second edge counterclockwise until it connects with the first arm (Fig. 46.4).

Peripheral Capsulorrhexis Extension

The frequency with which a capsulorrhexis radial tear occurs is usually related to the surgeon's experience. Anterior bowing of the lens-iris diaphragm will encourage peripheral extension. This condition is more common in patients with shallow ACs and with positive intralenticular pressure associated with a white intumescent cataract. Extension can be caused by excessive convex curvature of the anterior lens capsule that can be conceptualized as a "hill." If the capsular tear runs over the "edge of the hill," it will continue to pursue a "downhill" course despite attempts to redirect it (Fig. 46.5).

In young patients the leading edge of the anterior capsular tear also has a tendency to run peripherally. This may be the result of the elastic forces of the zonulocapsular apparatus, a higher endolenticular pressure, and AC shallowing associated with lower scleral rigidity. The

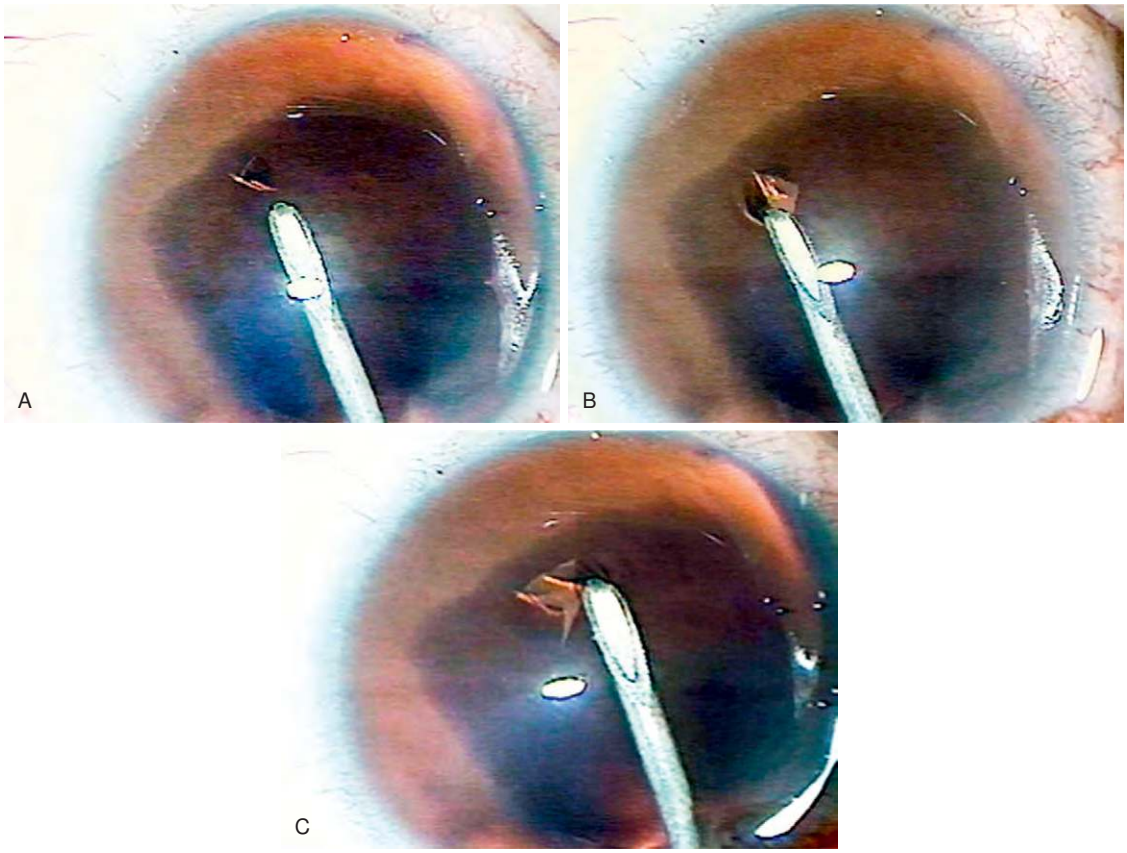

Fig. 46.4 Operating microscope view of an eye with aniridia. Trypan blue has been applied to the anterior capsule. (A) Capsulorrhexis is initiated with a bent 22-G needle. (B) The 22-G needle is used to reverse the direction of the lower arm of the capsular tear. (C) Using the upper arm, the remainder of the capsulorrhexis proceeds normally. However, should the surgeon encounter a problem with the capsulorrhexis, it can be restarted easily in the opposite direction.

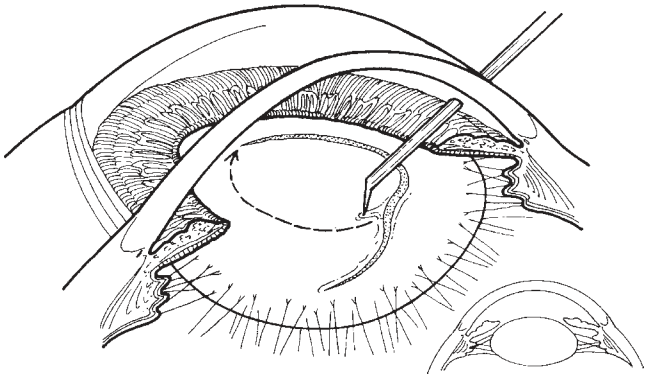

Fig. 46.5 Shallowing of the AC causes the capsule tear to run peripherally "downhill" instead of following the intended course (broken line).

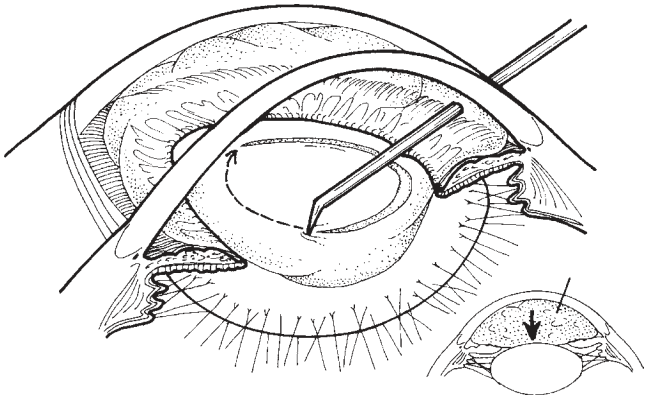

Fig. 46.6 Deepening the AC with OVD allows the capsule to tear along the desired course (broken line).

widely dilated pupil of a young patient may also encourage a larger diameter rhexis that may intersect with anterior zonular insertions. This induces the tear to follow the radial course of the zonule rather than the desired circumferential direction. This can also happen when the capsular tear encounters proximal zonules.[21,22] To achieve proper sizing of the rhexis regardless of pupil size or corneal diameter, circular corneal markers can be used to leave an imprint on the corneal surface, taking into account the corneal magnification of about 20%, which the surgeon can use as a guide.

The capsular flap is also more difficult to control in the presence of weak zonules, such as in patients with pseudoexfoliation. As one pulls on the capsular flap, the peripheral capsule is normally immobilized by the zonules. However, absent normal circumferential zonular countertraction, the peripheral capsule moves along with the flap until it suddenly wants to slingshot radially outward. Chang has called this phenomenon *pseudoelasticity*, in that the loss of flap control is similar to that encountered when tearing an elastic material, such as latex.[21]

Whenever there is difficulty in controlling the advancing capsulorrhexis flap, a conscious effort is made to create a slightly smaller diameter opening. This both improves control of the flap and affords enough time to redirect the flap if necessary. A small diameter capsulotomy can always be enlarged later. Ideally, it should not be so small as to compromise nuclear manipulation or subincisional cortical aspiration. Moreover, it is helpful to flatten the anterior capsular convexity with a generous amount of OVD in eyes with shallow ACs or whenever difficulty in controlling the capsulorrhexis tear is encountered. If the OVD is extruded, refilling the chamber may be required; alternatively, selecting a more retentive OVD such as Healon 5 or dispersive viscoelastic may be tried. It may be helpful to attach a cystotome to the OVD syringe to direct the tear, thereby reducing the tendency for the OVD to escape when capsule forceps are manipulated through the incision. Newer capsulorrhexis forceps have been designed to avoid incision deformation and inadvertent decompression of the AC. Deepening the shallow chamber makes the capsulorrhexis easier to guide in the desired direction (Fig. 46.6).

When redirecting the tear, Brian Little has described "unfolding" the anterior capsule back to its original position and then pulling the tear toward the center of the pupil with some mild posteriorly directed force.[22] Once the tear begins to move more centrally, one can redirect the flap in the conventional direction.

Occasionally, even in experienced hands, the anterior capsular tear will extend too far peripherally to be rescued. An experienced surgeon may recognize when the tear is too peripheral by the "feel" of resistance to his or her efforts to redirect the tear. The surgeon should return to the starting point and proceed with a second continuous tear using the "safety" capsulorrhexis strategy or switch to a can-opener technique until the capsulectomy is completed (Fig. 46.7).

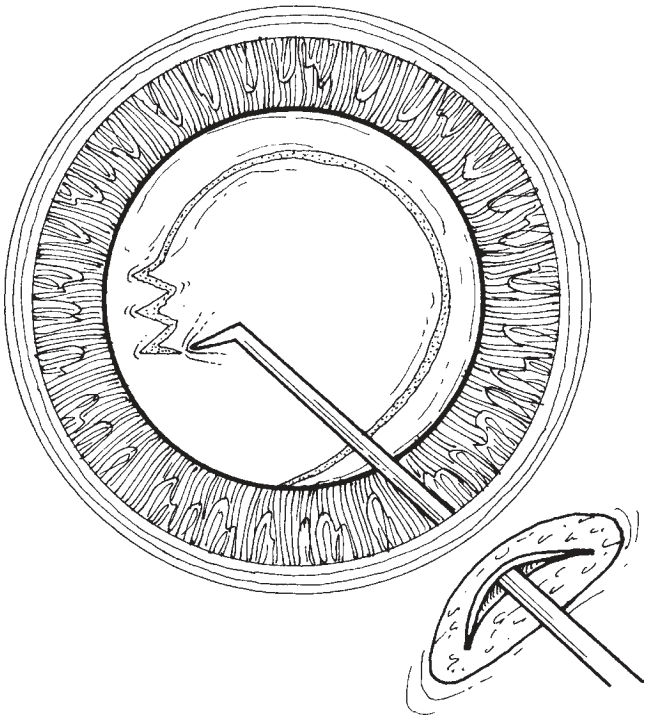

Fig. 46.7 Conversion of a capsulorrhexis that ran peripherally into a can-opener capsulotomy.

After a radial anterior capsule tear, phacoemulsification should be performed with extreme care to minimize any forces directed toward the capsular bag. As a technique, phaco chop is preferable to divide and conquer for this reason. If possible, one should avoid rotating the nucleus, as this typically requires lateral displacement of the nucleus and imparts the greatest force to the torn capsulorrhexis rim. Reducing the irrigation/aspiration (I/A) flow parameters slows the pace of phacoemulsification to avoid sudden fluctuations in chamber depth and excessive lens movement. Careful aspiration of cortex from the affected quadrant is performed only after the rest of the cortex has been removed. With a single radial capsulorrhexis tear, a single-piece hydrophobic acrylic IOL with slowly unfolding haptics exerts the least

amount of capsular force during implantation. If a three-piece IOL with stiffer haptics is used, consider unfolding the lead haptic in the AC. This allows one to dial the two haptics into the bag in such a way that the optic is never displaced toward the weakened capsulorrhexis tear. The haptics should be left oriented 90 degrees away from the area of the capsulorrhexis tear. Alternatively, a three-piece posterior-chamber intraocular lens (PCIOL) can be placed in the ciliary sulcus, with or without suture fixation.

In cases in which the capsulorrhexis edge finishes inside the starting point, creating a "notch" in the anterior capsule, the surgeon should have a management plan. A fine intraocular scissors can be used to make an angulated cut lateral to the notch. Intraocular forceps are used to grasp the resulting flap and enlarge the capsulorrhexis to create a smooth, continuous tear peripheral to the notch (Fig. 46.8A depicts a similar maneuver for enlarging the capsular opening). If the notch is proximal, the surgeon may either use a reverse cutting scissors (see Fig. 46.8B) to create a flap or a microincision blade to button-hole the capsule. After creating the button hole, one blade of an intraocular scissors is introduced into the hole and a snip is made, creating a flap as the button hole is connected to the edge of the capsulorrhexis. The flap is grasped, and the capsulorrhexis is enlarged, thereby excising the notch and replacing it with a continuous edge.

Small Capsulectomy

Although a larger capsulorrhexis diameter may promote peripheral extension, too small a diameter impedes removal of the nucleus and cortex. A small anterior capsular opening will especially challenge surgeons using a nucleus tipping or prolapsing technique.

A small diameter capsulotomy also complicates subincisional cortical aspiration. Using an angled or J-shaped I/A tip or biaxial instrumentation may be necessary. We believe that it is easier and safer to initiate cortical removal in the subincisional quadrant because the capsular bag will be kept partially expanded by the remaining cortex. A small diameter capsulorrhexis also increases the risk for "capsular block syndrome."[23,24] If the capsulorrhexis forms a tight seal against the anterior nuclear surface, the hydrodissection injection could blow out the posterior capsule if there is no path for trapped fluid to escape. Postoperative capsular block occurs if OVD is trapped behind the optic; the resulting osmotic gradient may displace the optic anteriorly, causing AC shallowing and an unintended myopic shift. A neodymium:yttrium-aluminum-garnet (Nd:YAG capsulotomy in either the central posterior capsule or the anterior capsule peripheral to the edge of the optic will break the capsulolenticular block, allowing this trapped material to escape.

An excessively small diameter capsulorrhexis also predisposes an eye with zonulopathy to the capsulophimosis syndrome. This is characterized by marked contraction of the anterior capsular opening with a severely fibrotic thickening of the capsulorrhexis margin. Severe capsulophimosis can result in progressive zonular disinsertion and a decentered IOL requiring surgical intervention.[24–27]

To enlarge a small diameter capsulectomy, an intraocular scissors can be used to create an oblique tear in the edge that is angled away from the surgeon, which can be grasped and retorn with the capsule forceps (see Fig. 46.8). This maneuver should be performed under OVD after the IOL has been implanted.

COMPLICATIONS DURING PHACOEMULSIFICATION

Traumatic Tip Insertion

Overly abrupt insertion of the phacoemulsification tip can tear Descemet's membrane, chafe the iris stroma, and even cause an iridodialysis. Because this is more likely to occur with shallow chambers and reduced space between the iris and cornea, the AC should be sufficiently deepened with OVD. These complications can be avoided with proper incision construction and by angling instruments posteriorly toward the pupil during entry. To better avoid impaling the iris, enter with the phaco tip bevel down and then rotate the bevel after the tip is safely past the edge of Descemet's membrane.

If iris prolapse occurs during insertion of the phaco tip, it should be repositioned using the techniques described earlier. Particularly with

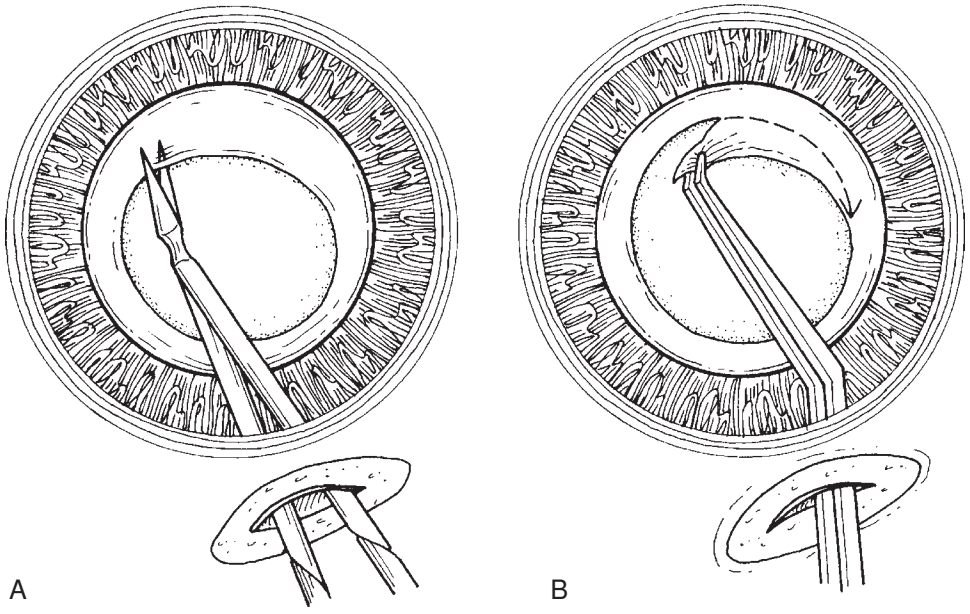

Fig. 46.8 Enlargement of the capsulorrhexis. (A) Capsular edge is incised with intraocular scissors to create a small flap. (B) Flap is grasped with forceps, and the new tear is directed to rejoin the capsulorrhexis (broken line). This technique may be used to enlarge the capsular opening or to excise a capsular notch and provide a new continuous capsular edge.

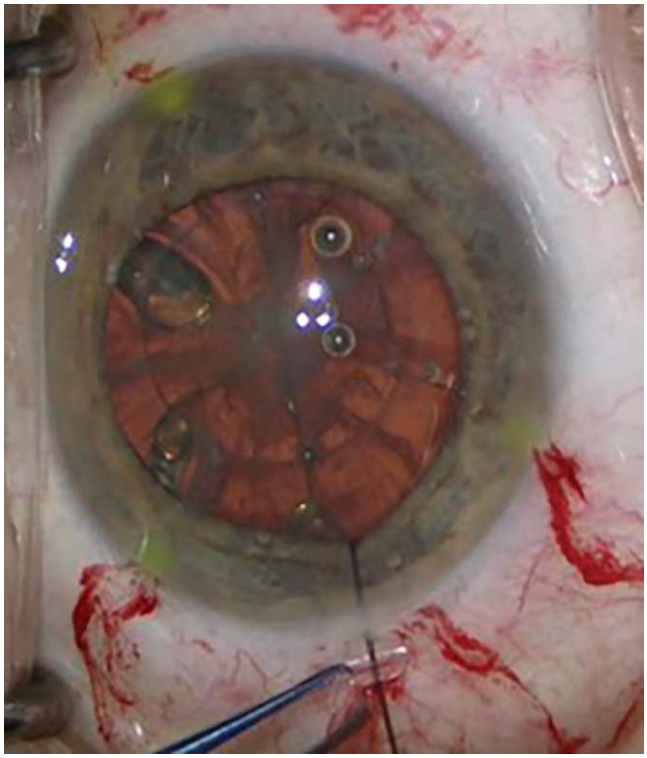

Fig. 46.9 Use of subincisional iris hook to prevent iris prolapse through the phaco incision.

a floppy iris, a paracentesis incision posterior to the CCI can accommodate a subincisional flexible iris hook to retract the subincisional iris away from the incision (Fig. 46.9 and Video 46.1). Injecting some OVD over the reposited iris will generally restrain it, unless the OVD is washed out as soon as the irrigating phaco tip is reinserted. In this case insert the phaco tip without irrigation, which can commence after the tip and irrigation openings are well within the AC.

Crowded Anterior Chamber

A shallow AC makes phacoemulsification extremely difficult. In addition to the aforementioned Descemet's membrane detachments, iris prolapse and damage to both the iris and corneal endothelium may occur during insertion of the phaco needle. Spontaneous prolapse of the nucleus can be minimized by carefully sizing the capsulorrhexis and avoiding excessive hydrodissection in these cases. The use of a higher-viscosity OVD will often help maintain sufficient AC depth. The risk for endothelial cell loss is greater in these eyes because the nuclear emulsification and fluidic turbulence occurs in closer proximity to the cornea. IV Mannitol 1.0-0.5 mg/Kg can be used to sufficiently dehydrate the vitreous to provide a deeper AC during phacoemulsification. Contraindications to mannitol include congestive heart failure and renal disease. Osher has described intermittent inferior scleral compression of the globe against the superior boney orbit which dehydrates the vitreous and creates space in the anterior segment. This maneuver can be combined with intravenous mannitol and Healon5, which is especially useful in nanophthalmic eyes.

Lens Iris Diaphragm Retropulsion Syndrome

During nuclear emulsification or cortical removal, excessive deepening of the chamber with pupil widening and posterior displacement of the iris border typifies the lens iris diaphragm retropulsion syndrome (LIDRS). This is the result of reverse pupillary block where contact between the iris and the peripheral anterior capsular rim seals the AC from the PC; the resulting hydrostatic pressure markedly deepens the AC. LIDRS is reversed by either elevating the iris or depressing the underlying anterior capsule with any instrument.[28] If this fails, an iris hook can also break the seal to equilibrate the AC and PC pressure.

Chamber Shallowing During Phacoemulsification

Abrupt AC shallowing or collapse risks damage to the cornea, iris, or posterior capsule. There are several potential causes.

Insufficient Inflow

Although excessive irrigation can potentially be traumatic to the corneal endothelium, insufficient infusion that results in chamber instability is more dangerous. Chamber collapse from inadvertent disconnection of the inflow line from the phaco handpiece is particularly hazardous. Besides inadequate bottle height, other causes of insufficient inflow include air block, clogged or kinked irrigation tubing, too tight an incision, or an irrigation sleeve port that is retracted too far from the phaco tip.

Excessive Outflow

Poor chamber stability caused by excessive fluid egress will occur if the incision is too large or is gaped by instrumentation or thermal injury. Switching to a new incision site should be considered.

The most common cause of chamber shallowing is postocclusion surge: momentary shallowing after an occluded phaco tip clears. Because vacuum levels build within the aspirating line after tip occlusion, fluid will rush in through the phaco tip opening to equalize the vacuum gradient as soon as the occlusion clears. A slow-motion phacoemulsification technique using a lower aspiration rate, vacuum, and bottle height creates a more stable chamber.[29]

Equipment manufacturers have designed numerous strategies to mitigate surge so that surgeons can access higher vacuum limits. These include the use of smaller lumen phaco tips and stiffer walled aspiration tubing to reduce the compliance, coiled aspiration tubing, and flow restrictors. Finally, smart pumps with active fluidics and IOP sensing can decelerate or reverse peristaltic pump speed as the maximum vacuum preset level is approached.

Positive Pressure During Phacoemulsification

Positive pressure increases the difficulty and risk for phacoemulsification. Signs include chamber shallowing, iris prolapse, and progressive miosis. As more nucleus is removed, the posterior capsule may bulge forward. This increases the likelihood for capsular rupture and makes cortical aspiration and IOL placement more challenging. The surgeon must always identify and address the cause of positive pressure.[30,31] Stopping the procedure, securing the incision and returning another day is reasonable if the positive pressure cannot be controlled.

Causes of Positive Pressure

A poorly designed lid speculum, or one that is improperly placed, can compress the globe, causing positive pressure. This is especially true with tight lids and narrow palpebral fissures that tether the globe. Globe compression can also result from an excessive volume of retrobulbar or peribulbar anesthetic injection, particularly in a small orbit.

Several signs indicate excessive lid pressure. When the eyelids are opened for insertion of the speculum, the surgeon may observe narrowed fissures with little visible sclera, or a blunted lateral canthal angle may be restricting the width of the fissure. Taut lids will also tend to snap closed when opened. Blepharospasm can cause positive pressure

and can even expel the lid speculum. Inadequate anesthesia with contraction of the extraocular muscles as in a strong Bell's phenomenon is another possibility.

After the speculum has been inserted and adequate anesthesia has been obtained, it may occasionally be necessary to perform a lateral canthotomy. A hemostat is used to clamp a few millimeters of the lateral canthal angle for 1 or 2 minutes. After releasing the hemostat, a horizontal incision is made with scissors through the canthus, and little if any bleeding results.

Ocular causes of positive pressure include posterior misdirection of irrigation fluid through a zonular or posterior capsular defect. Hydrating and expanding the vitreous gel displaces the capsule and iris forward. Although fluid misdirection is difficult to recognize, irrigation inflow must be reduced to avoid worsening the situation. An air bubble may also shallow the AC if it gets behind the iris and produces pupillary block. Scleral collapse and globe infolding can result in chamber shallowing, especially in eyes with poor scleral rigidity, or that have been "oversoftened" by prior vitrectomy. Suprachoroidal hemorrhage or effusion is the most ominous cause of positive pressure and can even flatten the AC. Nanophthalmos with thickened sclera is a particular risk factor.

Another cause of positive pressure is body habitus. Supine obese patients have increased orbital venous stasis causing external pressure on their globes. Slight reverse Trendelenburg positioning can significantly lessen the orbital venous pressure in these patients.

Valsalva maneuvers resulting from a full bladder, coughing, discomfort, or anxiety must be addressed lest they increase orbital pressure.

Several maneuvers may decrease the risk for proceeding with phacoemulsification in the face of a shallow AC and positive pressure.[30,31]

The use of a more highly retentive OVD can aid in maintaining a deeper chamber. Phaco and I/A tip entry without infusion may avoid iris trauma. Excessive hydrodissection that might spontaneously prolapse the nucleus should be avoided. The aspiration fluidic parameters should be reduced, and it may be necessary to elevate the bottle. Briefer application of ultrasound pulses may increase safety. The phaco tip angle within the incision must be adjusted to avoid scleral depression, gaping, or torquing. Although counterintuitive, intravenous hypertonic solutions may actually worsen scleral collapse, causing further chamber shallowing. Using a blunt second instrument through the stab-incision to restrain the posterior capsule permits nucleus emulsification to occur in the safe zone just above the instrument. Excessive chamber collapse may occasionally require removing cortex using a "dry" manual technique, whereby the bag is kept inflated with OVD rather than irrigation fluid. Hydration of the incision may tighten it enough to reduce any incisional fluid leakage.

Rarely, persistent positive pressure may preclude IOL implantation despite the use of a retentive OVD. Contingency maneuvers may be necessary under these circumstances. First, if the IOL can be introduced into the OVD-filled AC with adequate corneal clearance, side port instruments can rotate it into the capsular bag within a "closed" system. This avoids egress of the OVD, which must eventually be removed and exchanged for BSS or miotic in small aliquots through the side port incision.

If the chamber shallowing is progressive and the surgeon suspects a suprachoroidal hemorrhage, prompt closure of the incision is followed by either indirect ophthalmoscopy or viewing the posterior segment through an Osher panfundus surgical lens (Ocular Instruments). The management of this severe complication will be subsequently discussed, but the incision should be carefully sutured and the procedure aborted.

Absent any evidence of a suprachoroidal hemorrhage or effusion, the surgeon can consider aspirating fluid vitreous using a small-gauge vitrector through a trocar under direct visualization. The pars plana sclerotomy should be located 3.5 mm behind the limbus, or somewhat less in short eyes. The vitrectomy tip (cutting tip aimed posteriorly) is visualized through the pupil, and as soon as a small amount of vitreous is removed, additional OVD is injected into the AC through a paracentesis.[32] The chamber should deepen to allow the procedure to continue under safer conditions. Because a vitreous tap increases the risk for hemorrhage and retinal tear or detachment, this maneuver should be a last resort[30–33] and avoided in nanophthalmos because of the altered pars plana anatomy.

Iris Trauma

Damage to the iris during phacoemulsification can be caused by either iris prolapse or direct injury from the phaco tip or other instruments. Intraoperative miosis, iris depigmentation, bleeding, tissue loss, and an atonic or distorted pupil may result. Any trauma to the iris whether by contact with instruments, nuclear fragments, or even the IOL will increase prostaglandin release, increasing the likelihood of intraoperative miosis, and postoperative inflammation with cystoid macular edema (CME). Intraoperative miosis is also stimulated by sudden and dramatic fluctuations in the pupil diameter such as with repeated chamber collapse or the abrupt onset and reversal of pupillary block that characterizes LIDRS. Preoperative topical nonsteroidal antiinflammatory agents, adequate topical cycloplegia, and intracameral alpha agonists such as phenylephrine or epinephrine will help to maintain pupillary dilation.[13,14] Bisulfite-free 1:1000 epinephrine can be added to the BSS bottle or can be directly injected into the AC. However, because of its acidic pH epinephrine should be diluted 1:4 with BSS or BSS Plus before direct intracameral injection.[14] Epi Shugarcaine is a more concentrated combination of epinephrine, lidocaine and BSS, which can be used as an intracameral injection in IFIS.[14] Preservative-free intracameral phenylephrine 1.5% alone or phenylephrine 1% combined with Ketorolac (Omidria, Omneros) is also effective.[35–37]

Iris trauma from the phaco tip is more likely with crowded ACs, small pupils, and IFIS. Working centrally in the deepest part of the AC is preferable. Slowing the procedural pace by using low aspiration flow rates reduces the likelihood of inadvertent aspiration of the iris. Surgeons should be experienced in using a variety of small pupil strategies.[38] Intracameral alpha-agonists, including Omidria, can redilate a constricted pupil. A maximally retentive OVD, such as Healon 5, is very effective in achieving viscomydriasis. Radial iridotomy, multiple sphincterotomies, Frye sphincter stretching, the use of flexible iris retractors, and mechanical pupil expansion devices such as the Malyugin ring are all options for managing the small or constricting pupil.[39–48]

Posterior Capsule Tears

PCR with vitreous loss increases the risk for endophthalmitis, IOL malposition, CME, and retinal detachment. Proper management usually leads to a successful outcome with secure placement of a PCIOL.[49]

Prevention

Fortunately, the incidence of PCR decreases with increasing surgical experience. The most problematic posterior capsule tears occur during nuclear emulsification because of the presence of residual nuclear material. Several general principles help reduce the frequency of this complication.

Besides its advantages for IOL fixation, the capsulorrhexis has significantly reduced the rate of PCR. The smooth, continuous edge acts like an elastic waistband by stretching rather than tearing, and this allows the capsular bag to better withstand certain deforming forces.

Proper fluidic settings and chamber stability are also important in lowering the risk for this complication.

A soft silicone I/A tip provides superior capsular protection compared with traditional metallic tip designs that may have irregular, sharp burrs within the lumen of the aspiration hole capable of snagging and tearing the capsule.

A variety of phaco techniques have been conceived with the universal goal of maximizing capsular safety.[50–52] Slow-motion phacoemulsification,[53] the use of low-vacuum and low-aspiration parameters, will reduce the tendency for postocclusion surge and overpenetration of the phaco tip through the nucleus and posterior capsule.[53] Supracapsular techniques for soft cataracts such as phaco flip eliminate the need to perform nuclear emulsification in the proximity of the posterior capsule. Nucleofractis techniques, such as divide and conquer and phaco chop, fragment the nucleus so that manageable pieces can be elevated and then emulsified in the safe supracapsular zone.[50–52] Phaco chop uses mechanical forces to divide the nucleus so that less force is applied against the zonules and capsular bag compared with sculpting.[51]

The posterior capsule is most vulnerable as the last remaining nuclear fragments are removed. Without the bulk of nucleus material there to restrain it, the exposed posterior capsule can vault toward the phaco needle with either positive pressure or the slightest bit of postocclusion surge. This risk dramatically increases with diffuse zonulopathy in which the posterior capsule is less taut because of reduced centrifugal traction. Filling the capsular bag with dispersive OVD before the removal of the last fragment both safely distances the posterior capsule and makes it more taut so that it will not trampoline forward. In addition to reducing the vacuum and flow settings for this stage of the case, a second instrument tip may be placed behind the remaining nucleus to guard the posterior capsule. This should keep the capsule from trampolining toward the phaco tip as the occlusion is broken. We recommend dull-fingered instruments, which function as a nucleus manipulator, spatula, or chopper for this purpose because any sharp tip can inadvertently puncture the capsule.[52]

Certain types of cataracts increase the risk for PCR. The brunescent nucleus is not only firmer but also larger in its horizontal and vertical dimensions. Because of this, instrument forces and maneuvers, such as sculpting, cracking, and rotation, are directly transmitted to the capsular bag. In addition, the soft epinuclear cushion is often absent, which brings the phaco tip potentially into much closer proximity to the capsule. The surgeon should avoid vigorous hydrodissection initially to prevent excessive nuclear mobility during sculpting. Too much fluid injected around the lens may push the nucleus forward against the anterior capsular rim, creating an intraoperative capsular block syndrome as described previously.[53]

The posterior polar cataract and the cataract associated with posterior lenticonus or lentiglobus may be associated with a weakened or defective central posterior capsule.[54–60] The capsulorrhexis diameter should be approximately 4.8 mm to accommodate optic capture of the PCIOL (haptics in the sulcus and optic captured behind the capsulorrhexis) in the event that the posterior capsule tears. Because hydrodissection can rupture a thinned posterior capsule or widen any congenital capsular opening, it should either be partial or avoided in favor of careful hydrodelineation. One should assume that the posterior capsule is already open. Minimizing nuclear manipulation within a closed system, skillful use of OVD for dry cortical removal and tamponade of a tear, and converting any tear to a posterior capsulorrhexis are helpful principles for managing posterior polar cataracts.[54–60]

Osher has described the Escape Route technique in which hydrodelineation and removal of the fetal nucleus is followed by aspiration of the nasal epinucleus and cortex. The remaining epinucleus can then be safely loosened by hydrodissection with a J-shaped cannula because the dissecting fluid has an escape route to prevent pressure against the thinned central posterior capsule.

Finally, patients with congenital aniridia and Alport's syndrome have anterior capsules that are extremely thin and fragile and are much more likely to tear either into the zonule or around the equator through the posterior capsule[61] (Fig. 46.10).

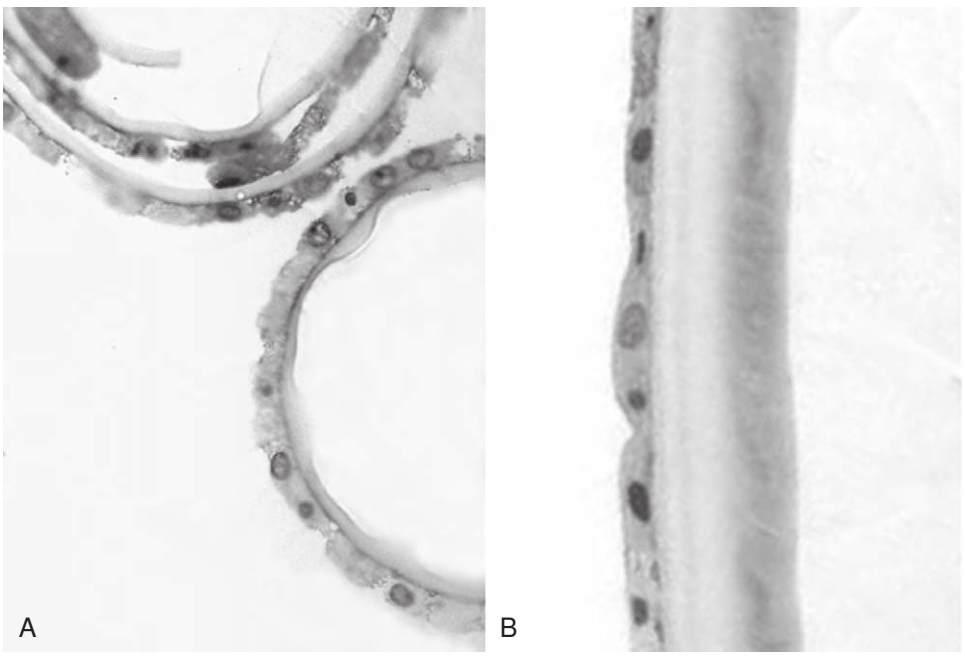

Fig. 46.10 (A) Anterior capsule from a patient with congenital aniridia. Note the thin anterior capsule and curling nature compared with (B) the anterior capsule from a patient without aniridia.

Management

At whatever stage a posterior capsular tear is recognized, maintaining a pressurized anterior segment is necessary. Allowing the AC to decompress and shallow will cause forward vitreous movement, rupture of the anterior hyaloid face, and extension of the tear with vitreous prolapse.

If a tear is discovered during phacoemulsification, residual nuclear material may be removed by either continuing phacoemulsification or converting to a larger incision, manual, extracapsular technique. If most of the nucleus has already been emulsified and there is no vitreous in the AC, the surgeon may use the second instrument to maneuver the remaining nucleus away from the tear to complete the emulsification. Directing hydrostatic infusion pressure toward the nucleus could propel it posteriorly into the vitreous cavity; however, lowering the irrigation bottle may cause chamber instability and collapse. The second instrument may be placed behind the nuclear fragment to prevent it from descending through a small rent. Because longitudinal ultrasound tends to repel fragments away, torsional ultrasound may be preferrable. Reduced I/A flow rates will effectively slow down surgical events within the eye. Whether or not the nucleus has been removed, the phaco handpiece should not be removed without simultaneously injecting OVD through the side paracentesis to prevent chamber shallowing and vitreous prolapse into the AC or into the incision. This critical maneuver often determines whether or not a vitrectomy must be performed. Because vitreous prolapse will expand any posterior capsular defect, this may also determine whether or not an IOL can be implanted into the capsular bag.

Adherence to several surgical principles facilitates cortical removal without expanding the capsular tear. Consider lowering I/A flow rates to slow the surgical pace. Start by removing cortex in those quadrants that are furthest away from the tear. Cortex should be stripped toward the rent because any force directed away from it will cause its extension. Depending on the location, it may be prudent to leave some cortex behind, rather than risk extending the tear. The AC must be kept expanded by injecting air or OVD before withdrawing the I/A handpiece. Bimanual, rather than coaxial I/A instrumentation permits the irrigation flow to be directed away from the capsular defect, even as nearby cortex is aspirated. An alternative method of cortical removal is manual aspiration alternating between a bent cannula and J-shaped cannula while maintaining the AC depth with repeated OVD injections. "Dry" manual aspiration of cortex is more tedious but decreases the risk for extending the tear and precipitating vitreous prolapse.

If vitreous is aspirated at any point during the procedure, perhaps signaled by an occlusion chime on the phaco unit, a low-flow bimanual vitrectomy should be performed. This is best accomplished by using a bimanual limbal or pars plana assisted anterior vitrectomy. Although a pars plana sclerotomy carries the theoretical risk for hemorrhage or retinal tears, this often affords a better angle of approach for drawing vitreous posteriorly from the AC toward the vitreous cavity. An alternative technique is a "dry" vitrectomy that uses repeated OVD injections instead of irrigation to maintain the AC while the vitrectomy is performed.[62] Triamcinolone vitreous staining, introduced by Burk and colleagues, dramatically improves visualization of the vitreous.[63] A nonpreserved preparation, Triesence (Alcon) has been approved for this purpose.

Four Special Maneuvers

There are several advanced techniques that can be considered in the setting of PCR with residual lens material.

If the nucleus has partially descended through a capsular defect onto the anterior hyaloid face, one must not chase it with the phaco tip. A modified version of the posterior assisted levitation (PAL) technique popularized by Charles Kelman can be used to rescue the descending nucleus.[64–69] A pars plana sclerotomy is made 3.5 mm behind the limbus, dispersive OVD is injected to elevate the nuclear fragment(s) and separate it from the underlying vitreous, and a spatula is used to maneuver behind the nucleus before levitating it forward. The advantage of the viscoelastic PAL technique is that it can protect against inducing vitreous traction when elevating the nuclear piece.[68,69] If the nuclear pieces are no longer visible or accessible from an anterior approach, it is always advisable to defer retrieval to a vitreoretinal surgeon.

If a vitrectomy must be performed with lens material still present in the AC, the authors have described the "Viscoelastic Trap" technique for preventing posterior descent of the residual nucleus and cortex.[68,69] Any free-floating lens material is elevated toward the cornea with dispersive OVD, which is then used to fill the AC. The bimanual anterior vitrectomy is then performed using a pars plana sclerotomy for the vitreous cutter. By keeping the cutter tip behind the pupillary plane, any prolapsing vitreous bands will be transected without aspirating the OVD that has filled the AC. With the Viscoelastic Trap, the residual lens material remains supported by the OVD layer, rather than by the vitreous, which is being removed.

The scaffold technique described by Kumar et al. is performed by placing a three-piece IOL in the sulcus to serve as a two-way barrier to prevent nuclear fragments from descending posteriorly after a posterior capsule tear. The surgeon can then emulsify the nuclear fragments anterior to the optic, which simultaneously blocks vitreous from being aspirated by the phaco tip. The technique should not be performed if there is any vitreous in the AC.[70]

Mark Michelson described inserting a trimmed sheets glide beneath the nucleus and in front of the posterior capsular tear to, in effect create an artificial posterior capsule.[71] This provides the same two-way barrier as the IOL scaffold.[71]

Finally, the surgeon may be able to convert a small, central linear tear into a posterior capsulorrhexis, as popularized by Howard Gimbel.[72–74] In this maneuver, the anterior hyaloid face is retroplaced with OVD, and a fine capsulotomy forceps is used to grasp and redirect the edge of the tear until a continuous edge is achieved.[73,74] If this is successfully accomplished, the capsular defect will not expand during capsular IOL implantation and positioning.

Intraocular Lens Placement in the Presence of a Capsular Tear

The key to successful placement of an IOL in the presence of a posterior capsule tear is clear visualization and understanding of the compromised capsulozonular anatomy. After OVD placement, the iris is gently retracted with a collar-button instrument (Fig. 46.11) to properly inspect the peripheral capsular anatomy. Based on the amount and location of the residual capsule, the surgeon must decide on the IOL design, and its optimal location and orientation.

A posterior capsular tear, when converted to a posterior capsulorrhexis, will permit implantation of virtually any PCIOL into the capsular bag. However, in the absence of a posterior capsulorrhexis, placing any IOL into a capsular bag with a small PC rent risks extending the defect. This risk is greatest with three-piece IOLs because of their stiffer haptics. If the posterior capsule tears during IOL implantation, it may be possible to prolapse and capture the optic through the capsulorrhexis (reverse optic capture). Depending on the size and location of the posterior capsule defect, it may be easier to implant a single-piece acrylic IOL into the bag. The latter must be well expanded with OVD, and decentering forces must be minimized and avoided during implantation. It should be universally recognized that single-piece acrylic IOLs are unsuitable for ciliary sulcus fixation because of the

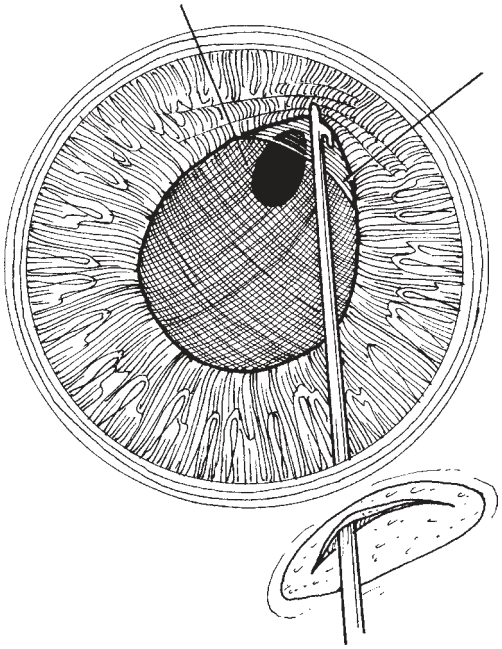

Fig. 46.11 Retraction of the iris to visualize the extent of a posterior capsular tear.

thicker haptics, the unfinished sharper edges, and the shorter overall IOL length. Thus if the capsular tear extends during implantation, the single-piece IOL cannot be moved into the ciliary sulcus and instead must be either captured or explanted.[75]

When the anterior curvilinear capsulorrhexis is intact, instead of using a single-piece acrylic IOL, the surgeon may consider traditional optic capture in which a three-piece IOL with C-loop haptics is placed into the ciliary sulcus and the optic is "button holed" through the capsulorrhexis (Video 46.2). Most foldable three-piece IOLs have an overall length of 13 mm and may not fully bridge the PC. Particularly when the anterior segment is large, capture of the optic by the capsulorrhexis border will prevent postoperative subluxation caused by insufficient overall IOL length.

Alternatively, the IOL may also be implanted into the ciliary sulcus. It is important to confirm adequate fixation by slightly decentering the lens toward each haptic and releasing it to observe for spontaneous recentering (Osher Bounce Test). If the IOL does not recenter itself, the haptic should be rotated to a different meridian. Persistent decentration warrants suture fixation to the iris or sclera or selecting another fixation technique. The surgeon should never rely on "chance."

Because of the different effective lens position, the power of a PCIOL must be reduced by approximately 0.5 D, depending on the power of the IOL when the optic is placed in the sulcus.[76–79] However, the higher the power the IOL, the greater the myopic shift when placed in the sulcus without optic capture (see https://www.doctor-hill.com/iol-main/bag-sulcus.htm).[80]

Power at Capsular Bag	Subtract from Bag Power
+5.0–9.0 D	No change
+9.5–17.0 D	–0.50 D
+17.5–27.0 D	–1.00 D
+27.5–30.0 D	–1.50 D

In the absence of sufficient capsular support, the surgeon has the option to either implant an angle-supported anterior-chamber IOL (ACIOL), suture fixate a PCIOL to the iris or sclera, or use intrascleral haptic fixation of a three-piece IOL with either the Yamane double-needle technique or Agarwal's glued IOL method (see Chapters 41 and 53). If an ACIOL is used, each haptic should always be flexed, lifted, and allowed to reseat itself in the angle to prevent inadvertent iris entrapment. Outside of the United States, an iris "claw" lens is another useful option that allows for IOL fixation to either the anterior or posterior surface of the iris stroma.[80]

Once the IOL is well centered and its stability has been confirmed, acetylcholine or carbachol may be used to constrict the pupil. This makes it easier to identify vitreous prolapse and incarceration while helping to prevent vitreous aspiration as the OVD is removed. OVD can be removed manually or with an I/A handpiece with low infusion. However, if the chamber collapses, there is a risk for further vitreous prolapse or loss of an optic capture. Therefore consider injecting air or BSS through the paracentesis simultaneously with IA tip withdrawal to prevent momentary chamber collapse and further vitreous prolapse. The air bubble can then be removed in small aliquots and exchanged for a BSS so that the AC depth is always maintained.

Sweeping the pupil with a microhook is helpful to ensure that there are no remaining incarcerated vitreous strands. If the posterior capsule was torn but a vitrectomy was not performed, a peripheral iridectomy should be considered to prevent vitreous-induced pupillary block.[81] Intracameral air has the advantage of allowing any vitreous to fall back while delineating transcameral vitreous strands by their interruption of the smooth round bubble observed in the AC. However, staining with triamcinolone is the best way to visualize vitreous strands.[63] Diluted preservative-free triamcinolone acetate 40 mg/mL (Triesence, Alcon Surgical) with BSS (1:10) can be injected in the AC to confirm the absence of prolapsed vitreous.[63,82–85] See Chapter 47 for a full discussion of anterior vitrectomy techniques.

Dropped Nucleus

Posterior dislocation of a partially emulsified nucleus into the vitreous cavity is a complication dreaded by every phacoemulsification surgeon. Excessive infusion, gross manipulation, ultrasound repulsion, vitreous liquefaction, or forward displacement of the anterior vitreous are potential contributing factors to nucleus descent.[72]

As previously discussed, if the nucleus falls back into the mid to anterior Vitreous, the viscoelastic PAL technique may be performed as long as the nucleus can be visualized. If a nuclear piece can be levitated forward, there are two options. It can be manually removed with a lens loop through an enlarged incision, or resuming phacoemulsification can be considered. The latter should not be done in the presence of any vitreous prolapse because vitreous incarceration by the phaco tip is likely to cause a giant retinal tear. Upon completion of an anterior vitrectomy, resuming phacoemulsification within the AC can be considered if the nucleus can be safely supported by the iris or by an IOL or Sheets Glide scaffold.[64–71] If the entire nucleus is intact, the surgeon may experience difficulty bringing it forward through the intact capsulorrhexis. First bisecting the nucleus may be necessary to preserve the capsulorrhexis.

If the nucleus descends as far as the mid or posterior vitreous or the retinal surface, it should be left alone. The surgeon should perform an anterior vitrectomy and remove accessible cortex. Whether to implant an IOL during the primary surgery will depend on the surgeon's judgment and comfort level, and both options are acceptable. Early referral to a vitreoretinal specialist to assess and eventually remove retained lens material will improve the ultimate prognosis. Knowing this, one must avoid overly aggressive attempts to remove any posteriorly displaced nuclear fragments.

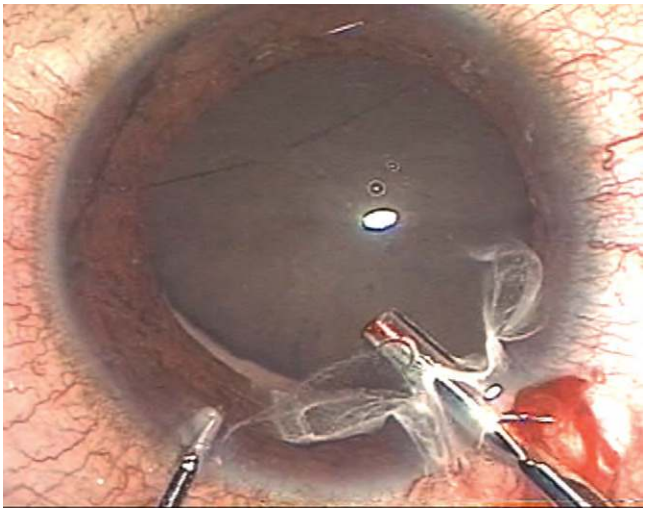

Fig. 46.12 Vitreous gel made clearly visible by the injection of triamcinolone particles seen streaming into the vitrectomy port.

Vitreous Loss

Vitreous prolapse and incarceration is associated with serious intraoperative and postoperative complications. Fortunately, meticulous vitreous clean-up can maintain a good final visual prognosis.[63] Highlighting the difficulty of visualizing vitreous, a recent survey found that over 80% of ophthalmologists had the experience of unexpectedly discovering vitreous incarceration postoperatively.[63,72–88] More liberal use of triamcinolone staining should prevent this problem[63] (Fig. 46.12).

ACUTE CORNEAL CLOUDING

There is always the remote possibility of inadvertently injecting either the wrong drug or the wrong concentration of a drug into the eye. Corneal endothelial toxicity may cause immediate intraoperative clouding of the cornea.

Prompt recognition followed by immediate intracameral lavage with BSS is indicated. Proper labeling and communication between members of the surgical team should minimize the risk for this potentially disastrous complication. See Chapter 49 for more on Toxic Anterior Segment syndrome.

INADVERTENT CANNULA INJECTION

The accidental injection of a cannula can cause scleral penetration, iris damage, posterior capsule tear, zonular dialysis, vitreous hemorrhage, and retinal tear. Detachment of the cannula hub from the syringe tip during forceful injection of a solution or OVD creates a sharp projectile capable of penetrating intraocular tissues. Luer lock systems do not guarantee that a mishap will not occur, and the potential risks of improper setup must be reviewed with the surgical staff. We recommend that the surgeon always inject with the dominant hand while the index finger of the fellow hand contacts the hub of the cannula. This creates instantaneous tactile feedback the moment the cannula ejects, at which point the surgeon will cease the injection and the index finger will blunt the forward movement of the cannula. At the end of surgery when the incision is forcefully hydrated, the stream should be directed perpendicular to the wound so a detached cannula will strike the lateral wall of the incision rather than enter the eye.

EXPULSIVE SUPRACHOROIDAL HEMORRHAGE

The catastrophic complication of suprachoroidal expulsive hemorrhage is more likely to occur in older patients with brunescent lenses, preexisting uveitis, glaucoma with elevated IOP, high myopia or hyperopia, anticoagulant use, and systemic hypertension.[89,90] The single greatest risk factor is PCR with vitreous loss and vitrectomy. Early recognition is the key to successful management. Chamber shallowing with positive pressure and iris prolapse may be the first sign. The surgeon may notice loss of the red reflex, and the patient may complain of pain despite adequate anesthesia. If the surgeon suspects this diagnosis, ophthalmoscopy should be performed to determine whether a suprachoroidal choroidal hemorrhage is developing. Although the indirect ophthalmoscope should be readily available, the Osher Panfundus lens (Ocular Instruments) allows fundus visualization through the operating microscope. The panfundus lens also allows for excellent visualization of the retinal vessels to confirm perfusion.[91]

Any globe that suddenly becomes firm demands immediate closure of the incision using finger tip tamponade if necessary.[91,92] Once the incision has been secured, prolapsed uveal tissue can be reposited (or rarely excised), and the AC can be deepened with air, BSS, or OVD injection. If the AC fails to deepen or if the incision cannot be safely secured, the surgeon may attempt to drain the suprachoroidal hemorrhage via a posterior sclerotomy 3.5 to 4 mm posterior to the limbus that avoids the larger vessels at the 3 and 9 o'clock locations. If accessible, a vitreoretinal surgeon could be called upon.

Surgeons should generally avoid the temptation to continue surgery, because any decompression of the AC will likely induce further hemorrhage. Fortunately, this complication is extraordinarily rare with phacoemulsification through small, self-sealing incisions.

A suprachoroidal effusion will often mimic a hemorrhage in its clinical presentation.[91,92] Immediately closing and securing the incision to avoid extrusion of intraocular tissue is still paramount. Although it may be impossible to distinguish between a suprachoroidal hemorrhage and effusion using ophthalmoscopy, effusions tend to be more circumferential and low-lying. Sometimes it is difficult to visualize an effusion, even though it creates severe posterior pressure that prohibits safe completion of the surgery. If an effusion is suspected, it is inadvisable to attempt a partial vitrectomy to relieve the pressuse. Lowering the IOP with vitrectomy could exacerbate the effusion and could be catastrophic if there is a suprachoidal hemorrhage. Once the incision is secure, one should pause surgery and wait for a presumptive effusion to resolve. Returning the patient to the holding area and reassessing the ocular pressure after 1 hour is an option. With repressurization of the globe, a suprachoroidal effusion may resolve after only a few minutes or within an hour. Resuming surgery is a consideration after spontaneous and dramatic softening of the previously firm globe. Fortunately, with self-sealing small incisions, there is literally no point in the procedure when surgery cannot be aborted with the plan of completing the case at a later and safer time, including a day or more later.

SUMMARY

- A wide range of intraoperative complications can occur.
- Successful management requires:
  - Careful preoperative planning
  - Access to special instruments designed to manage selected complications
  - Flexibility to adjust surgical techniques to optimize the outcome
  - A backup plan for modifying IOL selection and method of fixation

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Video 46.1 Use of a subincisional iris hook to address iris prolapse caused by a short incision and floppy iris syndrome.

Video 46.2 Optic capture of a three-piece IOL in the setting of a ruptured posterior capsule and dropped/retained nucleus.

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Vitrectomy for the Anterior Segment Surgeon

Alexis K. Warren and Keith A. Warren

CONTENTS

KEY POINTS

- Cataract surgery is not without complications, which may require intraoperative vitreous management and therefore a fundamental knowledge of vitreous anatomy to achieve the best postsurgical outcomes.
- Anterior segment surgeons may encounter the need for intraoperative vitrectomy for a variety of reasons, including capsular rupture, zonular dialysis, trauma, pediatric cataract, and posterior pressure.
- Management of vitreous requires a few general principles, including maintenance of the anterior chamber, removal of as much lens material as possible, identification and excision of any vitreous prolapse, and primary implantation of a stable intraocular lens if possible. If there are any retained lens fragments, the patient may require postoperative antiinflammatory medication and prompt referral to a vitreoretinal surgeon.

INTRODUCTION

Nothing is more anxiety provoking than when the expected rapidly turns into the unexpected. Cataract surgery is one of the more frequently performed outpatient procedures in the United States.[1] The success and rapidity of today's planned small-incision cataract surgery depends on the development of a series of surgical maneuvers with little variation. Accordingly, nowhere else in ophthalmology is there more anxiety generated than when a routine cataract procedure is complicated by capsular rupture, vitreous loss, and posterior dislocation of the lens fragments. Although the lens fragments may be lost posteriorly and the surgeon may begin to perspire, all is not really lost. With the proper intraoperative and postoperative management, patients can have an excellent result, and the cataract surgeon's acute management plays an important role in bringing a good outcome to fruition.

ANATOMIC CONSIDERATIONS

The vitreous is of mesenchymal embryonic origin, and the primary vitreous plays important roles in the development of the anterior segment structures. The ciliary muscle, iris vasculature, and vitreous humor are all derived from the primary vitreous. By 40 weeks' gestational age, the primary vitreous has cleared and is optically clear with a refractive index equal to water. Not surprisingly, this complex intraocular structure is primarily composed of water. It is the hyaluronic acids and other metallomatrix proteins that account for the gelatinous nature of the vitreous, and it is this consistency that requires the vitreous be removed by excision.[2]

The vitreous in the adult eye has a configuration similar to that of a triangle. The base of the triangle is parallel to the posterior lens surface with the apex of the triangle located at the optic nerve (Fig. 47.1). There are several attachments of the vitreous body to other structures that have important implications.

- The vitreous is firmly attached to the pars plana at the vitreous base, which includes the ora serrata of the retina.
- There are also firm attachments of the vitreous to areas of lattice degeneration and chorioretinal scars, including those resulting from laser photocoagulation.
- There are moderately firm attachments to the optic nerve, macula, and the retinal vasculature.

Understanding the anatomic and biochemical properties of the vitreous plays a significant role in both the pathophysiology of disease and the surgical treatment of the retina and vitreous. Accordingly, it is alterations in these known properties of the vitreoretinal interface that often times directly result in pathologic changes and ultimately vitreoretinal diseases that have become so familiar to us.

INDICATIONS FOR VITRECTOMY

There were almost no descriptions of vitreous surgery in the ophthalmic textbooks of the early 1900s. Most prominent ophthalmologists at the time believed that excision of the vitreous was dangerous, with complications involving the cornea, iris, and retina, frequently resulting in loss of the eye. Ophthalmologist David Kasner, a well-known cataract surgeon, also experienced in eye banking, performed the first opened sky vitrectomy on an eye after trauma.[4] Contrary to popular perception, the operation was successful, and the eye tolerated the procedure well. Because of the frequency of complications associated with open sky procedures, vitrectomy has limited anterior segment indications. These included removal of vitreous to allow for wound closure or

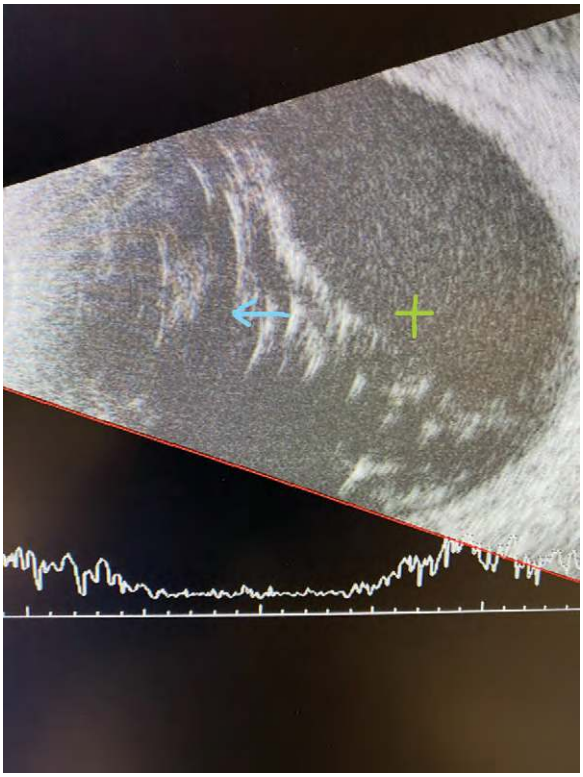

Fig. 47.1 The vitreous shown in this ultrasound remains partially separated. The posterior hyaloid face is parallel to the lens *(blue arrow)* while the apex of the vitreous remains attached to the optic nerve *(green cross)* where it detaches last.

TABLE 47.1 Pathological Diseases associated with Vitreous Traction

Pathologic Disease	Mechanism
Myopia	Poorly understood vitreoretinal disorder characterized by axial elongation, vitreous liquefaction, and collagen degradation with resulting in vitreous detachment.[3]
Rhegmatogenous retinal detachment	The culmination of vitreous traction at the vitreoretinal interface, retinal tear, and the egress of liquified vitreous.
Vitreomacular traction (VMT) and macular hole	Tractional forces at the vitreoretinal interface that may eventually causing a full thickness gap in the retinal nerve tissue.[20]
Epiretinal membrane formation (macula pucker)	Glial cell fibroplasia with resultant fibrous deposition and contraction on the retinal surface following vitreous separation.[20]

From McCannel C, Atebara N, Kim S, et al. Diseases of the Vitreous and Vitreoretinal Interface. Retina and Vitreous. American Academy of Ophthalmology; 2017-2018:190. Basic and Clinical Science Course.

vitreous presenting in the anterior segment before lens removal. After Dr. Kasner's discovery, Dr. Robert Machemer began work on the development of a closed system to remove the vitreous from a pars plana approach.[5] Vitreous removal at the pars plana, so-called *pars plana vitrectomy*, led to a number of important advancements in the treatment of previously untreatable vitreoretinal disease. These included complex retinal detachment with proliferative vitreoretinopathy, vitreous hemorrhage, traction diabetic detachment, macular pucker, macular hole, and diagnostic vitrectomy for the diagnosis of infection and tumors.

Still, advances in vitrectomy surgery have important implications to the anterior segment surgeon as well, although most often related to the crystalline lens and associated complications or pathology.

Vitreous loss related to capsular rupture during phacoemulsification is the most common indication for vitrectomy in the anterior segment setting. This can result in infection, inflammation, glaucoma, and cystoid macula edema (CME), among other complications. Prompt and adequate removal of the vitreous with intraocular lens placement at the time of surgery can significantly reduce the incidence of these complications.

Vitreous prolapse and zonular lysis after ocular trauma may also require appropriate management of vitreous for the anterior segment surgeon. Proper vitreous cleanup with intracapsular or posterior chamber placement of the lens can achieve excellent outcomes and avoid the secondary complications associated with an anterior chamber intraocular lens.

Pediatric cataract can be readily managed by a pars plana approach. The soft nucleus is easily removed with the vitreous cutter, and the posterior capsule can be opened, if necessary. The anterior capsule can be left intact for a secondary intraocular lens. This can be accomplished with skilled hands with little to no vitreous prolapse into the anterior chamber.

Posterior pressure or malignant glaucoma are both effectively managed by limited vitrectomy at the pars plana. The vitreous is removed to deepen the anterior chamber to allow for safe removal of the lens or, as is the case in malignant glaucoma, to improve the aqueous outflow.

In these anterior segment conditions with vitreous-related pathology, an understanding of the anatomy and fundamentals of vitrectomy, along with the efficient use of current vitrectomy instrumentation, can produce excellent patient outcomes.

PRINCIPLES OF VITRECTOMY

Derived from the surgical suffix of Greek origin *-ectomy*, which means "the act of cutting out," the term *vitrectomy* refers to surgical removal of the vitreous. Safe and efficient vitrectomy requires an understanding of the anatomy, effective utilization of currently available instrumentation, and performance in a closed system.

An important tenet for the successful performance of any surgical procedures is adequate illumination and exposure of the surgical field. Important first steps are visualization and careful observation. With small pupil phacoemulsification, successful performance of the procedure is difficult because of the limited view. A larger pupil allows for a safer capsulorrhexis and completion of lens removal and cleanup.[6] After vitreous loss, the surgeon should remain focused, then perform a careful survey. In addition, visualization is tantamount for the effective and successful removal of vitreous.

The vitreous is optically clear. This transparency can sometimes make it difficult to determine the extent and location of vitreous in the anterior chamber despite even the best illumination or magnification. Retroillumination can be used in the posterior segment to obtain good visualization of the vitreous. Careful inspection for clues indicating the presence of vitreous may be helpful. These may include tilting or posterior displacement of the lens, immobility of a previously mobile lens, obvious capsular defect, and peaking of the pupil.[7]

Because of poor visibility, several methods to improve visualization of the vitreous have been explored. Fortunately, blood does an excellent job of "staining" the vitreous. The posterior hyaloid face can be readily seen with preretinal hemorrhage and provides a nice plane of dissection for the creation of a complete posterior vitreous detachment. However, in most cases, sans hemorrhage, visualization requires the use of an adjuvant. Several substances have been examined, most of which do

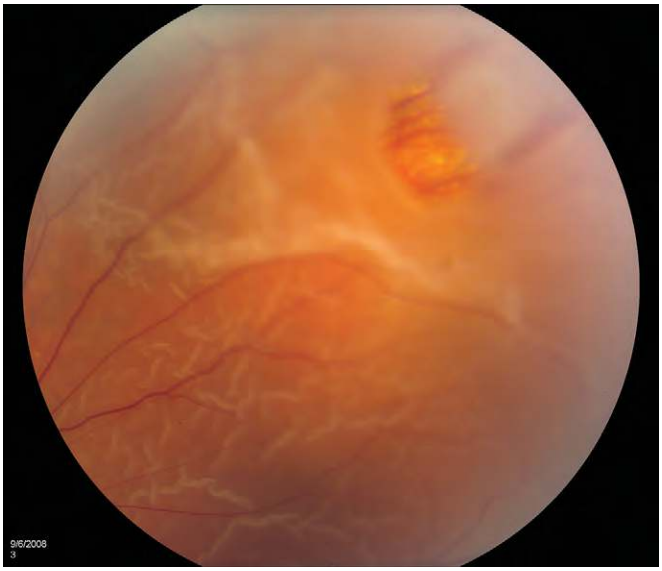

Fig. 47.2 Peripheral retinal tear via biomicroscopy. The anterior flap of this horseshoe tear is held open by the attached vitreous.

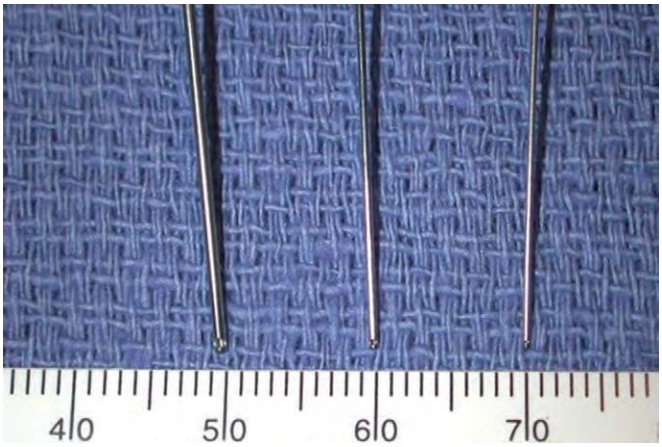

Fig. 47.3 Vitrectomy cutters. Diameters range from 1.0 mm (20 gauge), 0.75 mm (23 gauge), to 0.5 mm (25 gauge). Small variations in diameter result in exponentially large differences (4th power) in flow rate.

not "tag or stain" the vitreous well.[8] Burk and associates demonstrated a relative inexpensive and effective means to stain the vitreous with the use of preservative-free triamcinolone acetonide (Kenalog®).[9] The ready accessibility and ease of use make this a common and frequently used adjuvant. Moreover, the antiinflammatory properties of this corticosteroid offer additional advantages. Application of this important tool will be discussed in further detail in the surgical management of vitreous loss.

When considering vitreous resection in the anterior segment, the surgeon should always recognize the effect on the anatomic attachments of the vitreous in the posterior segment. When the vitreous has prolapsed into the anterior chamber through a capsular or zonular defect, this results in anteroposterior traction at the vitreoretinal interface. This traction is the underlying etiology of retinal tear (Fig. 47.2) and may play a role in macula edema. Accordingly, it is important that the surgeon recognize these anatomic relationships and performs the vitreous excision in a manner that mitigates any secondary complications related to traction at the vitreoretinal interface.

The original vitrectomy instrument developed by Machemer employed the use of a rotary cutter.[5] Although effective in removal of the vitreous, the rotating cutter created torque that resulted in vitreous traction and secondary retinal tears. As a result, guillotine style cutters were designed to reduce this vitreous traction. With the development of small-incision vitrectomy, these newer instruments have increased capabilities. With a smaller diameter, lasered cutting surface, high-speed cut rate, and improved fluidics, the newest generation cutters can function as multipurpose instruments that are as versatile as a Swiss Army Knife®.

- Although the vitreous behaves as a Newtonian fluid once it has undergone liquefaction, the formed vitreous must be excised into smaller packets before the same laws of physics apply.[10]
- High-speed excision converts the formed vitreous into these smaller packets, diminishing the tractional forces on the vitreoretinal interface during vitreous removal, thereby reducing traction-related complications.
- High-speed excision with smaller diameter microincision cutters requires a significant increase in aspiration force by either vacuum (Venturi) or peristaltic methods to achieve the desired speed (flow) of vitreous removal.
- Understanding the flow characteristics and therefore functionality of the various diameter cutters (Fig. 47.3) offers many advantages for use in anterior segment vitrectomy.

Finally, a closed system provides the safest and most stable environment for vitrectomy, regardless of the anatomic location of the vitreous. The rapid decline in the pressure gradient from the posterior to anterior chamber with an open-sky cornea or open wound results in further, significant prolapse of the vitreous down the pressure gradient into the anterior segment. With maintenance of the anterior chamber by infusion and ophthalmic viscosurgical devices (OVDs), bimanual small incision anterior or pars plana vitrectomy can minimize vitreous loss, and the patient can have an excellent outcome without additional complications.

ANTERIOR VERSUS PARS PLANA VITRECTOMY

The ability to safely excise the vitreous represents an important advance in the treatment of a variety of eye disorders. Although the approach may vary by anatomic location, the same principles of vitreous surgery apply regardless of the indication for surgical intervention. Pars plana vitrectomy is generally planned, so the surgeon usually has an opportunity to understand the anatomic relationships and visualize the pathology before intervention. Anterior vitrectomy may be the result of a surgical complication, presenting the surgeon with a variety of unforeseen challenges including an inability to see the major offending culprit or vitreous that requires attention.

The pars plana approach is the ideal location for vitrectomy. Its major limitation, poor visualization, is easily overcome with endoillumination and wide-angle viewing systems. A three-port system is employed with separate entry ports for excision, illumination, and infusion. This platform allows the surgeon to see and treat vitreous and retinal pathology as far anterior as the ora serrata. Vitrectomy is performed with constant attention to the vitreoretinal interface. After separation of the posterior hyaloid face, resection of the vitreous is carried out as far anteriorly as is safely possible in the same outside-in manner described for membrane peeling.[11] When approaching the ora serrata, the cutter speed is increased and aspiration decreased to reduce traction at the vitreous base. The access to both posterior and

anterior segment structures makes this the most effective site for vitreous removal.

Anterior vitrectomy is most likely indicated for vitreous prolapsed into the anterior segment. It is commonly related to lens pathology, trauma, or intraoperative complications. When the presentation is acute, there may be lens material and/or other structures involved. Poor visualization, collateral tissue involvement, and the acute nature can make the resection difficult. Careful attention to the basic tenets of anterior vitrectomy can yield excellent results.

- First, care should be taken to maintain a formed anterior chamber.
- The vitreous should then be stained to enhance visualization and as complete a removal as possible.
- Excision of the vitreous should be carried out away from the surgical wound.
- A bimanual approach is desirable.
- Anterior vitrectomy should proceed from an outside to inside approach. This means that the vitreous should be initially engaged at the point farthest away from the vitreous prolapse with the excision proceeding back toward the posterior segment to reduce any potential vitreoretinal interface traction.
- The cutter speed should be as high as possible, and the cutter should remain active until it is removed from the incision.

Attention to these basic principles and other methods to be presented in detail in the sections to follow can result in complete and safe removal of the anteriorly displaced vitreous.

MANAGING VITREOUS LOSS

Even in the hands of experienced cataract surgeons, complications can occur. What defines the good surgeon is preparedness, an ability to maintain focus despite the unexpected, and then execution of the required steps to regain control of the clinical situation. Perhaps nowhere is this more accurate in ophthalmology than with posterior capsular rupture during planned cataract surgery. If the surgeon understands the pathophysiology of vitreous loss and has developed a well-prepared plan, the unexpected can be promptly and effectively managed.

- Rupture of the posterior capsule does not necessarily ensure vitreous loss.
- If the anterior hyaloid face is intact, maintenance of a formed anterior chamber reduces the likelihood of vitreous prolapse.
- Accordingly, upon recognition of a capsular tear, the surgeon should inject an OVD at the phacoemulsification tip before removing the phacoemulsification handpiece to displace the vitreous face posterior and maintain a stable anterior chamber. This maneuver reduces the pressure gradient that can result in vitreous prolapse.
- Depending on the size of the posterior capsule defect and confirmation that the hyaloid face has not been disrupted, the surgeon may proceed with phacoemulsification, taking heed to maintain a stable anterior chamber to prevent further vitreous loss.
- If the surgeon is able to complete the nucleus removal and significant cortical cleanup, an intraocular lens should be placed in a manner that maximizes an interface between the anterior hyaloid and anterior chamber.

Sometimes, despite the best made plans, vitreous prolapse occurs and complicates the fracas! All, however, is not lost. The first order of business remains securing the anterior chamber with an OVD. After this has been accomplished, the surgeon should secure the surgical wound with a 10-0 nylon suture followed by careful observation and inspection. Surgeons are expert at what they do most often. Trouble tends to follow when they attempt what they do infrequently. This is when it is important to understand the confines of one's own expertise and to stay within those confines. Although taking a moment to survey the new reality of the procedure, it is also important to inspect the surgical field so that an accurate assessment and plan of action can be formulated. A few important questions may be asked:

- Is there vitreous at the wound?
- How much lens material is left anteriorly?
- What is the status of the capsule?
- Have any lens fragments displaced posteriorly?
- Is the remaining lens material nuclear or cortical in nature?

The answers to these questions will serve as a roadmap to developing a successful plan of attack.

The next step is identifying the extent of vitreous prolapse. Inadequate cleanup of the vitreous is fraught with complications including infection, pupil irregularity, CME, and retinal tear and detachment (Video 47.1).

- Identification of displaced vitreous can be accomplished with placement of rinsed triamcinolone acetonide (Kenalog®) or Triesence (preservative-free triamcinolone acetonide) into the anterior chamber.
  - If using Kenalog®, this should be rinsed first to remove any preservative as described by Burk et al.[9] Using 0.2 mL of injectable triamcinolone acetonide (Kenalog®), 40 mg/mL should be drawn in a 5 µ filter and rinsed with 2 mL of balanced salt solution (BSS).
  - The solution can then be resuspended in 5 mL of BSS and recaptured to thoroughly remove the preservative.
  - Finally, the Kenalog® particles are resuspended in 2 mL of BSS and injected into the anterior chamber through a 27-gauge cannula.
  - The triamcinolone should also be diluted before instillation, most commonly a 1:4 dilution of triamcinolone to BSS. Specifically, 0.25 mL of 40 mg/mL triamcinolone is diluted to a volume of 1 mL with BSS (Fig. 47.4).

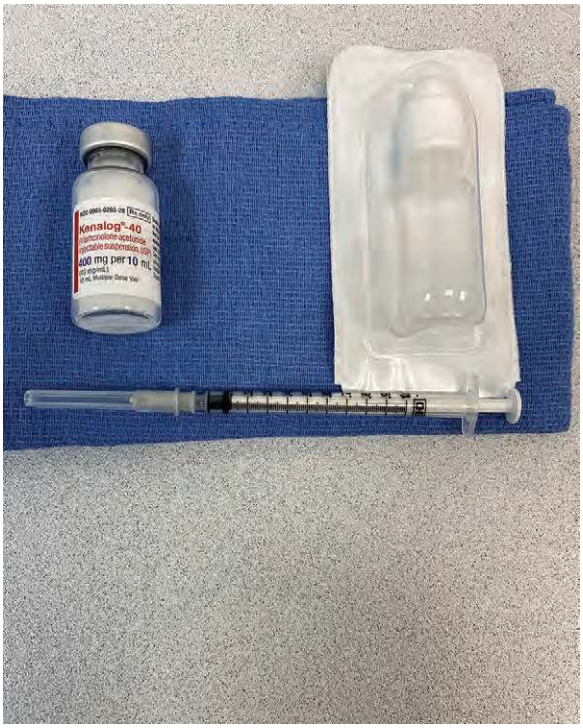

Fig. 47.4 Triamcinolone solution for staining vitreous. This should be washed of preservative (if applicable) and then diluted 1:4 with balanced salt solution (BSS) before it is irrigated into the anterior chamber. The mixture can then be washed out with BSS to allow for visualization of vitreous in anterior chamber.

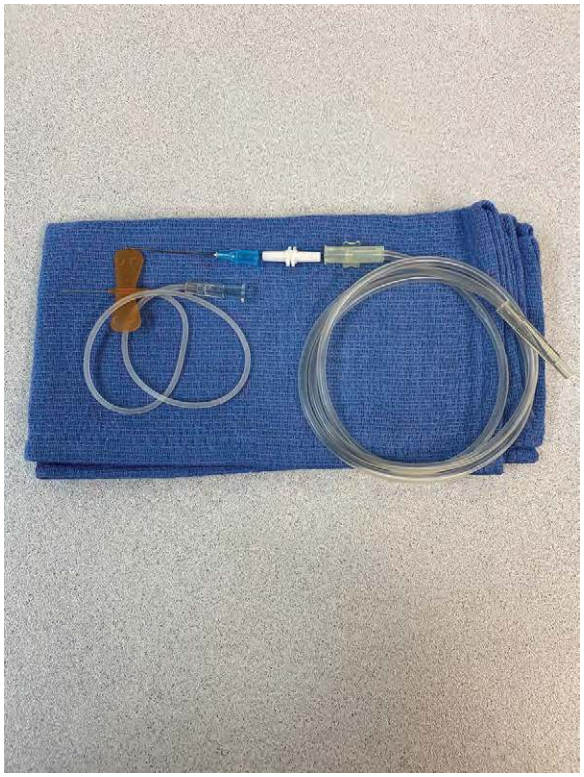

Fig. 47.5 Infusion set for anterior vitrectomy. This includes a 21-gauge butterfly needle or a 23-gauge retrobulbar needle and a male-to-male adaptor. The radius of infusion line will have a direct exponential effect on infusion pressure.

- This 1-mL solution is placed into the anterior chamber and then irrigated out with BSS. This particulate suspension is excellent at "tagging" the vitreous.
- An OVD can then be used to "compartmentalize" the vitreous away from the wound for easier removal.[12]
- Paracentesis incisions should be made away from the wound at an angle that allows easy access to the wound and capsular defect.
- An infusion line to provide irrigation and stabilize the anterior chamber should be placed through a paracentesis.
- The infusion line can be can constructed using materials already available in the operating room. A 23-gauge blunt retrobulbar needle or 21- to 23-gauge angiocath can be connected to irrigation using a male-to-male adaptor (Fig. 47.5). The irrigating handpiece of a bimanual irrigation/aspiration system also works well.
- The infusion rate required to maintain the anterior chamber is significantly affected by the diameter of the catheter. Nothing smaller than a 23-gauge diameter infusion catheter is recommended.
- The cutter should be at the highest possible cut rate using enough infusion to maintain the chamber. Using current vitrectomy cutters, a cut rate between 800 and 4000 cuts per minute (cpm) and, depending on the diameter of the cutter, a vacuum setting between 300 and 600 mm Hg should be used.
- Flow-operated systems should employ the same cutters speed (800–4000 cpm) with a flow rate between 3 and 7 mL/min.
- The infusion should be placed at 30 to 35 mm above the surgical wound or between 30 and 35 mm Hg. This should create a stable anterior chamber in a relatively closed system.
- The anterior vitrectomy should commence from the wound anteriorly first and then proceed posteriorly toward the capsular defect to reduce any vitreous traction. The same technique should be used for vitreous that has prolapsed anteriorly after zonular dehiscence or traumatic cataract.

For the advanced anterior segment surgeon, a pars plana approach should be considered. The advantage of this approach is direct access to the prolapsed vitreous that can be removed from the anterior segment more efficiently with minimal vitreoretinal traction. Use of this technique requires a clear understanding of the anatomic relationships and use of the cutter using illumination from an anterior light source. Practicing this procedure using eye bank eyes before using it under the stressful circumstances of a surgical complication is strongly recommended.

- Additional local anesthesia will be required for a pars plana approach. The placement of 0.3 to 0.5 cc of 2% subconjunctival lidocaine over the sclerotomy site is recommended.
- After allowing the anesthesia 7 to 10 minutes to take effect, the sclera is marked 3.5 mm posterior to the limbus, and a 20- or 23-gauge microvitreoretinal (MVR) blade is used to make an incision perpendicular to the limbus.
  - Upon entry, the blade is aimed toward the optic nerve and passed about 2 mm beyond the widest point of the MVR blade.
- With the infusion running in the anterior chamber, the cutter is then placed through the sclerotomy with the aperture facing the surgeon and directly visualized before activating the cutter.
- The cutter should be advanced posterior to the capsular opening and activated to excise the vitreous that has prolapsed through the capsular defect. The cutter should be held in that position for a few minutes to allow the displaced vitreous to move posteriorly.
- Cessation of posterior capsular motion and the absence of triamcinolone particles should indicate when the appropriate amount of vitreous has been cleared.
- Upon removal, it is important to remember to keep the cutter in active cutting mode until it has been completely removed from the eye.
- If vitreous prolapse is noted at the sclerotomy site, the cutter should be passed in and out of the sclerotomy site in active mode until vitreous is no longer present at the wound.
- The sclerotomy should then be closed with a figure of 8 or interrupted 8-0 Vicryl suture.
- Any residual vitreous remaining in the anterior segment can then be excised using the anterior vitrectomy techniques described above.
- Finally, an OVD should be placed in the anterior segment over the capsular opening to retard any further vitreous prolapse.

MANAGING RETAINED LENS FRAGMENTS

Retained lens fragments after capsular rupture and vitreous loss can be difficult to manage. A clear and accurate assessment of the anterior segment, in particular the capsular status, extent of vitreous loss, and type (nuclear vs. cortical) and amount of residual lens material are important factors in formulating a good surgical strategy.

With anterior vitrectomy, stability of the anterior chamber is of paramount importance. Placement of a suture to secure the wound and the use of a dispersive OVD are excellent tools in achieving control of the anterior chamber. Before removing the phacoemulsification handpiece, an OVD should be placed at the phacoemulsification tip and over the capsular defect to posteriorly displace the vitreous and inhibit

any prolapse. Once a survey of the residual lens material and capsular status has been completed, identification of the extent and amount of vitreous loss should be assessed. This should be carried out by irrigation of the anterior segment with 0.5 to 1.0 mL of a 1:4 dilution of 40.0 mg/mL preservative-free triamcinolone acetonide. The triamcinolone solution is then washed out of the anterior chamber anterior with BSS. The triamcinolone particles will adhere to any vitreous rendering it visible for excision. If no vitreous prolapse is identified, phacoemulsification can be used to clear the anterior segment of small nuclear and cortical fragments. Larger fragments can be removed by enlargement of the incision and the use of a lens loop. Care should be taken to ensure maintenance of the chamber with OVD to prevent further vitreous prolapse. Once the fragments are removed, any anterior vitreous should be removed. Paracenteses should be placed superiorly at the 10 o'clock and 2 o'clock positions to allow access to the anterior chamber at a site away from the initial wound. Using a bimanual technique, an anterior vitrectomy should be carried out moving from anterior to posterior toward the capsular defect. The cutter should be set at a high cut speed (800–4000 cpm) with an infusion rate of 3 to 5 mL/min or a 30- to 35-cm bottle height. Cortical material is easily aspirated and excised with the vitrectomy cutter by reducing the cut rate to allow the cutter aperture enough time to "grasp" the cortex. Careful inspection of the chamber angle and sulcus for hidden fragments should be performed. Every attempt should be made to place an intraocular lens if there is adequate support. This provides a physical barrier that has been demonstrated to reduce the likelihood of complications related to vitreous prolapse into the anterior chamber including endophthalmitis, glaucoma, and retinal tear.[13]

Multiple and/or larger fragments of retained lens material may be difficult to remove. These are more easily accessed with a pars plana approach. If fragments do displace posteriorly, retrieval of those fragments is best left to a vitreoretinal surgeon. Attempts to retrieve lens fragments suspended in the anterior vitreous can be fraught with significant vitreoretinal complications. Those fragments can be easily and safely removed later by an experienced retinal surgeon.

Alternatively, if appropriate, retained fragments can also be removed in a technique described by Chang, which uses dispersive OVD to create a "Viscotrap" of the retained lens material in the manner described below.[12, 14]

- After the vitreous is "stained" with preservative-free triamcinolone, the OVD is used to displace any lens fragments and cortical material at the iris plane forward into the anterior chamber for removal. The OVD provides a "cushion" between the lens material and vitreous.
- The vitrectomy cutter is then used from behind the lens capsule to excise the vitreous toward the posterior segment, exerting less traction at the vitreous base.
- Once the vitreous has been excised, the fragments can then be removed. Careful inspection for retained fragments in the angle and sulcus should be carried out.
- The cutter should always be removed in active cutting mode, and the sclerotomy site should be examined to be free of vitreous then secured with an interrupted 8-0 Vicryl suture.
- If any lens fragments are observed to migrate posteriorly, the patient should be referred for vitreoretinal evaluation.

Regardless of whether an anterior or posterior approach is employed for vitreous cleanup, an intraocular lens should be placed in as stable position as the capsular remnant will allow. Current literature suggests that primary insertion of an intraocular lens, when possible, can provide satisfactory visual acuity outcomes and may be the most efficient practice, especially in preparation for a pars plana vitrectomy by your vitreoretinal colleagues.[15, 16] With meticulous attention to vitreous cleanup and lens removal, and with a stable intraocular lens in place, most patients will have a good outcome despite this dreaded complication.

POST VITRECTOMY MANAGEMENT AND REFERRAL

After any prolapsed vitreous and residual lens material has been addressed and an intraocular lens has been placed, the surgeon's management of this unfortunate complication is near completion. The most important remaining consideration in the management of these patients is aggressive antiinflammatory treatment to reduce the risk of CME, the most common cause of vision loss in this patient population.[17] A posterior sub-Tenon's block or periocular injection of preservative-free triamcinolone (20 mg/0.5 mL suspension) into the conjunctival cul-de-sac can provide an extended antiinflammatory effect and is an excellent option that avoids the issue of patient compliance. Other topical treatment regimen include prednisolone 1%, difluprednate (Durezol®), or a steroid ointment (dexamethasone) in combination with a nonsteroidal antiinflammatory drug. Treatment should continue beyond the usual postoperative time course and can even be extended to 6 weeks in most of these complicated cases.

The cataract surgeon usually prefers prompt referral for vitreoretinal evaluation, particularly if there are retained posteriorly dislocated lens fragments. The patient may report floaters or impaired vision secondary to debris in the visual axis. Although immediate referral is frequently desired, it is usually better for the retinal surgeon to have a chance to evaluate the patient and discuss the risk for and benefits of surgical intervention under more controlled and less stressful circumstances. The indications for removal of residual lens fragments in the posterior segment include media opacity obscuring the visual axis, intraocular inflammation, and glaucoma. With adequate cleanup of the anterior segment and placement of a lens implant, the literature reports improved visual outcomes and a lower incidence of secondary glaucoma and CME.[18] Regarding timing of removal of retained lens fragments by pars plana vitrectomy, no difference was noted between immediate removal or delayed removal with regard to final vision when the removal occurred before 30 days.[19] Worse outcomes were reported in eyes with poor presenting vision, CME, retinal detachment, or delay beyond 30 days. Most patients in this report had have favorable outcomes, with the vast majority achieving 20/40 or better vision.

In summary, patients with complicated cataract surgery are best managed with cleanup of the anterior segment and placement of an intraocular lens at the initial surgery. Removal of any residual lens fragments before 30 days can usually have excellent visual results. Most complications are related to poor vitreous management. Although this can be a stressful event for both patient and physician, most patients can have a favorable outcome.

Step 1: Dilute the triamcinolone acetonide to a 1:4 dilution with sterile BSS.

Step 2: Place diluted triamcinolone solution into the anterior chamber through the main wound or paracentesis.

Step 3: Irrigate the anterior chamber with sterile BSS to remove the diluted triamcinolone solution, leaving any anteriorly displaced vitreous tagged and visible.

Step 4: Use the vitreous cutter either from an anterior or pars plana approach to excise any vitreous or lens particles form the anterior chamber, and, if necessary, perform anterior vitrectomy first addressing the most anterior vitreous then moving further back toward the posterior segment to eliminate any possibility of vitreoretinal traction.

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Video 47.1. Anterior vitrectomy using triamcinolone acetonide to stain the prolapsed vitreous.

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Issues in Wound Management

Roberto Pineda, Patricia S. O. Kalout, Douglas D. Koch, and Li Wang

CONTENTS

INTRODUCTION

The cataract incision serves as more than just the access point to the anterior segment. It affects corneal stability and overall ocular integrity. Wound construction is the critical determinant of this integrity, and two key elements of the wound involve size and architecture. Wound management after cataract surgery is required in cases of wound leakage, burns, or dehiscence.

This chapter reviews wound construction, mechanisms of wound healing, factors that can predispose to wound compromise, and the management of wound leakage, burns, and dehiscence.

WOUND CONSTRUCTION

Cataract surgery has evolved from large incisions (>10 mm) to smaller incisions (1.8–3.0 mm), leading to more stable parameters during surgery, shorter healing time, and less surgically induced astigmatism with better visual outcomes.[1] The two principal approaches to small cataract incisions are scleral tunnels (<3 mm) and clear corneal incisions (CCIs) (1.8–3.0 mm).

The traditional limbal or anterior scleral incision was designed for ready access to the anterior chamber and simple closure with radially oriented sutures. Two or three planes were incorporated into the incision, but the intrascleral (or intralimbal) portion was short (1 mm or less), and the site of entry into the anterior chamber was located near the iris root. In contrast, key elements of the self-sealing scleral tunnel incision include a long (>2 mm) intrascleral component and an anterior entry into the chamber.[2,3] The latter creates an internal corneal valve that is closed by intraocular pressure (IOP).

Stimulated in part by advances in foldable lens implant design, the small incision (3.5 mm or less) has largely supplanted the traditional 6- to 7-mm scleral tunnel incision. Likewise, the scleral tunnel incision has largely been replaced by clear-corneal incisions except in special cases (Table 48.1).

The clear corneal incision was first described by Fine in 1992 and has evolved over the past several decades, permitting incisions smaller than 2 mm,[7] but its construction principles remain the same: create adequate tunnel length with an internal corneal valve to create a self-sealing wound.

- Several corneal incision constructions have been used: paracentesis incision, two-plane or grooved incision, hinged incision, and three-plane incision.
- Ernest et al.[2] showed that clear-corneal incisions with an internal corneal valve demonstrated resistance to leakage comparable to similarly constructed scleral tunnel incisions.
- In an animal model, Ernest el al.[8] evaluated the role of the site of external opening of the incision-on-incision healing and stability. They found that starting incisions in the vascular region (limbus) resulted in a fibroblastic response that enhanced incision stability and allowed rapid incision healing within 7 days postoperatively compared with the 60 days of healing time required for incisions started in the avascular region (cornea). Their findings were compelling, and more recent clinical studies have been performed, showing that wound location and architecture are the major factors for faster visual improvement[4] (Table 48.2).

After successful use in refractive surgery for laser in situ keratomileusis flap construction, the femtosecond laser was introduced in 2009 for use in cataract surgery.[9] Although there appears to be promise in using femtosecond laser technology for wound construction in cataract surgery, the utility is still under consideration. Advantages include reproducibility of wound architecture, capsulorrhexis circularity with consistent optic overlap,[10,11] less energy necessary for the nucleus fragmentation, and potential for smaller incisions. However, problematic endothelial gape and incision leakage have been reported in recent studies.[12] The overall benefit of femtosecond laser assisted wound construction is still under evaluation.

WOUND HEALING

A scleral, limbal, or corneal incision creates a tissue gap that initiates a process of repair by tissue-addition. For scleral and limbal incisions, active wound healing begins within 48 hours of surgery; the initial phase is the ingrowth of episcleral vascular tissue.[13,14] Over the next several weeks, this tissue fills the entire incision, creating a fibrovascular plug. Over the ensuing 2 years or more, remodeling occurs, resulting in reorientation of the wound healing collagen so that it becomes parallel to existing scleral collagen. Concurrently, vascularization and cellularity diminish.

- At 1 week postoperatively, wound strength is approximately 10% of that found in normal nonincised tissue.[15–17]
- By 8 weeks postoperatively, this value is roughly 40%, and by 2 years postoperatively, the wound has regained approximately 75% to 80% of its original strength.
- Therefore, although the wound is most vulnerable to dehiscence early in the postoperative period, depending on its size and

TABLE 48.1 Scleral Tunnel[4–6]

PROS	CONS	
Self-sealing sutureless wound	*If too deep:*	Expose the ciliary body (problems related to hemostasis)
Less SIA[a] if small		Poor wound stability
Used for different techniques surgeries		Posterior entry into the anterior chamber
		Iris prolapse
	If too shallow:	Button hole
		Leakage
	If too long:	Anterior entry to the AC (difficult maneuverability of instruments)
		Cornea striae (poor visibility during surgery)
	If too short:	Wound closure issues (leakage, IOP fluctuation, iris prolapse)
	Others:	Hyphema, SIA for incisions >4 mm

[a]*SIA*, Surgically induced astigmatism.

TABLE 48.2 Clear Cornea Incision[4–6]

PROS	CONS
Avoidance of the conjunctiva and sclera (virtually bloodless surgery); no suture-induced astigmatism	Poorer wound healing compared with limbal or scleral-tunnel incisions
No suture-induced astigmatism)	Wound dehiscence after minimal trauma
Minimal induced astigmatism (temporal incisions) or reduced postoperative astigmatism (steepest meridian)	Risk for cornea opacities (thermal burns)
Easier access	Notable decrease in endothelial cell count compared with scleral-tunnel incisions
Safer surgery	
Reduced operating time and fewer complications	
Faster visual recovery	

construction, the cataract incision retains a permanent susceptibility to traumatic dehiscence.[18–20]

- Corneal incisions heal by ingrowth of keratocytes,[8] which initially are oriented parallel to the incision and therefore, perpendicular to lamellae of the cornea stroma. These keratocytes then undergo fibroblastic transformation and, over months, reorient themselves to become parallel to the corneal lamellae. Compared with scleral and limbal wound healing, the wound-healing process of the corneal incision is much slower and ultimately produces a weaker incision, as attested by the relative fragility of corneal graft wounds.
- The clinical impact of this slower healing for cataract corneal wounds depends in large part on incision size and construction. For standard 2.2- to 2.7-mm corneal tunnel incisions, the small incision size and wound construction appear to largely or even fully compensate for the deficiencies in the corneal wound-healing process. However, the slower healing of corneal incisions can predispose to problems with dehiscence in poorly constructed small incisions and in incisions longer than ~3 mm.
- In addition, it is probable (but unproven to date) that there is greater against-the-wound astigmatic shift with corneal incisions compared with limbal or scleral wounds of the same size, but this appears to pertain primarily to superior clear corneal incisions and perhaps to temporal clear corneal incisions >3.0 mm. Data suggest that a 2.4 clear corneal incision induces a mean astigmatic shift of less than 0.1 to 0.2 D.[21]

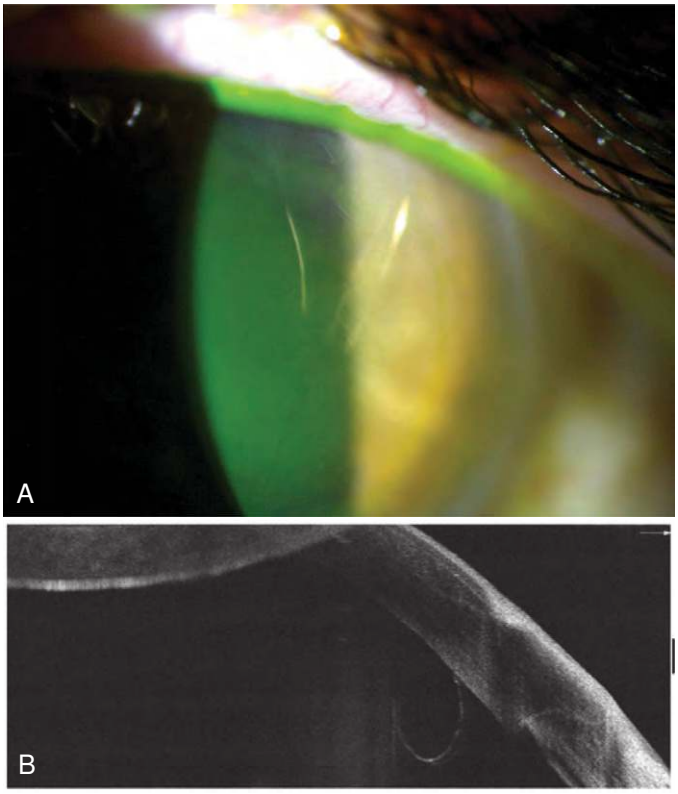

Fig. 48.1 (A) Slit lamp photograph of a Descemet's detachment at the entry of the main incision causing a scrolled appearance of Descemet's membrane. (B) Anterior segment optical coherence tomography image of a Descemet's detachment at the entry of a CCI.

COMPROMISE OF WOUND INTEGRITY

One of the biggest concerns of any procedure is postoperative infection and endophthalmitis, which can be caused by a compromised incision.[22]

Wound Leakage

A wound leak that occurs in the first few days postoperatively is a major risk for bacterial contamination and usually is caused by an inadequate suture closure for that particular wound configuration. Endothelial or epithelial gaping or misalignment, Descemet membrane detachment (Fig. 48.1), and/or loss of coaptation along the stromal tunnel might be seen immediately after surgery and are contributors to wound leakage[7] (Fig. 48.2).

The clinical signs of wound leak include poor vision, ocular hypotony, broad corneal folds, shallow anterior chamber, hyphema, choroidal effusions, choroidal folds, and optic nerve edema. IOP is typically low (<5 mm Hg), and the definitive diagnosis may be made by instilling concentrated fluorescein (Seidel testing) using either fluorescein strips or 2% fluorescein solution. It can be helpful to evaluate the internal corneal valve: in the presence of a wound leak, the valve can be seen gaping with posterior displacement of the posterior portion of the wound.[23]

Fig. 48.2 Ultrasound biomicroscopy of a poor apposition of the clear corneal wound in a patient with postoperative hypotony and wound leak.

The seal of the internal corneal valve is IOP dependent, and a watertight wound can leak as a result of postoperative hypotony. The latter, in turn, can be caused by insufficient chamber inflation at the conclusion of the surgery, sluggish ciliary body (CB) function, or accidental wound lip compression (e.g., eye rubbing) that leads to aqueous egress. Ultrasound biomicroscopy has been reported to be helpful in detecting a subtle wound leak as a cause of chronic hypotony.[24] Using optical coherence tomography, Taban et al. examined various self-sealing incisions over various IOPs and found that higher IOP was associated with more tightly sealed wounds in general. Furthermore, larger angle (more perpendicular) incisions sealed better at lower IOP while, conversely, smaller angle (less perpendicular) incisions sealed better at higher IOP.[25] Also, studies have demonstrated that square configuration is stronger than rectangular configuration.[26] Clear-corneal self-sealing wounds may have more variable structural changes in the first hour after the procedure.[22,27]

The corneal or scleral tunnel incision may be subject to intraoperative compromise that can predispose to later leakage. Excessive episcleral cautery may devitalize the flap, delaying the tissue ingrowth that is essential to wound healing and, in extreme cases, precipitating flap necrosis. Tearing or buttonholing of the roof of the tunnel can make closure difficult, and a groove or dissection into the CB, if sufficiently anterior, can create a deep channel into the anterior chamber. False passages in the tunnel itself with multiple levels of anterior chamber entry may also arise and escape detection and closure. Incorrect suture placement and tying also may distort wound architecture and predispose to leakage. Finally, at the close of surgery, a seton may be left in the tunnel, creating a wound fistula.[28] This may occur with capsular or cortical remnants, vitreous, or prolapsed iris.

Management of wound leak depends on several factors, including etiology, timing, severity, and the structural appearance of the incision. Wound leaks that are noted in the first or second day postoperatively often seal themselves as a result of the postoperative inflammatory process. Wound leaks that occur after the first few days can sometimes be managed medically, particularly if wound apposition is generally good and the integrity of the eye is unaffected. Unfortunately, in the authors' experience this is often not the case, and these cases generally fit into the category of wound rupture requiring surgical repair (discussed later in the chapter). Adjunctive medical management can include the following:

1. Decreasing corticosteroid therapy
2. Prophylactic administration of topical antibiotics
3. Cycloplegia, preferably with a long-acting agent such as atropine or scopolamine to improve CB function and/or treat CB detachments
4. Full-time patching if IOP <2 mm Hg
5. Use of a 48- or 72-h collagen shield or disposable soft contact lens
6. Topical administration of aqueous inhibitors (e.g., beta-blockers) to decrease aqueous flow if IOP is normal
7. Hydrogel sealants if the area is dry before application (ReSure, Food and Drug Administration (FDA) approved; OcuSeal, European Conformity but not FDA-approved yet)[29]
8. Cyanoacrylate-based adhesives with overlying contact lens to promote strong wound closure[29,30]

Resuturing is indicated in the following scenarios:

1. The AC is flat.
2. IOP remains low for several days, particularly in the presence of a shallow AC.
3. There is iris prolapse.
4. There is extensive external wound gape, particularly if excessive flattening along the meridian of the incision has developed. Alternatively, use of tissue adhesives, such as cyanoacrylate, appears to be well tolerated and may have future applicability.[31]

Recently interest has increased as to whether CCIs and their potential for wound leakage may be associated with an increased incidence of endophthalmitis. Some studies have shown an increase in the incidence of endophthalmitis beginning with the time period of transition to CCIs,[32–34] particularly in the setting of observed wound leak.[35] This is further supported by cadaveric and in-vivo studies showing that fluctuation in IOP (simulating eye rubbing and blinking) can compromise wound integrity and cause entry of surface fluids.[36–38] Other studies, however, have not conclusively borne out this trend in incidence.[39–42] No sufficiently large randomized study has yet compared CCIs with other types of incisions, although several studies have related the increase in the number of cases of endophthalmitis to the time CCIs were introduced.[5] However, it is apparent that any incision (corneal, limbal, or scleral) should be sutured if it is not self-sealing at the conclusion of surgery.[43]

Wound Thermal Burns

A wound burn is a thermal injury of the incisional tissue and is characterized by whitening of the overlying corneal tissue, contraction and striae of wound tissue, and wound gape. Wound burns are caused by inadequate cooling of the phacoemulsification tip, which, in turn, is caused by one or more factors, including occlusion of the phaco tip by nuclear material or dispersive ophthalmic viscosurgical devices, compression of the irrigation sleeve from an excessively tight incision or poor angulation of the phacoemulsification handpiece, and absence of irrigation fluid. Its incidence may have been increased by advances in small incision surgery and small-caliber phacoemulsification needles.

Bradley et al. in a survey of practicing ophthalmologists found an incidence of wound burn of approximately 0.1% with the majority occurring during fragment removal. Divide-and-conquer and carousel techniques showed a higher incidence than chop techniques,[44] possibly because of the greater tendency to impale larger nuclear pieces with the former approaches.

Prevention of wound burn is of utmost importance and the following strategies can minimize the occurrence:

1. Matching of wound size to the size and design of the phacoemulsification tip. In addition, it is vital to test fluid flow before handpiece insertion.
2. Clearing of dispersive viscoelastic before commencing ultrasound.
3. Setting appropriate vacuum and power settings for a given nucleus density to minimize the risk for tip blockage by nuclear material.
4. Careful nuclear sculpting, avoiding occlusion, and prompt recognition of auditory signals from the phacoemulsification device indicating tip obstruction.
5. Being alert to visible signs of decreased fluid flow ("lens milk") and early wound tissue whitening.

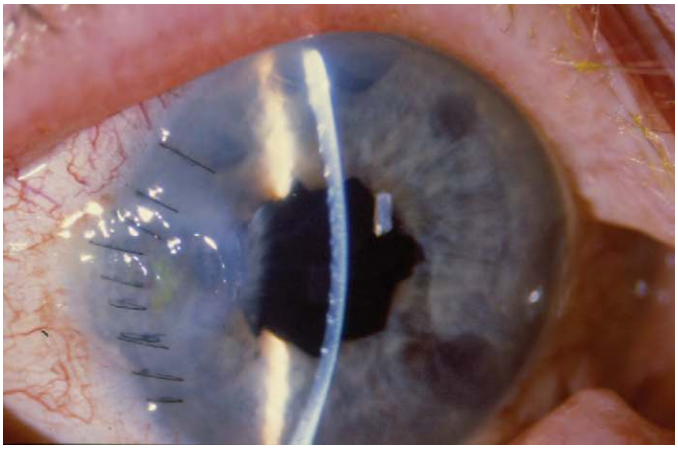

Fig. 48.3 Severe wound burn requiring multiple interrupted sutures to achieve a watertight closure. Note the induced corneal striae. The cause was undetected obstruction of the phacoemulsification tip by a dispersive ophthalmic viscosurgical device caused by low flow and vacuum settings.

Advances in phacoemulsification machine engineering, perhaps with thermal coupling, may further limit this potentially devastating complication.

If a burn occurs, there are a range of treatment options:

- Meticulous suturing of the wound with multiple radial sutures is often needed (Fig. 48.3).
- Another approach is to use a vertical mattress suture to avoid excessive traction on the tissue; however, this can be technically difficult to insert when there is marked tissue contracture.
- Haldar et al. described a conjunctival flap technique based at the fornix in five patients with having uneventful recovery and satisfactory postoperative vision with low residual astigmatism.[45]
- In less severe cases, a bandage contact lens may assist with wound closure, and we have found fibrinogen glue and, more recently, hydrogel sealants to be an effective adjunct and use it whenever wound integrity is uncertain despite careful suturing.
- In severe cases, it may be difficult to achieve watertight closure with sutures alone and, occasionally, a scleral patch graft may be necessary.

Wound healing tends to be slow, and sutures typically should be removed only after several weeks elapse. Our preference with severe burns is to begin suture removal as late as 3 months postoperatively, when we can be assured that endothelial cells covering the incision have deposited new Descemet's membrane.

Wound burns create astigmatism along the meridian because of both tissue contracture and the sutures. One immediate step to reduce the amount of induced astigmatism is to place a scleral relaxing incision just posterior to the sutures. The depth should be approximately 50%, and the length should match that of the incision.

The tissue contracture often largely regresses over the ensuing year, but some or, rarely, large amounts of astigmatism can persist. The latter can be addressed with relaxing incisions that are made in the peripheral cornea in the area of the burn as long as the wound integrity is confirmed.

Wound Dehiscence

Wound dehiscence typically occurs later, postoperatively, after the wound has been documented as being closed at one or more postoperative visits. Causes of wound dehiscence are direct ocular trauma or, less commonly, spontaneous loosening or breakage of a suture or tissue melting or necrosis.

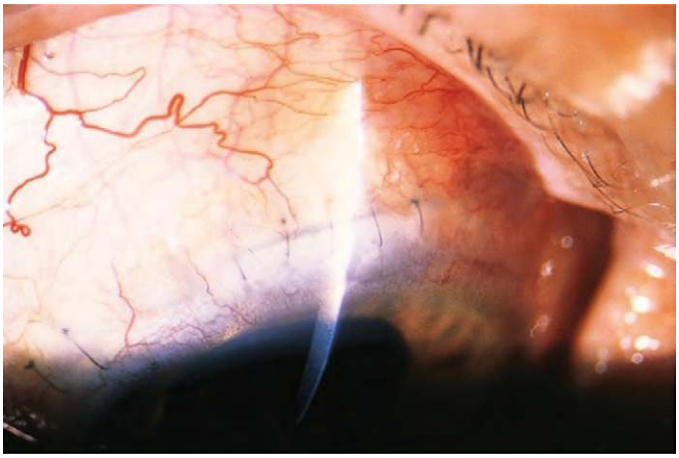

Fig. 48.4 Scleral "melting" and 6 D of against-the-wound (ATW) astigmatism developed in a 68-year-old white female 3 weeks after uncomplicated planned extracapsular cataract extraction. The wound was resutured, but within 4 weeks there was spontaneous loosening of all sutures and recurrence of 4 D of ATW astigmatism. Note wound gape, scleral edema, and loose sutures. Because of poor scleral integrity, no further wound revision was attempted.

Although the actual incidence of wound dehiscence is likely to vary moderately depending on multiple factors, the shift to small-incision surgery and the evolution in techniques of wound design have reduced the incidence markedly, with reports indicating a range of 0.02% to 1.5%.[46–51]

Factors Predisposing to Wound Dehiscence

The surgical incision and its closure are only as reliable as the corneoscleral tissue substrate (Fig. 48.4). Particularly for larger incisions, wound healing may be delayed or incomplete in the setting of profound systemic illness[48] and malnutrition (particularly vitamin C deficiency). When trauma is a cause for wound dehiscence, the patient's visual outcome is strongly correlated with the time between the injury and the surgery.[52] Elderly patients can be more visually impaired after traumatic wound dehiscence, especially when associated with large incision extracapsular cataract extraction as many cases result in poor visual outcome.[53]

Peripheral ulcerative keratitis and scleritis associated with underlying collagen vascular disease can produce marked scleral and/or corneal thinning, rendering wound closure extremely difficult. These entities also may flare up after surgery, leading to melting of the tunnel incision.

Manifestations and Management of Wound Dehiscence

Manifestations of wound dehiscence include wound leakage (discussed previously), inadvertent filtering bleb, wound rupture, epithelial downgrowth (ED) and fibrous ingrowth (FI), and against-the-wound astigmatism.

Inadvertent Filtering Bleb. A wound leak under sealed conjunctiva results in formation of a filtering bleb. Gonioscopy is helpful in visualizing and evaluating the internal wound as reported by Jain.[54] The management is again highly dependent on the timing and severity. Filtering blebs noted in the first few days postoperatively typically resolve. This process can be hastened using the medical measures discussed earlier for management of a wound leak.

Filtering blebs that develop after the first several postoperative days usually reflect the breakdown of an initially well-apposed wound, which can occur from trauma, suture breakage or loosening, or scleral

melting. Spontaneous resolution of blebs with this cause is less likely because there is insufficient inflammation to promote closure of the incisional gaping.

Regardless of the time of onset and the cause, blebs that persist beyond several days can undergo epithelialization of the fistulous tract. This channel is resistant to medical treatment and many forms of surgical intervention.

Treatment of persistent filtering blebs depends on the level of the IOP, the overall integrity of the wound, and patient comfort. Surgical repair is indicated in eyes with poorly tolerated hypotony, ocular discomfort because of the size of the bleb, or reduction in vision because of encroachment of the flap over the cornea. Large, thin-walled blebs that "weep" aqueous may predispose to the development of endophthalmitis, and surgical closure should be considered. Filtering blebs accompanied by poor wound apposition typically induce against-the-wound astigmatism, and, if this is excessive for the patient's need, it is a relative indication for surgical repair. Dellen can form adjacent to large blebs, and these can be resistant to standard therapy with topical lubricants.[55] Some patients are uncomfortable because of lid contact with the filtering bleb or may have cosmetic concerns when the bleb is large and cystic; in these situations, bleb repair may be indicated (Fig. 48.5).

Closure of a long-standing filtering bleb is complicated by epithelialization of the fistula.[56] Relatively noninvasive methods to close or shrink chronic blebs include cryotherapy, chemical cauterization with trichloroacetic acid, argon laser treatment after application of methylene blue or rose bengal (Steinert RF, personal communication, 1994), neodymium:yttrium-aluminum-garnet laser,[57] and diathermy.[58,59]

Surgical closure of the fistula requires either its excision or sufficient compression and inflammation to foster cicatricial closure. We recommend excision of the conjunctiva that was involved in the filtering bleb to eliminate these channels. The wound must be carefully explored, and the fistula identified. The fistulous tract is covered by a layer of endothelial cells, and it should, therefore, be scraped or excised, and, if necessary, the remaining hole covered or filled with a scleral graft or a folded half-thickness scleral flap.[60,61] The wound is then meticulously resutured. If the sutures appear to induce excessive astigmatism, this can be minimized by placing a scleral relaxing incision just posterior to the sutures. This incision is placed at a depth of around 300 μm and should extend the length of the sutured region. Finally, the conjunctiva and Tenon's capsule are advanced and meticulously sutured. Postoperative antiinflammatory treatment is kept to a minimum. Even with these steps, complete closure of a bleb is not always successful. However, a large bleb can sometimes be dramatically reduced in size and low pressure ameliorated, thereby achieving partial surgical success.

Patients with persistent filtering blebs should be warned of the risk for development of bleb-induced endophthalmitis. The incidence and severity of postcataract endophthalmitis are increased in patients with filtering blebs,[62–64] and early detection is desirable.

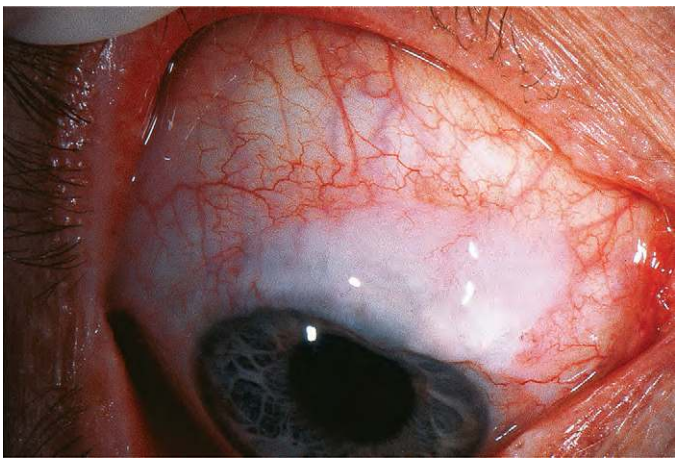

Fig. 48.5 Persistent inadvertent filtering bleb 2 years after cataract surgery. The IOP was 11 mm Hg in this eye and 19 mm Hg in the fellow eye. Patient complained of progressive, severe eye irritation and tearing. Surgical repair consisted of excision of cystic conjunctiva, scraping of fistulous track, closure of the track with interrupted 9-0 nylon sutures, and coverage of the track with a half-thickness scleral flap. The bleb recurred but at less than 50% of original size, and the IOP was 14 mm Hg.

Wound Rupture

One of the most severe sight-threatening presentations of wound dehiscence is frank wound rupture,[65–68] which is the traumatic reopening of a wound that had previously been sealed, usually accompanied by extrusion of intraocular contents. Susceptibility to traumatic wound rupture is presumably highly dependent on the size and architecture of the incision, with a possible contribution of the patient's predisposing factors. Indeed, wound failure can occur without apparent precipitating trauma in patients with abnormal sclera or poor healing. Conversely, in patients with small self-sealing incisions, a traumatic rupture of the globe without compromise of the incision is even possible. Case reports of traumatic expulsion of anterior segment structures with resealing of the wounds have been reported, testifying to the unique integrity of these wounds compared with traditional extracapsular wounds.[69,70]

Most traumatically induced wound ruptures have extensive structural disruption of the incision with poor wound edge apposition and iris prolapse (Fig. 48.6). The amount of damage to the wound is almost always much more widespread than is evident preoperatively. The initial steps of surgical repair consist of dissecting free the conjunctival flap, exploring the incision, reopening the wound beyond the margin of dehiscence, and freshening the wound edges by scraping them with a sharp blade.

Iris prolapse occurs in the majority of eyes that sustain late postoperative wound rupture. This may in part be caused by the infrequent use of peripheral iridectomy, which predisposes to a large disparity in

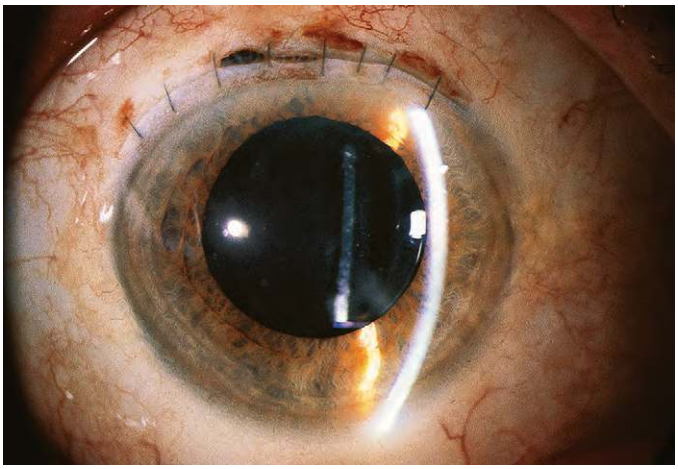

Fig. 48.6 Presumably traumatic wound dehiscence that was detected 3 weeks after uncomplicated extracapsular cataract extraction. The patient indicated that he had rubbed the eye. Note iris prolapse; no wound leak was present.

pressure between the posterior and anterior chambers at the moment of traumatic wound opening. Iris that is frankly necrotic should be excised and cultured. Viable iris can usually be reposited after it is meticulously scraped to remove any adherent epithelial cells. There is some controversy over the management of iris that has been prolapsed over 24 hours because of concern about the introduction of epithelium or microorganisms.[71,72] Epithelial downgrowth has been reported after repositioning an iris that was prolapsed for 7 days. It is often easiest to reposit iris tissue through a separate stab incision. The surgeon should be cautious to avoid exerting excessive traction on the iris root, which can result in bleeding, iridodialysis, or both.

Vitrectomy is performed as needed, and the intraocular lens is repositioned and fixated or exchanged as necessary. The wound is then meticulously resutured; our preference is interrupted 10-0 or 9-0 nylon sutures. With limbal and scleral incisions, the conjunctiva is pulled centrally over the peripheral cornea and meticulously sutured at each end to ensure good wound coverage. Topical and broad-spectrum intravenous or oral antibiotics are usually recommended for 2 to 5 days after wound repair.

Epithelial Downgrowth and Fibrous Ingrowth

One of the rarest but most insidious manifestations of wound dehiscence is ED.[73,74] This is a rare complication of cataract surgery. It can appear in three different forms (pearls, cysts, and sheets)[75] and has multiple presentations, including corneal decompensation, severe glaucoma with or without obvious angle closure, chronic anterior uveitis, and the presence of a retrocorneal membrane with a demarcated leading edge[74] (Fig. 48.7). The sheet-like presentation is the most common and is associated with more complications, like secondary glaucoma (caused by intense inflammation[76]) but also could be associated with hemorrhage and permanent vision loss. These cells can grow over different structures of the eye.[75]

The presence of ED can be identified by slit lamp (translucent growth, Seidel tests to identification of fistulas) with gonioscopy or by irradiating the affected iris with an argon laser. Using laser settings 100 to 200 µm, 100 to 200 mW[75,76] spot size, a white blanching is seen at the site of laser treatment as opposed to a standard burn or brown color change of the normal iris surface. ED can sometimes be diagnosed with specular endothelial microscopy; a sharp line can be seen separating endothelial cells, which are often abnormal in size and configuration) from dark, poorly defined cells representing the epithelium.[77,78]

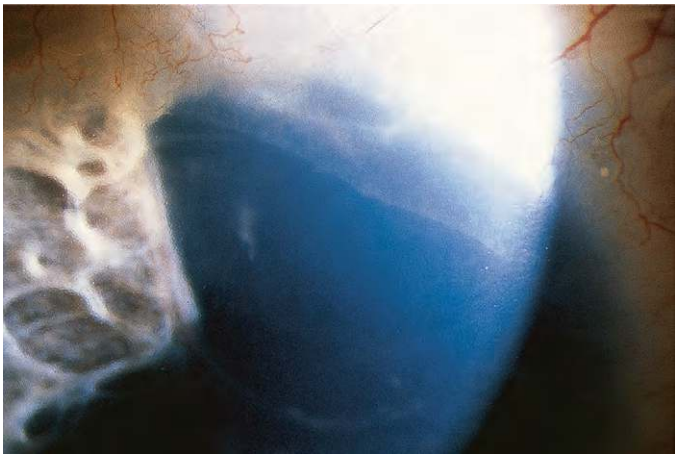

Fig. 48.7 Epithelial downgrowth with membrane on corneal endothelial surface 21 months after traumatic wound rupture. Note prominent leading edge. Diagnosis was confirmed by frozen section obtained at the time of iridocyclectomy.

Confocal microscopy is less affected by corneal edema, is more sensitive, and can differentiate fibrous and ED. When using anterior segment optical coherence tomography, the ED will show up as a hyperreflective layer. Definitive diagnose could be achieved by cytology (anterior chamber aspirate) with Papanicolaou staining, when free-floating cells are present, but the gold standard test is histopathologic analysis with identification of stratified bon-keratinized squamous epithelium.[75]

Another manifestation of ED is the presence of an intraocular cyst (Fig. 48.8).[79] This usually involves the iris and is often adherent to the posterior surface of the cornea. The cyst is slowly expansile and readily transilluminates. An epithelial implantation cyst can readily be transformed into true ED if the cyst is inadvertently lysed.[80]

The time of onset of ED is highly variable, but it typically presents within months of the surgery. It appears to be more common in patients who have undergone multiple procedures or in patients who have experienced postoperative complications with wound closure.

Patients with ED usually have nonspecific symptoms like pain, photophobia, and blurred vison. Signs can include corectopia and microcystic corneal edema.[76]

Definitive treatment of ED consists of complete destruction or excision of all intraocular epithelial tissue.

Surgical technique includes cryotherapy in potential combination with penetrating keratoplasty (PKP), Descemet's membrane endothelial keratoplasty, or fistula resection[75]; iridocyclectomy with excision of

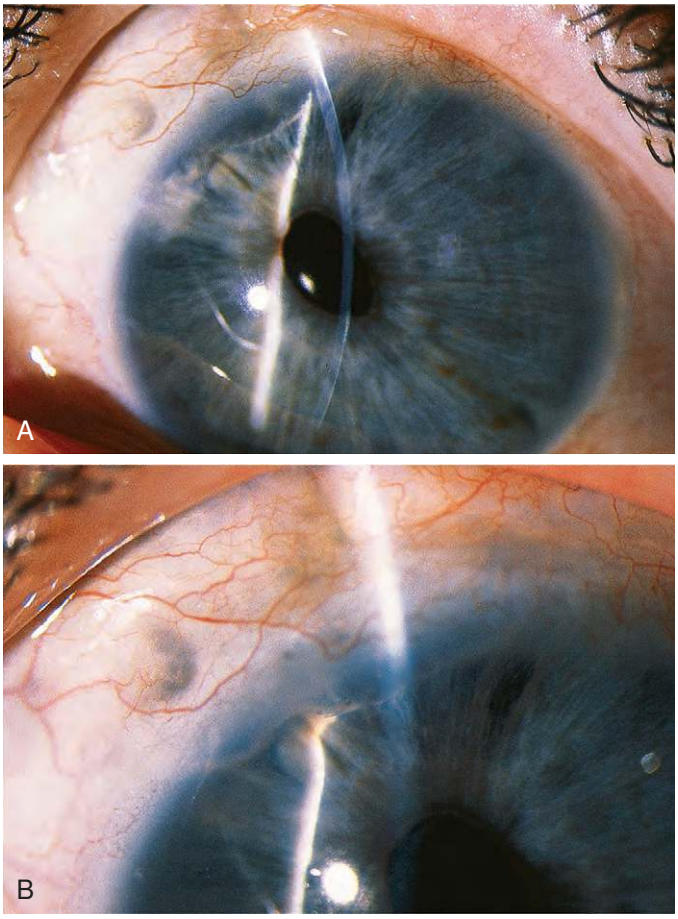

Fig. 48.8 (A) Iris epithelial cyst that was noted 18 months after IOL exchange and scleral flap recession. (B) High-magnification detail of the cyst. Patient has done well with 20/40 vision 18 months after iridocyclectomy and suture-fixation of a posterior chamber lens.

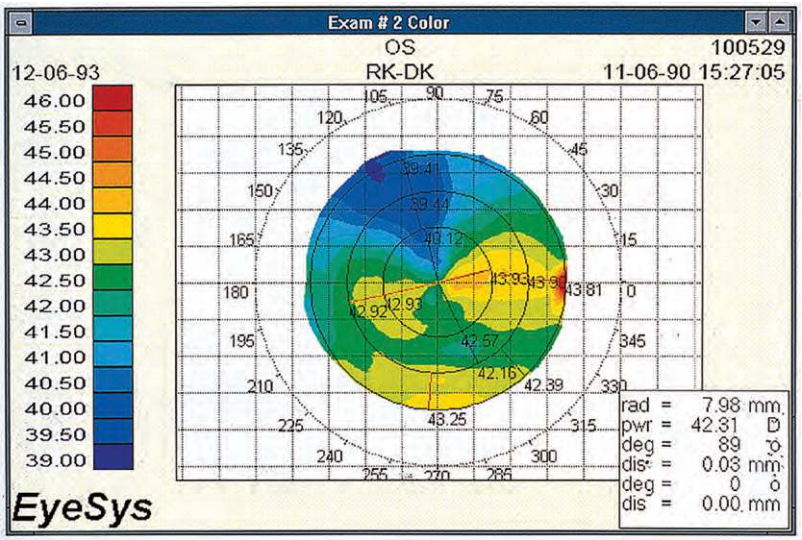

Fig. 48.9 Computerized videokeratographic map showing ATW astigmatism of 2.75 D 4 years after secondary IOL implantation through a superior 7-mm incision. Note asymmetric flattening greater in the semimeridian adjacent to the incision.

the internal corneal flap in the affected region; and pars plana vitrectomy with removal of all involved iris, CB, and lens with endolaser of any suspected involved areas.[28] Unfortunately, the prognosis is poor.[81]

Transcorneal photocoagulation with an argon laser has been used for the cystic form of ED and is a less invasive technique but could demand multiple sessions and increase IOP. Endoscopic coagulation using a diode laser is another technique specially in cases with cornea opacities. All photocoagulation techniques, if not eliminating the cyst, could lead to its rupture with further progression of the diffuse form of ED.

Intracameral injection of 5-fluorouracil (5-FU) and mitomycin-C (MMC) also have been reported as treatments.[75]

Although cataract surgery seems to be the most important causes of ED, PKP, on the other hand, seems to be the most frequent cause of FI.[76] FI is the abnormal invasion of the anterior chamber by connective tissue from the incision.[82–84] This condition is uncommonly diagnosed clinically, and it occurs in eyes with deficient wound closure, possibly in the presence of abnormal endothelium. Similar to ED, the symptoms for FI are likewise nonspecific. Clinically, by slit-lamp biomicroscopy, FI appears as a thick, opaque membrane on the posterior surface of the cornea. Vascularization is sometimes evident.[76] It is typically detected histopathologically in tissue from eyes that have undergone incisional repair or in enucleated specimens.

The main differences of FI from ED are as follows:

- FI is usually vascular with an obvious fibrous appearance.
- FI tends to be slower growing and more clearly demarcated than ED.
- FI typically causes less visual impairment.
- Glaucoma with FI is often less aggressive.
- FI can evolve to a quiet scar.
- Treatment options are similar for both pathologies, but bevacizumab has been reported as a treatment for FI.

Long-Term Flattening Along the Meridian of the Incision

Large (>6 mm) superior corneal, limbal, and anterior scleral incisions can produce an ongoing flattening along the meridian of the incision, greatest adjacent to the incision (Fig. 48.9). Although not a true dehiscence per se, it occurs because of poorer wound integrity compared with virgin tissue. Treatment is ablative corneal refractive surgery or contact lens wear, as attempts to repair and resuture the incision produce initial excessive steepening followed by recurrence of flattening.

SUMMARY

Compromise of wound integrity is a relatively uncommon but potentially devastating complication of cataract surgery. It has multiple manifestations and causes, requiring a wide spectrum of therapeutic responses. It is an evolving area because of advances in wound-construction techniques, particularly, the conversion to CCIs of diminishing size with improved incision design. Advances in multiple areas, including techniques of wound construction, phacoemulsification machine design, femtosecond lasers, and small-incision IOLs, will further reduce the incidence and complications of wound compromise.

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Surgical Instrument Care and Toxic Anterior Segment Syndrome

Phillip Qu and Nick Mamalis

CONTENTS

KEY POINTS

- All personnel involved in the handling of intraocular surgical instruments should adhere to established protocols to ensure that the instruments are safely prepared for use.
- Although many general principles of cleaning and sterilization of surgical instruments apply to intraocular instruments, there are important distinctions that must be made because of the unique characteristics of the eye and intraocular surgery.
- Some important considerations include the risks of routine enzymatic detergent and ultrasonic water bath use.
- In cases of acute postoperative inflammation, surgeons must quickly differentiate TASS from bacterial endophthalmitis.
- When a case of TASS is recognized, it is important to identify the cause to prevent more cases from occurring. The most commonly identifiable cause of TASS is inadequate cleaning and sterilization of surgical instruments.

INTRODUCTION

Toxic anterior segment syndrome (TASS) and postoperative endophthalmitis (POE) are rare, but potentially blinding, complications of cataract surgery. TASS is caused by the introduction of a toxic, noninfectious substance into the anterior chamber.[1] POE is caused by the propagation of an infectious pathogen, most commonly bacteria, inside the eye.[2] The risk for both conditions can be minimized with proper care of intraocular surgical instruments.

Although most general recommendations for surgical instrument care also apply to intraocular instruments, some accepted practices may be dangerous for patients undergoing cataract surgery because of unique characteristics of the eye and intraocular surgery. This issue of patient safety was recognized and addressed with the formation of the Ophthalmic Instrument Cleaning and Sterilization (OICS) Task Force. Composed of representatives from the American Society of Cataract and Refractive Surgery (ASCRS), American Academy of Ophthalmology (AAO), and Outpatient Ophthalmic Surgery Society (OOSS), the OICS Task Force collaborated on a set of specialty-specific guidelines outlining minimum standards of intraocular surgical instrument care.[3]

- Improper surgical instrument care is the most common identifiable cause of TASS, which is an acute, sterile, postoperative inflammatory response to a toxic substance in the anterior chamber.[4]
- Unlike POE, the inflammation in TASS is sterile because the toxic substance is not a microbial pathogen.
- Specific inciting substances that have been identified in cases of TASS include enzymatic detergents, bacterial endotoxins, denatured ophthalmic viscoelastic devices (OVDs), ocular medications, preservatives, and intraocular solutions incompatible with eye tissue preservation.[4]
- Common exam findings include diffuse "limbus-to-limbus" corneal edema, severe anterior segment inflammation, and fibrin formation.
- The goal of treatment is to suppress inflammation and prevent long-term inflammatory sequelae with intense topical corticosteroid therapy.[1,5]
- A thorough investigation of the source of contamination should commence once a case of TASS is discovered to prevent more cases from occurring.[1,5]

This chapter reviews guidelines for surgical instrument care and clinical information on TASS.

SURGICAL INSTRUMENT CARE

All intraocular instruments used during cataract surgery are critical items and must be cleaned and sterilized. Because of the small size of the eye, intraocular instruments rank as some of the smallest surgical instruments. Because of the nature of surgery, used cataract surgical instruments carry a low tissue and bacterial burden compared with procedures on other body parts. The eye's small size and sensitivity to toxins make it especially susceptible to both iatrogenic and infectious contaminants.[3] Even trace amounts of toxins that might be well tolerated in other body cavities can cause TASS in the eye.[6,7] As a result, some accepted instrument care practices should be avoided or used with caution for cataract surgeries. Lastly, cataract surgery can be performed quickly and at high volumes relative to most other surgical procedures. Consequently, efficient instrument turnover must be accomplished while maintaining the integrity of the sterilization process. This chapter focuses on recommendations intended to maximize the sterility of intraocular surgical instruments while minimizing the risk for introducing toxic substances to the eye which can cause TASS.

General Principles

There are many steps that must be taken before the actual processing of instruments to prevent future surgical complications.

- All surgical facilities should establish a set of clearly written protocols for instrument cleaning and sterilization.
- During the creation of these "policies and procedures," input from all groups of personnel involved in the handling of surgical instruments should be considered.
- Written protocols should be derived from current industry standards and manufacturer's instructions for use (IFU).
- Given the diversity of ophthalmic surgical products and instruments, physicians and nursing staff should be able to adjust written protocols with guidance from the best available clinical evidence.
- Upon completion, the written protocols should be approved by the facility's governing body.
- Updated facility protocols and equipment IFUs should be made readily available to all operating room (OR) and instrument processing staff.
- The policies and procedures should be reviewed annually and when any new instruments or equipment is acquired.[8,9]

After cleaning and sterilization protocols are established, all personnel involved in the handling of surgical instruments should be educated on the general principles of asepsis and trained on the proper mechanics of intraocular instrument processing.

- This training should cover cleaning, inspection, preparation, packaging, sterilization, storage, and distribution of relevant instruments or machines.[8,9]
- Appropriate personnel should also undergo any other training needed to do their job, such as the operation and maintenance of machines.
- Continued competency should be checked with performance evaluations completed annually and whenever any new instruments or equipment are acquired. The results of the competency evaluations should be recorded and saved for future reference.[8,9]

TASS and POE are rare, but significant, postoperative complications of cataract surgery that may be attributed to improper instrument processing. OR staff should understand the causes and precautionary measures that can be taken against both conditions. A facility's incidence of TASS and POE should be tracked to judge the effectiveness of the written protocols and the successful completion of the described procedures.[3] An increase in frequency of either condition necessitates an early and thorough investigation to find the cause to prevent a larger outbreak. The investigation should include a review of medication, instrument, and equipment use, as well as maintenance and inspection records.[1,5,8,9] Hence, accurate documentation consistent with facility policies can help prevent more cases of TASS and POE.

Cleaning Surgical Instruments (Fig. 49.1)

Cleaning is the removal of "soil" from objects and is required before disinfection or sterilization. This process removes any foreign material that may interfere with the effectiveness of disinfection or sterilization.[10,11] To limit the risk for cross-contamination, there should be a central processing area divided with physical barriers into at least three areas designated for instrument cleaning and decontamination, instrument packaging, and instrument sterilization and storage. It is recommended that ophthalmic instruments should be processed and stored in an area separate from nonophthalmic instruments.[3]

During ophthalmic instrument cleaning, multiple steps can be taken to ensure adequate removal of all residues, including OVD.[1,5]

- Debris that has been allowed to dry on the surface of instruments is especially difficult to remove[11]; therefore contaminated instruments should be soaked or rinsed soon after use.[1,5]
- Devices should also be wiped with a damp, lint-free cloth or scrubbed with a soft brush if indicated by the manufacturer's IFU.[9]
- Upon completion of cleaning, instruments should be inspected to confirm the absence of visible deposits. It may be determined on an instrument-by-instrument basis that some cleaning steps must be repeated to achieve adequate material removal.[12]

The act of rinsing and flushing ophthalmic instruments with water is especially important for removing debris from small lumens that may be difficult to access with a cleaning instrument.

- Lumened equipment such as phacoemulsification and irrigation/aspiration (I/A) handpieces can be placed in sterile water baths to prevent OVDs from drying and should be cleaned and flushed promptly after use as described in the instrument manufacturer's IFU.[8,9] The manufacturer's IFU should specify the water volume and type.
  - A common recommendation for many intraocular instruments is to use critical water (sterile distilled, reverse osmosis, or deionized) for the cleaning and final rinsing of reusable instruments.[1,5]
- It is also recommended to flush 120 mL of critical water through each port of both the phacoemulsification and I/A handpieces.
- Instruments with lumens should be flushed starting in the OR and finished in the decontamination area.[9]
- All effluent from flushing should be directed into a separate container with special care taken to minimize splashing and aerosolization to decrease the spread of contaminants.

Instrument cleaning procedure	Recommendation
Immediate soaking, rinsing, and flushing with adequate amount of critical water	This is the ideal cleaning procedure and has been shown to be both safe and effective. Immediately soaking instruments prevents substances from drying on the instrument surface. Rinsing instruments and flushing lumened equipment with at least 120 mL of critical water removes any remaining debris.
Use of enzymatic detergents	Not recommended. Enzymatic detergents can cause TASS. Complete removal of detergent residues can be difficult. The benefits are diminished by the minimal bioburden retained on ophthalmic instruments.
Use of ultrasonic cleaners	Not recommended. Ultrasonic cleaners can harbor bacterial endotoxins, which can cause TASS. If an ultrasonic cleaner is required, it is recommended that the unit is cleaned appropriately between uses.

Fig. 49.1 Recommendations for common instrument cleaning procedures.

- Likewise, any water baths used for soaking soiled instruments should be distanced from the sterile field.[3]

Cleaning utensils, such as syringes or brushes, should be handled in a similar fashion to the surgical instruments. Reused cleaning utensils should be inspected after cleaning for visible contamination or damage and be cleaned and disinfected between each use.[13] Facilities might also weigh the costs and benefits of implementing single-use cleaning tools.

Enzymatic Detergents

The use of enzymatic detergents to decontaminate intraocular surgical instruments is controversial. These detergents contain enzymatic proteins such as proteases, amylases, or lipases to hydrolyze organic tissue.[11] The utility of enzymatic detergents in debulking biomaterial on surgical instruments is widely recognized, and many manufacturer's IFU for intraocular instruments and ultrasonic cleaning baths recommend the use of enzymatic detergents to supplement other cleaning procedures. Because of the small amount of bioburden retained on intraocular instruments after cataract surgery and the sensitivity of ocular tissue, the benefits of enzymatic detergents may be negligible, and even harmful, when applied to intraocular instruments.[3]

The dangers of enzymatic detergents to ocular structures have been well documented.

- Both animal and human studies have demonstrated the dose-related toxicity of enzymatic detergents to the corneal endothelium.[7,14,15]
- Outbreaks of TASS have also been linked to the use of enzymatic detergents before inadequate rinsing and flushing of surgical instruments.[4,16]
- Rabbit studies performed at the Moran Eye Center showed that even trace amounts of enzymatic detergent were capable of inducing TASS-like responses, including severe anterior segment inflammation with fibrin formation within 72 hours after the intraocular administration of detergent.[6] The study determined a positive correlation between the concentration of enzymatic detergent injected into the anterior chamber and the degree of anterior segment inflammation.
- Similarly, postmortem corneal vital staining confirmed a dose-related endothelial toxicity after exposure to various concentrations of enzymatic detergent.

Compounding their deleterious effects on the eye, enzymatic detergent residues can persist on the surfaces of intraocular instruments even after thorough flushing and rinsing.

- Intraocular surgical instruments are necessarily small and delicate, and many instruments are designed with small-diameter lumens. These characteristics hinder the cleaning process and make the complete removal of enzymatic detergent difficult.
- One study from the Moran Eye Center used scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) to detect residual detergent on the surface of phaco tips that were soaked in an appropriately diluted enzymatic detergent solution and sterilized.[17]
  - Even after thoroughly flushing and rinsing the instruments with sterile water before sterilization, small amounts of detergent remained on the phaco tips.
  - Thus, even after adequate rinsing and flushing, minute enzyme residues can persist on the surfaces of intraocular instruments.

Sterilization, which follows the cleaning of surgical instruments, is ineffective in neutralizing the dangers of enzymatic detergents.

- The subtilisin (protease) and alpha-amylase enzymes commonly found in enzymatic detergents remain stable up to a temperature of 140°C, although autoclaves typically only reach a maximum temperature between 120°C and 130°C.[7]
- Because autoclave sterilization does not denature the enzymes and thorough cleaning does not always eliminate detergent residues, the use of enzymatic detergents is a risky practice that can expose patients to a harmful substance.
- The main role of enzymatic detergents is to help remove bulk biomaterial, but this can be effectively and safely completed by manual irrigation.
- The OICS Task Force determined that the use of enzymatic detergents is superfluous in removing the minimal accumulated material on surgical instruments. Instead, intraocular surgical instruments can be adequately debulked with prompt moistening before thorough rinsing and flushing with sterile water.[3]

Despite the potential risks of using enzymatic detergents to clean ophthalmic surgical instruments, their use is still recommended by many instrument manufacturers. Therefore the avoidance of using enzymatic detergents in the cleaning process is considered off-label and may violate the policies of the Centers for Medicare and Medicaid Services (CMS) or other regulatory agencies. To reconcile this discrepancy between policy and patient safety, the OICS Task Force appealed to intraocular surgical instrument manufacturers to approve alternate cleaning methods that exclude the use of enzymatic detergents. The OICS Task Force[3] concluded:

> *We are not aware of any study showing that enzyme detergent for intraocular instruments reduces the rate of endophthalmitis. Lacking proven efficacy for endophthalmitis prevention, enzymatic detergents might unnecessarily elevate the risk for TASS without providing significant benefit to the patient. It is our position that, if intraocular surgical instruments are thoroughly rinsed with critical water promptly after each use, the routine use of enzyme detergents is unnecessary and should not be required for routine decontamination of ophthalmic intraocular instruments.*

Ultrasonic Cleaners

The ultrasonic instrument cleaner is another commonly used cleaning tool that is a risk factor for TASS.[3] Using waves of acoustic energy through an aqueous medium, an ultrasonic cleaner displaces matter from the surfaces of submerged surgical instruments.[11] Like enzymatic detergents, ultrasonic cleaners are designed to reduce the bioburden on surgical instruments while also potentially introducing contaminants that can cause TASS. Ultrasonic cleaners, water baths, autoclave reservoirs. and other infrequently exchanged reservoirs of water can harbor endotoxin-generating gram-negative bacteria.[1,18,19] Although the organisms are destroyed during autoclave sterilization, the heat-stable endotoxins endure and have been linked to outbreaks of TASS.[18,20] The ideal method for removing debris and biologic material is by moistening used surgical instruments before adherent substances become dry and then adequately rinsing and flushing the instruments with sterile water.[3] If instruments are vigorously rinsed and flushed, the use of ultrasonic cleaners is unnecessary.

If the use of ultrasonic cleaners is indicated by the instrument manufacturer's IFU, certain precautions should be made to minimize the risk for bacterial colonization. Cleaning units used for ophthalmic instruments should be used strictly for ophthalmic instruments and physically distanced from units used to clean other surgical instruments.

Technicians operating the ultrasonic cleaners should also perform a daily maintenance routine that includes draining, cleaning, disinfecting, rinsing, and drying the units.[18,20] Preferably, an Environmental Protection Agency-registered disinfectant should be used and followed by rinsing with an adequate amount of critical water to remove any residual

disinfectant.[3,21] A final rinse of the cleaning compartment with 70% to 90% ethyl or isopropyl alcohol can displace endotoxins from the bath walls[22] and should be considered if not contraindicated by the manufacturer's IFU. Finally, the machine should be dried with a lint-free cloth and cleaned before its next use as instructed by the manufacturer's IFU.[13,21,22]

Sterilizing Surgical Instruments

Sterilization is the process that eliminates all microbial life from surgical instruments; therefore it is essential for infection control in a surgical facility. Technicians should clean instruments of any visible "soil" before sterilization so that the sterilization process is not compromised.[11] The main components of the sterilization process are the instruments in need of sterilization, the packaging system that contains the instruments, and the sterilizer. The method of sterilization should be compatible with recommendations for the surgical instruments and packaging. For steam sterilization, instruments need to be packaged appropriately, exposed to an adequate temperature for a specified amount of time, and allowed to dry. Before sterilization, all components should be in proper condition as described by the manufacturer's IFU. For example, hinged instruments should be in the open position, and multipiece instruments should be deconstructed. Packaging material should be carefully inspected for gross damage, and the sterilization machine should be in working condition.[11] Confirmation of sterilizer effectiveness should be performed with biologic indicators as described by the manufacturer's IFU.[8,9] The results should be documented and saved for future reference. Sterilizers should receive scheduled inspection, cleaning, and maintenance as described by the manufacturer's IFU, and their completion should be documented as well.[8,9]

Different sterilization cycles can be used for ophthalmic surgical instruments.

- For instruments that will be stored for future use, a terminal, wrapped sterilization cycle should be performed.
- Cataract surgeries are often performed consecutively during a single day and, when scheduled in this manner, are considered *same-day sequential* ophthalmic procedures.[23]
- Short-cycle steam sterilization is an acceptable terminal sterilization cycle that facilitates faster instrument turnover while returning instruments to a safe and usable condition.
- Short-cycle sterilization should not be confused with immediate-use steam sterilization (IUSS), which is used for instruments that are needed immediately and includes minimal to no instrument drying time.[24]
- In 2014, the CMS replaced the antiquated term "flash" sterilization with IUSS and confusion over the difference between IUSS and short-cycle sterilization ensued.
- In 2015, the CMS clarified that short-cycle sterilization is a distinct entity that is acceptable for routine use when performed according to manufacturer's IFU.[24]

TOXIC ANTERIOR SEGMENT SYNDROME (TASS)

TASS is an acute, sterile, postoperative inflammatory response to a toxic substance in the anterior chamber. TASS can be easily confused with POE because both entities involve intraocular inflammation in the acute postoperative time frame. Some findings more typical in TASS include onset within 12 to 48 hours after surgery, negative Gram stain and culture, inflammation primarily in the anterior chamber, and clinical improvement after steroid therapy.[1,5] Rapid identification of the cause of inflammation is critical, as the treatments for TASS and POE are fundamentally different. The mainstay of treatment for TASS is topical corticosteroid therapy,[5] while treatment for POE requires the clearance of the infecting organisms either medically or surgically.[2] Although most cases of TASS resolve with treatment, severe cases may cause permanent damage to various structures in the anterior chamber that can lead to blindness.[1,5] After a diagnosis of TASS has been made, the surgeon should attempt to identify the inciting agent to prevent further outbreaks. It is important that personnel who handle ophthalmic surgical instruments learn about the causes of TASS and diligently remove potential contaminants to minimize the risk for this rare surgical complication.[3]

Background

The expression *toxic anterior segment syndrome* was coined by Monson et al. in 1992 when the authors described three cases of acute postoperative inflammation with negative cultures.[25] Other terms that have been used to describe TASS in the past include *sterile postoperative endophthalmitis* and *toxic endothelial cell destruction syndrome*.[1] Fortunately, TASS is a rare surgical complication with a reported incidence of 0.22% (60 out of 26,408 eyes) after cataract surgery.[26] TASS often affects patients in clusters that can be traced back to a shared contaminant.[1,4,5] It is believed that TASS is caused by toxic substances that are introduced into the anterior chamber during or after intraocular surgery.[5] Although TASS is most commonly reported after cataract surgery, it can occur after any procedure that requires intracameral access, including keratoplasty, posterior segment surgery, and intravitreal injection.[27–29] TASS should be included in the differential diagnosis for patients who present with acute inflammation after any invasive procedure.

Clinical Presentation

TASS is an acute, inflammatory process that usually presents within 12 to 48 hours after intraocular surgery. There is a severe inflammation primarily limited to the anterior segment. Further workup will always show Gram stain and culture negativity, and treatment with steroids results in clinical improvement. Patients with TASS commonly report blurry vision and eye redness. The absence of pain is more common in TASS, while approximately 75% of POE patients report pain.[1] Because patients with POE may have similar complaints, making an accurate diagnosis can be a challenge, and clinicians should be aware of several key features that can help differentiate between the two conditions.

The timing of TASS usually occurs earlier than POE.

- In TASS, intraocular inflammation usually begins within 12 to 48 hours after surgery.
- Patients with POE usually present 2 to 7 days after surgery or later. It is important to note, however, that the time of presentation of these conditions can vary.
- Atypical presentations of TASS have been reported with a delayed onset of inflammation, although some especially virulent infections may manifest within 48 hours.[1,5]
- Correlation of the onset of inflammation with other clinical findings helps identify the underlying condition.

Common exam findings in TASS include "limbus-to-limbus" corneal edema (Fig. 49.2) and signs of anterior segment inflammation. The diffuse corneal edema is caused by extensive endothelial damage and is usually focal or absent in POE. Signs of intraocular inflammation such as hypopyon (Fig. 49.3), fibrin, and cell and flare are characteristic of

BOX 49.1 Clinical Pearls

- The most common characteristics of TASS include:
  - "Limbus-to-limbus" corneal edema
  - Signs of severe anterior segment inflammation (aqueous flare and inflammatory cells in the anterior chamber with possible hypopyon)
  - Signs of iris and trabecular meshwork damage
- Presentation within 12–48 hours after surgery

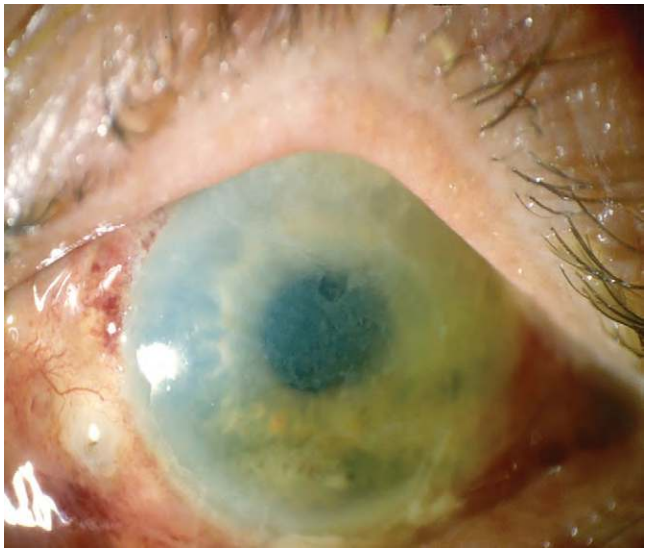

Fig. 49.2 Classic finding of diffuse "limbus-to-limbus" corneal edema. Reprinted with permission from Mamalis N, Edelhauser HF, Dawson DG, Chew J, LeBoyer RM, Werner L. Toxic anterior segment syndrome. *J Cataract Refract Surg*. 2006;32(2):324–333.

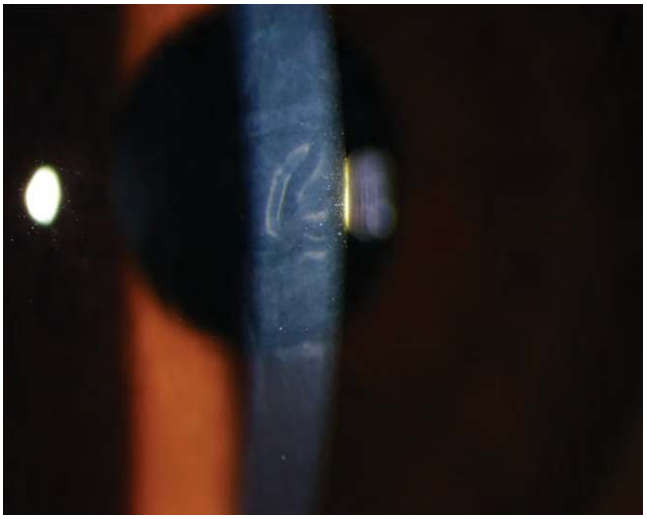

Fig. 49.4 Descemet's membrane folds.

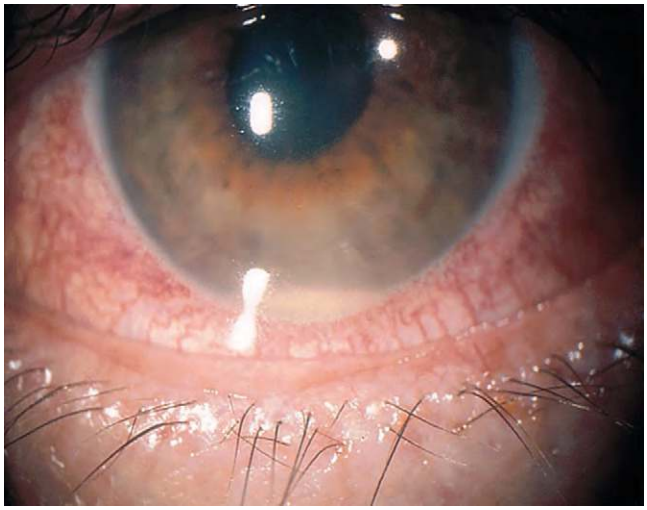

Fig. 49.3 Hypopyon formation. Reprinted with permission from Mamalis N, Edelhauser HF, Dawson DG, Chew J, LeBoyer RM, Werner L. Toxic anterior segment syndrome. *J Cataract Refract Surg*. 2006;32(2):324–333.

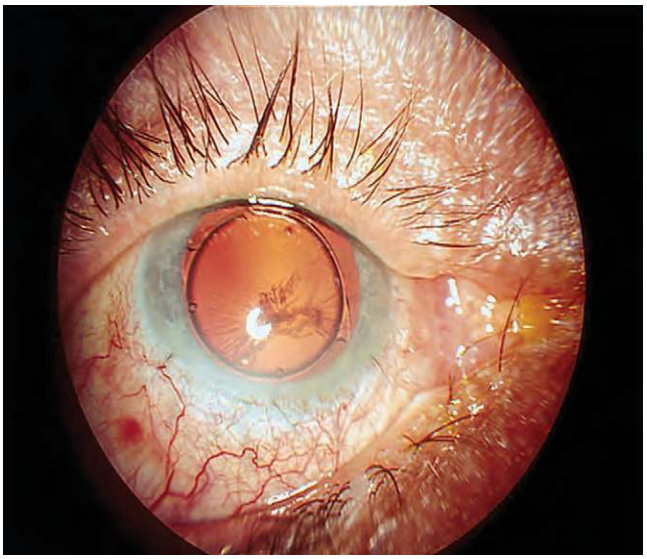

Fig. 49.5 Dilated and slightly irregular pupil. Reprinted with permission from Mamalis N, Edelhauser HF, Dawson DG, Chew J, LeBoyer RM, Werner L. Toxic anterior segment syndrome. *J Cataract Refract Surg*. 2006;32(2):324–333.

both TASS and POE, but the location of inflammation is an important clue. Patients with TASS present with severe inflammation primarily in the anterior segment. These findings may include Descemet's membrane folds (Fig. 49.4) or signs of iris damage with a subsequent fixed, dilated pupil after surgery (Fig. 49.5). In addition, trabecular meshwork damage may result in a delayed-onset glaucoma that may be difficult to control.[1] POE typically involves the entire eye and shows much greater inflammation of the vitreous.

In severe or ambiguous cases of postoperative inflammation, additional testing may be necessary to determine the diagnosis. Gram stain and culture of the anterior chamber and vitreous can confirm the presence or absence of an infectious organism. Unfortunately, some cases of infectious endophthalmitis are Gram stain and culture negative.[30] The use of B-scan ultrasonography may also be useful in assessing the posterior segment in patients with a limited view. Physicians should always use the entire clinical picture to guide their decision-making.

Atypical reports of TASS show that there is still much to be learned about this disease entity. Literature indicates that delayed-onset TASS may be more common than previously thought.

- Two reported outbreaks of delayed-onset TASS were attributed to residual aluminum polishing compounds on the surfaces of intraocular lenses (IOLs).
- Jehan et al. reported a series of 10 cases of TASS after placement of a hydrophilic acrylic IOL (MemoryLens, models U940A and U940S, CIBA Vision). These cases presented with TASS on average 7.8 days after cataract surgery with a range of 1 to 21 days.[31]
- Miyake et al. presented a series of 6 cases of TASS after placement of a hydrophobic acrylic IOL (iSert, model 251, Hoya Surgical Optics). After placement of the IOL, the onset of TASS ranged from 42 to 137 days.[32]

- Sato et al. reported five cases of TASS after intravitreal bevacizumab injections. The authors described inflammation in both anterior and posterior segments that occurred 2 to 4 days after injection.[29]
- Given the variability in timing and findings of these uncharacteristic cases, physicians should consider TASS even if the presentation differs from the classic description.

The ASCRS created a TASS Task Force to analyze new cases of TASS and further characterize the condition. It is important that clinicians report identified cases of TASS to the task force so that it can investigate the cause and prevent an outbreak in the short term while gathering information to develop a greater understanding in the future. The TASS Registry website (https://ascrs.org/tools/tass-registry) developed by the TASS Task Force provides useful information and a voluntary questionnaire for clinicians reporting a case of TASS.

Treatment and Clinical Course

In TASS patients, the goal of treatment is to quiet the inflammatory reaction and minimize damage to ocular tissue. Rapid diagnosis and treatment and consistent follow-up help to prevent serious sequelae such as corneal decompensation, secondary glaucoma, fixed pupil, and cystoid macular edema (CME).[1]

The mainstay of TASS treatment is an intensive regimen of topical corticosteroids.

- Prednisolone acetate 1% drops every 1 to 2 hours has proven to be an effective initial choice of treatment.[5] Dexamethasone 0.1% has also been reported to successfully treat TASS and is a suitable alternative.[33]
- Topical nonsteroidal antiinflammatory drugs (NSAIDs) may also reduce inflammation and help prevent CME in addition to providing analgesia.
- After starting treatment, slit lamp examinations should begin soon and be repeated frequently. Clinicians should perform the first slit lamp exam within a few hours after topical steroid therapy is initiated to evaluate any change in inflammation.
- Follow-up exams over the next several days should be conducted to confirm an improvement of the patient's clinical findings.
- During the exam, intraocular pressure (IOP) should be noted as it can fluctuate. Low IOP is common soon after the initial insult, but it can increase rapidly as the eye recovers. IOP measurements also help monitor for the development of secondary glaucoma.
- Anterior chamber washout is not recommended in most cases of TASS, but, if residual material can be seen in the eye, anterior chamber washout may be considered.
- After improvement of the initial inflammation, follow-up exams should include specular microscopy to evaluate the corneal endothelium and gonioscopy to evaluate the anterior chamber angle and trabecular meshwork.[1,5]

If topical corticosteroids do not adequately control inflammation, several measures should be considered.

- Oral prednisolone up to 40 mg per day may help control inflammation in severe cases of TASS.[32]
- Dotan et al. treated 40 patients with severe fibrin formation refractory to topical steroids with intracameral recombinant tissue plasminogen activator. He reported that 95% of the patients showed a complete resolution of fibrin reaction 1 month after injection.[34]
- Because a case of severe TASS can be difficult to distinguish from POE, repeat cultures or initiation of a broad-spectrum antibiotic such as moxifloxacin should be considered.[33]

The clinical course of TASS depends on the degree of toxic damage. Important prognostic factors include type of toxicity, duration of exposure, and time before initiation of appropriate treatment. Most cases are mild and resolve soon after beginning treatment. Moderate cases may have a delayed resolution of inflammation and corneal edema. Patients with severe TASS may experience permanent corneal damage or severe glaucoma and require surgical intervention.

Secondary conditions after an episode of TASS can significantly affect vision and require further treatment. Corneal decompensation leading to permanent corneal edema may require corneal transplantation.[35,36] Secondary glaucoma caused by damage to the trabecular meshwork may require glaucoma medication and surgery.[1,5] Nizamani et al. reported a series of 14 patients who developed Urrets-Zavalia Syndrome after TASS.[37] Urrets-Zavalia Syndrome is a postoperative complication in which patients exhibit fixed, dilated pupils. CME can also occur after TASS and require intraocular steroids or antivascular endothelial growth factor injections.[38]

Etiology and Recommendations

TASS is caused by toxic materials that enter the eye during the intraoperative and perioperative time frames. Although the inciting agent is often unable to be identified, many materials have been shown to cause TASS, and precautions against these known dangers should be taken. Specific TASS-causing substances that have been identified include enzymatic detergents, bacterial endotoxins, denatured ophthalmic viscoelastic devices (OVDs), ocular medications, preservatives, and intraocular solutions incompatible with eye tissue preservation.[4] Site visits conducted by the TASS Task Force have identified inadequate cleaning and sterilization of ophthalmic instruments as the most common behavior associated with TASS. Specifically, insufficient flushing of phacoemulsification, I/A handpieces, and lumened equipment occurred at 89% of the sites.[16] The "Surgical Instrument Care" section details precautions that should be taken when preparing ophthalmic instruments.

Enzymatic detergents, bacterial endotoxins, and OVD are common contaminants that can remain on instruments after inadequate cleaning. The widespread usage of enzymatic detergents and ultrasonic cleaners during cleaning was also observed by the TASS Task Force, and the risks are discussed in the "Cleaning Surgical Instruments" section.16 The OVD used during cataract surgery has also been reported to cause TASS. Removal of OVDs from surgical instruments before sterilization is important because residual OVDs can denature during sterilization into a toxic substance.[39] In addition, reports have linked OVDs contaminated by endotoxins to cases of TASS. Some varieties of OVDs are manufactured by bacterial fermentation, and the OVD can trap endotoxins that are also produced. Because of these complications, the need for regulation on endotoxin limits in OVDs has been voiced.[33,40] After instruments are used, they should be moistened with sterile water before the OVD is allowed to dry and then vigorously flushed and rinsed.[8,9] The instruments should then be inspected to ensure all traces of OVD have been removed before sterilization.

Ocular medications have also been implicated in cases of TASS.

- Intracameral medications that are improperly mixed can cause TASS resulting from pH or osmolality that is incompatible with ocular tissue preservation.[41–43]
- Inadvertent injection of high-dose (20 mg/0.5 mL) gentamicin has been reported to cause severe TASS.[44]
- Intravitreal injection of bevacizumab has been reported to cause TASS with more pronounced posterior segment clinical findings.[29]
- TASS has also been reported after the use of postoperative ophthalmic ointment which entered the anterior chamber.[35]
- The preservative benzalkonium chloride (BAK) has been shown to be highly toxic in the eye. BAK has been reported to cause severe TASS, and rabbit studies have demonstrated the development of

TASS-like findings after the introduction of BAK into the anterior chamber.[45–47] Care should be taken that products containing BAK do not enter the anterior chamber.

The source of contamination can even be far outside the surgical facility. Multiple outbreaks have been traced back to a single IOL manufacturer; it is believed that errors in the manufacturing process left residual aluminum compounds on the IOL that caused the outbreaks of TASS.[31,32] Thus TASS can be caused by the introduction of toxins anywhere from the location of material manufacture to the OR. It would be impossible to identify the causative agent in every case of TASS, but great efforts should be made to prevent harm to additional patients. The investigation is more efficient if detailed records have been consistently kept so that any recent changes or oversights can be easily identified. To prevent TASS, all personnel who handle surgical instruments should learn about the disease and diligently minimize risks for contamination.[1,5]

SUMMARY

Proper surgical instrument care is essential before every cataract surgery and is the best way to prevent TASS. The cleaning and sterilization of surgical instruments can be complicated, but the process should be approached in a standardized manner. With a holistically developed protocol and its scrupulous completion by medical personnel, ophthalmic instruments can be prepared for surgery safely and efficiently. Cataract surgeons should recognize that the practice of adequately flushing and rinsing surgical instruments with sterile water makes the use of enzymatic detergents and ultrasonic cleaners unnecessary. Surgeons should be aware that there are many other potential contaminants that can cause TASS. Although TASS is a rare surgical complication that usually resolves, prompt recognition and treatment of the disease can prevent sequelae that can significantly impair the patient's vision. Once a case of TASS has been identified, an earnest effort should be made to identify the cause to prevent further harm. A thorough understanding of both surgical instrument care and TASS can minimize risks and improve outcomes of cataract surgery.

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PART VIII

Postoperative Complications

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50

Corneal Edema After Cataract Surgery

Cassandra C. Brooks and Preeya K. Gupta

CONTENTS

KEY POINTS

- The etiology of postoperative corneal edema is broad.
- Thorough preoperative evaluation can help elicit patients at higher risk for postoperative corneal edema.
- Corneal edema can lead to acute and chronic changes in visual acuity and to eye pain.
- Management is tailored to the patient's specific cause of corneal edema but can involve hypertonic solutions, antiinflammatory therapies, Descemet's membrane reattachment, intraocular lens (IOL) exchange, and/or corneal transplantation.

INTRODUCTION

Corneal edema after cataract surgery is not uncommon and is typically localized around corneal incisions. More significant corneal edema after cataract extraction is an uncommon but well-known complication of cataract surgery. The most severe form of irreversible corneal edema, referred to as *pseudophakic bullous keratopathy* (PBK), occurs in about 1% of patients after traditional cataract surgery but can climb to 11% to 24% in patients with <1000 endothelial cells/mm^2. Postoperative corneal edema can vary in location from superficial epithelial swelling to full-thickness edema. Though most postoperative edema will resolve with time, a variety of management options can be employed to expedite and increase the likelihood of recovery. Management of postoperative corneal edema is critical in achieving optimal patient satisfaction and anatomic outcomes.

This chapter reviews the differential diagnosis and treatment of corneal edema after cataract surgery. Chapter 37 addresses combined corneal and cataract surgery in patients with preoperatively compromised corneas.

CAUSES

A variety of risk factors are associated with reduced endothelial cell density and resultant postoperative corneal edema. Given that the central endothelial cell density has been shown to decrease by as much as 8.4% at 1 year after phacoemulsification cataract surgery, it is imperative to identify patients at increased risk for corneal decompensation to potentially avoid, or expeditiously treat, corneal edema.[3] Table 50.1 lists the principal risk factors and causes of postoperative corneal edema after cataract surgery.

PREOPERATIVE

Advanced Age

Endothelial cell density decreases physiologically with time (Table 50.2).[4,5]

Ethnicity

Variation in endothelial cell counts by ethnicity have been reported, with lower cell counts in Japanese, American, Chinese, and Filipino eyes, while higher counts have been identified in Indian, Thai, and Iranian eyes.[7–11]

Medications

Systemic medications, such as amantadine used for Parkinson's disease, and topical medications, such as carbonic anhydrase inhibitors, can affect endothelial cell function.[12–14]

Systemic Diseases

Medical conditions such as chronic obstructive pulmonary disease, diabetes mellitus, and renal insufficiency are associated with decreased endothelial cell count and function.[15–18]

History of Ocular Disease, Surgery, or Trauma

Patients with a history of glaucoma, particularly angle-closure glaucoma, uveitis, and pseudoexfoliation syndrome are associated with reduced endothelial cell density.[15,19,20] Patients with a history of same eye trauma or anterior segment, glaucoma, or retina-related surgery are also at risk for decreased endothelial cell density.[15,21,22]

Shallow Anterior Chamber

Shallow anterior chambers and short axial lengths that decrease the distance between the cornea and phacoemulsification tip expose the

TABLE 50.1 Risk Factors and Causes of Corneal Edema After Cataract Surgery

Preoperative	Intraoperative	Postoperative
Advanced age	Surgical trauma	IOL*-related
Lower endothelial cell count found in the following ethnicities: Japanese, Chinese, Filipino, and American	Toxic anterior segment syndrome (TASS) & chemical injuries	Retained lens fragment
Medications	Increased phacoemulsification power	Membranous ingrowth
Systemic Diseases	Descemet's membrane detachment	Inflammation
Dense cataract		Glaucoma
History of ocular disease, surgery, or trauma		Brown-McLean Syndrome
Corneal endothelial dystrophies		
Shallow anterior chamber		

*IOL, intraocular lens.

TABLE 50.2 Endothelial Cell Density by Age

Endothelial Cell Density by Age[6]

Age (years)	Cell Density (mean ± SD cell/mm^2)
6–20	3101 ± 268
20–29	2843 ± 285
30–39	2798 ± 247
40–49	2714 ± 263
50–59	2632 ± 277
60–69	2558 ± 233
>70	2571 ± 283

endothelium to higher levels of ultrasound energy and increase the risk for endothelial cell loss during surgery.[23–25]

Dense Cataract

Dense nuclear cataracts require higher levels of ultrasound energy for increased lengths of time and are at higher risk for increased chatter and turbulence during phacoemulsification.[15,23,26,27]

Corneal Endothelial Dystrophies

The most common corneal endothelial dystrophy is Fuchs' dystrophy, which is characterized by dysfunction and premature death of endothelial cells. Patients with Fuchs' dystrophy can be at particularly increased risk for postoperative corneal edema.[28,29] Some have recommended preoperative pachymetry thresholds of greater than 640 microns for consideration of initial triple procedures.[30] Other endothelial dystrophies, such as iridocorneal endothelial (ICE) syndrome, are also associated with postoperative corneal edema.[31]

High-Risk Endothelial Features

- Cell count <1000 cells/mm[1,2]
- Coefficient of variability >60%[32]
- Hexagonality <20%

INTRAOPERATIVE

Surgical trauma

Surgical trauma is often the culprit in unexpected early postoperative corneal endothelial decompensation. Local injury to the endothelium with an instrument, IOL, or residual lens fragment in the anterior chamber will result in a discrete patch of edema. Diffuse edema is often the result of a difficult lens extraction in extracapsular cataract extraction, higher infusion volumes, or prolonged ultrasound with phacoemulsification.[25,27] Over time, the migration of adjacent endothelial cells can restore corneal clarity if the area of injury is not overly large.[33]

Toxic Anterior Segment Syndrome (TASS) and Chemical Injuries

Chemical contaminant toxicity can result in TASS, a sterile postoperative anterior segment inflammation seen within 12 to 48 hours of surgery. If left uncontrolled, TASS can result in diffuse endothelial decompensation.[34,35] It is frequently, but not always, accompanied by other evidence of intraocular toxicity, most notably a fixed and dilated pupil and elevated IOP. In more extreme cases, toxicity can result in an excessive fibrinous anterior chamber reaction, ciliary body shutdown, hypotony, and potentially acute retinal inflammation or necrosis in the absence of vitritis. It is critical to differentiate TASS from infectious endophthalmitis to provide appropriate and timely treatment.

- When toxicity is suspected, all intraocular solutions and medications are suspect and should be reviewed.[36]
- More commonly, toxicity results from agents not intended for use inside the eye or agents used in excessive concentration.
  - Examples include detergents used in cleaning reusable instruments, incorrect concentrations of additives, use of preserved instead of nonpreserved additives in infusions, or confusing an intended intraocular medication with some other substance that is toxic.
  - Antibiotics particularly can be suspect and errors in the dilution of medications may occur. External antibiotics may also inadvertently enter the anterior chamber, particularly through an unstable wound.
  - Although rare, a subconjunctival bolus superiorly overlying a bleb or superior corneal scleral tunnel may be expressed into the anterior chamber through the filtration channel or via lid pressure, for example. Aminoglycoside antibiotics, in particular, have profound retinal toxicity at all but extremely low concentrations.

Descemet's Membrane Detachment

Detachment of the Descemet's membrane can also result in postoperative corneal edema (Fig. 50.1) but is usually recognized intraoperatively.[37] However, in an OCT study of wound morphology after cataract surgery, Wang et al. noted small Descemet detachments in 37% of corneas, with none noted in corneal image at 3 months postoperatively (Fig. 50.2).[38] Recently, subclassification of Descemet's membrane detachments into rhegmatogenous, bullous, tractional, and complex has been proposed.[39]

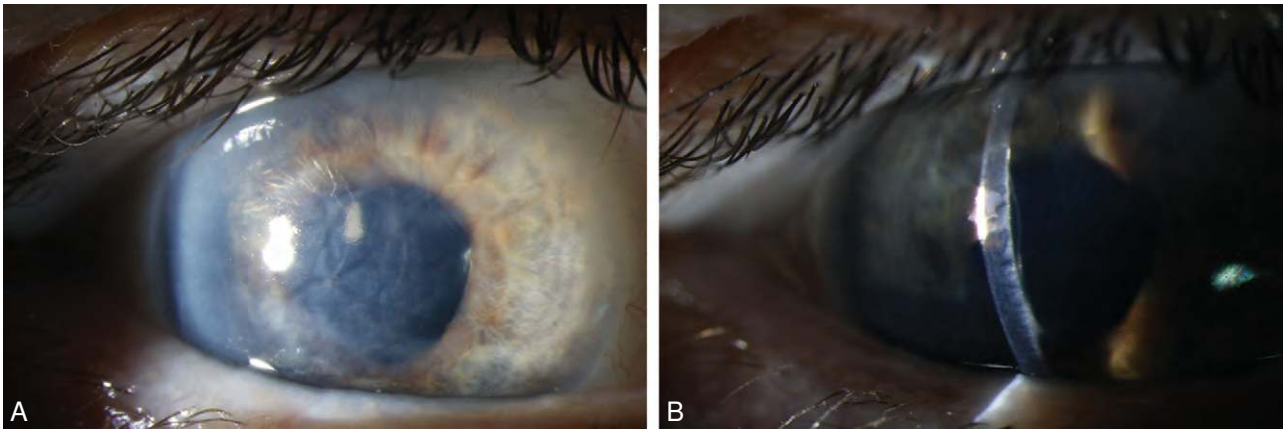


Fig. 50.1 (A) Slit-lamp photomicrograph with diffuse illumination showing severe corneal edema secondary to Descemet's membrane detachment after cataract surgery. (B) Corneal cross section showing the Descemet's detachment. (Image courtesy Alan Carlson MD.)

- The more commonly seen variety is the rhegmatogenous detachment where the Descemet's membrane has a tear and is seen floating in the anterior chamber. Postoperatively, slit-lamp examination through the edematous cornea may be challenging but a glassy membrane similar to the lens capsule may be seen separated from the posterior stroma. Anterior segment OCT helps identify and delineate the detached Descemet's membrane.
- More rarely, a bullous Descemet's detachment may be seen after accidental hydroseparation of Descemet's membrane during stromal hydration if the irrigating cannula is positioned too close to the posterior stroma.[40] A planar or mildly convex separation of the Descemet's membrane is seen without break. If there is severe corneal edema, then anterior segment optical coherence tomography can be diagnostic.[41]
  - Localized detachments are often in close proximity to their proper anatomic location. If the Descemet's membrane can be brought back into proper anatomic apposition with the posterior stroma, and the endothelium itself has not been irreversibly damaged, the endothelial pump function will itself reattach the Descemet's membrane because of the relative vacuum created by the endothelial pump.
- Although reattachment of the Descemet's membrane and restoration of corneal clarity is urgent, it is not an emergency. The endothelium is bathed in aqueous, even in the detached form. The endothelium will remain viable while an orderly reintervention is planned.
- Even large shallow detachments can sometimes spontaneously resolve by 3 months or so after surgery, although this late reattachment can some result in visually disturbing Descemet folds.
- In case of bullous detachment, relaxing Descemetotomy may be performed by means of a keratome entry to intentionally create a break in the Descemet's membrane through which the overlying trapped fluid can then drain. Alternately, the keratome may be used to only enter into the supra-Descemetic space to allow drainage of fluid followed by air tamponade.

POSTOPERATIVE

IOL-Related

A loose or malpositioned anterior-chamber IOL (ACIOL) or a large or loose pupillary-supported iris plane IOL can directly traumatize the corneal endothelium, causing a progressive attrition of endothelial cells, and ultimately lead to clinically evident corneal edema (Fig. 50.3).[42] The edema will characteristically begin in a localized zone over the area of IOL-related trauma but will progress as the remaining endothelial cells migrate into the area of damage. ACIOLs in particular have previously been associated with increased intraocular inflammation; however, newer, more flexible open-looped models have greatly improved outcomes when properly sized and correctly placed.[43–45]

Retained Lens Fragment

Retained lens fragments are often located in the inferior angle, though one study reported that 13% required gonioscopy to be identified.[46] Corneal edema occurs in approximately half of cases and, though uncommon, can result in edema that does not resolve after removal, thus requiring corneal transplant.

Glaucoma

A history of preexisting glaucoma, as discussed earlier, is associated with a decreased endothelial cell count before surgery. After surgery, elevated intraocular pressure (IOP), particularly in the early postoperative period, is associated with corneal edema and endothelial cell loss ($p = 0.001$), even after adjusting for nuclear density and phacoemulsification time (Fig. 50.4).[47]

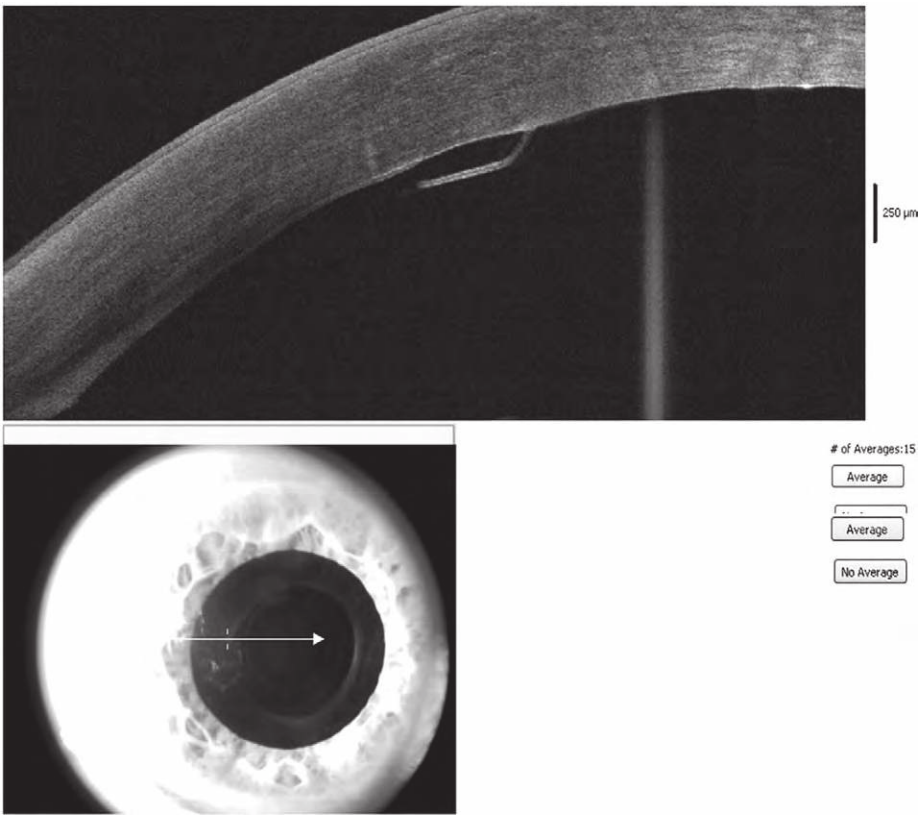
Brown-McLean Syndrome

Perhaps the rarest and most benign form of corneal edema is Brown-McLean Syndrome.[48,49] In the classic syndrome, an aphakic patient experiences peripheral corneal stromal and epithelial edema that spares the superior cornea (Fig. 50.5). Pigment deposits are present on the underlying endothelium. A central zone of 5 to 7 mm remains clear and compact indefinitely despite the peripheral edema. The peripheral iris may show transillumination, but the trabecular meshwork is not necessarily hyperpigmented. If the patient is bilaterally aphakic, the syndrome is usually present in both eyes. There is no clinical inflammation, and the cause is unknown. Although the classic presentation is after intracapsular cataract extraction, it may occur after extracapsular cataract extraction.[50]

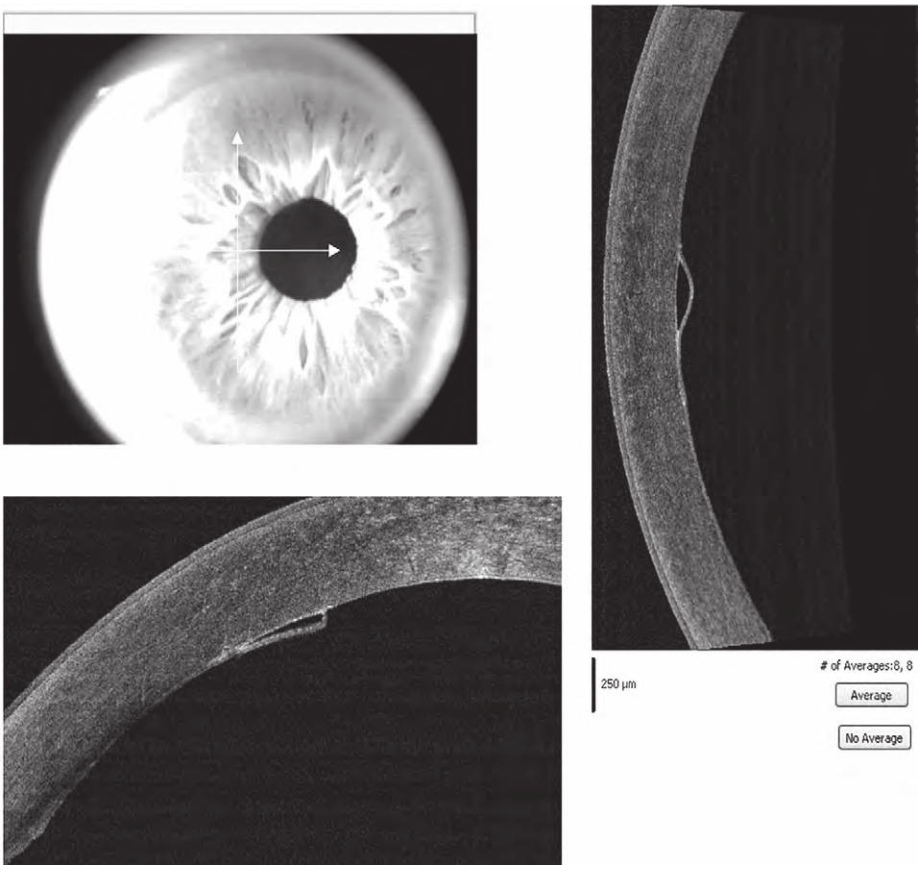
PREOPERATIVE ASSESSMENT

Careful preoperative slit-lamp biomicroscope inspection of the cornea with a broad oblique beam at high magnification can aid in assessing overall corneal and endothelial health.

- Ophthalmologists can specifically look at the endothelium for guttae, Latin for "drops," that have a beaten-metal appearance and represent collagen excrescences from stressed corneal endothelial cells.



A



B

Fig. 50.2 (A) Anterior segment OCT of a patient with a Descemet's membrane detachment 3 weeks after cataract surgery. (B) Partial resolution at 2 months without any intervention. (Images courtesy Douglas D. Koch and Li Wang.)

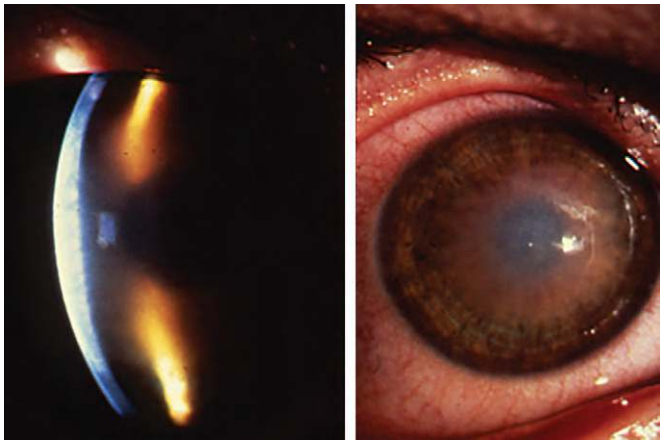


Fig. 50.3 Slit-lamp photomicrographs of a patient with an anterior-chamber intraocular lens causing central corneal edema. (Image courtesy Alan Carlson MD.)

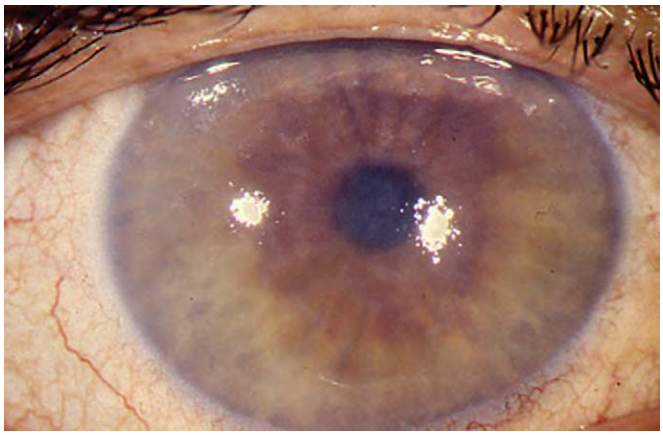


Fig. 50.4 Slit-lamp photomicrograph of high intraocular pressure causing diffuse corneal edema. (Image courtesy Alan Carlson MD.)

- Alternatively, formal specular microscopy with endothelial cell photography can be used to examine the health of the endothelium, but this is often reserved for cases of probable abnormality rather than as a screening tool.
- However, in unique cases where a patient experiences unexpected corneal edema in the absence of preoperative specular microscopy after apparently atraumatic surgery, preoperative specular microscopy on the fellow eye may be appropriate. Low endothelial cell density in the absence of acquired pathology will almost always be bilateral. Examination of the fellow eye will therefore help in the differential diagnosis of unexpected postoperative corneal edema and be particularly useful if considering cataract surgery in the second eye.

In eyes that are determined to be at increased risk for corneal edema, it is important to modify the surgical approach to minimize risk. During surgery, generous use of dispersive viscoelastic should be employed on a frequent basis. Additionally, using techniques such as chop or prechopping instruments such as the Akahoshi prechopper and advanced technology such as femtosecond laser can help minimize the use of ultrasound energy and subsequent endothelial cell injury.

POSTOPERATIVE ASSESSMENT

Symptoms

Symptomatology can vary from asymptomatic when edema is mild to decreased contrast sensitivity and visual acuity when edema is more significant. At more severe stages, such as when there is epithelial edema, patients can experience a significant decline in visual acuity and report pain caused by corneal nerve stretching and/or ruptured corneal bullae.

Signs

Corneal examination can reveal focal or diffuse edema of the epithelium, stroma, and/or endothelium. Edema can result in epithelial microcysts or bullae, stromal haze or scarring, and Descemet's membrane folds posteriorly. Obtaining pachymetry can be useful for monitoring changes over time. Additionally, exam findings such as a torn Descemet's membrane, bullous Descemet's detachment, residual lens fragments in the angle, transillumination defects, pupil irregularity, ruptured posterior capsule, or presence of vitreous in the anterior chamber can help identify the potential cause of corneal edema. Chronic edema can lead to corneal neovascularization.

Management

The treatment options for corneal edema are listed in Table 50.3.

HYPERTONIC SOLUTIONS

Hypertonic solutions, typically 5% sodium chloride ophthalmic preparations, can improve the visual function of a patient with mild, predominantly microcystic epithelial edema. This will be particularly beneficial to the patient on awakening in the morning, when edema is maximal because of lack of evaporation during the night when the eyelids are closed. Use of a 5% sodium chloride ointment at bedtime will also help reduce the accumulation of edema while the eyelids are closed during sleep. However, the use of hypertonic solutions is only palliative. It does not improve or restore endothelial pump function or the integrity of the cell barrier. These drugs function by generating a hypertonic tear film that draws water out of the edematous cornea but can be associated with irritation.

ANTI-INFLAMMATORY THERAPY

Reduction of intraocular inflammation may be of benefit in some cases of postoperative edema, given that inflammation can lead to transient endothelial pump dysfunction and resultant corneal edema. Moreover, inflammation can result in endothelial cell death, particularly when significant and prolonged. Therefore pharmacologic treatment with topical corticosteroids and perhaps nonsteroidal antiinflammatory drugs may help maximize the surviving endothelium, thus improving the likelihood of corneal clarity returning postoperatively. Treatment regimens should be individualized to the patient's degree of inflammation but can include prednisolone acetate (1%) or dexamethasone (0.1%) as often as every 1 to 2 hours in cases of acute postoperative corneal edema. Antiinflammatory therapy is particularly useful in the management of TASS which can involve topical treatment for mild or moderate and systemic therapies in severe cases.

Notably, in cases where postoperative corneal edema is not related to inflammation, such as in Fuchs' dystrophy, steroid therapy is of limited benefit. One controlled study of patients with Fuchs' dystrophy found that topical dexamethasone did not decrease the incidence of corneal edema compared with a placebo.[51]

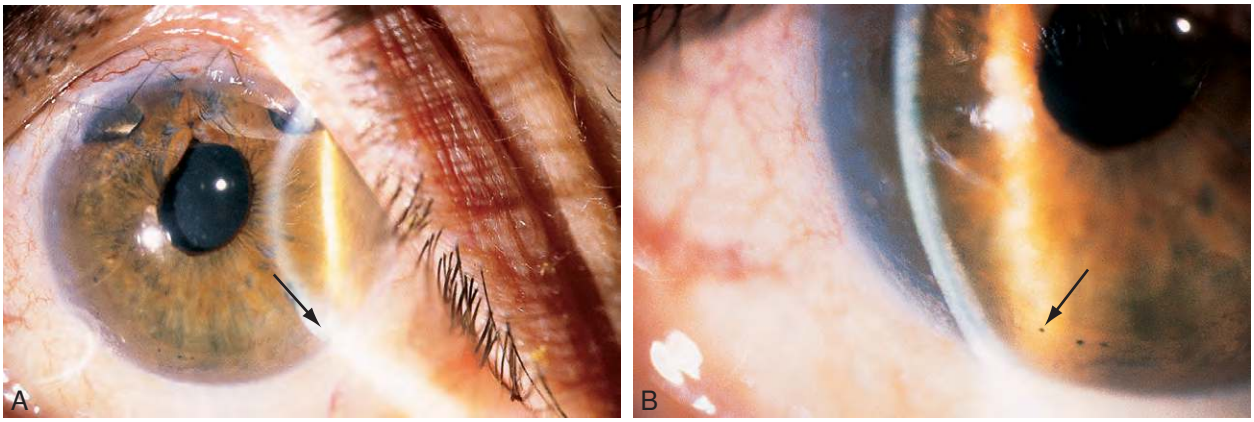


Fig. 50.5 (A) Slit-lamp photomicrograph of a patient with Brown-McLean syndrome of peripheral corneal edema (*arrow*). (B) High magnification reveals classic pigment deposits on the endothelium underlying the area of edema (*arrow*).

TABLE 50.3 Management of Postoperative Corneal Edema

Address cause
Treat inflammation
Normalize intraocular pressure
Remove residual lens fragment
Eliminate tissue-IOL contact
Reattach Descemet's membrane
Hypertonic agents
Pain management
Lubricants
Soft contact lenses
Cautery of the Bowman's layer
Conjunctival flap
Corneal transplantation
DSEK
DSAEK
DMEK, PDEK
Penetrating keratoplasty
Future Therapeutics

IOL, intraocular lens; DSEK, Descemet-stripping endothelial keratoplasty; DSAEK, Descemet-stripping automated endothelial keratoplasty; DMEK, Descemet membrane endothelial keratoplasty; PDEK, Pre-Descemet's endothelial keratoplasty.

DESCEMET'S MEMBRANE DETACHMENT

- Repositioning of Descemet's membrane is best accomplished surgically by introduction of an air bubble or nonexpansile gas (e.g., 18% SF_6) through a paracentesis incision. This can be performed intraoperatively or postoperatively at the slit-lamp microscope in favorable cases.
- Suturing might be needed when the Descemet's membrane is held away from the stroma by traction or likely to fall away from the stroma, or when it has less post-operative air support, such as with an inferior detachment. A full-thickness through-and-through 10–0 nylon suture can forcefully reappose an area of intractable detachment and is best passed under air tamponade.
  - Instrumentation of the membrane itself should be avoided because of the local injury to the endothelium that will occur and the risk for tearing or further stripping Descemet's membrane.
  - Use of viscoelastic agents should be avoided in an effort to reappose the Descemet's membrane. If the viscoelastic agent enters between the posterior corneal stroma and the Descemet's membrane, it will prevent reattachment of the membrane and may remain as a barrier indefinitely.

SURGICAL PEARLS

- Create an inferior peripheral iridotomy.
- Make an incision 180 degrees away from area of detachment.
- Insert filtered air via a 30 G cannula.
- Fill the entire chamber for 5–10 min to reappose Descemet's Membrane.
- Partially remove air bubble to smaller size to avoid pupillary block.

ANTERIOR-CHAMBER IOL

Management of a patient with localized corneal edema in the presence of an anterior-chamber IOL can be challenging. Often the endothelium will be severely damaged from IOL touch or chafe against the endothelium in the localized area and, for a time, the central cornea can remain clinically clear. Nevertheless, the longer the edema persists, the more likely that it will cause irreversible corneal decompensation. One approach to management is an intense course of topical steroids and nonsteroidal antiinflammatory agents (e.g., dexamethasone, 0.1%, or prednisolone acetate, 1%, combined with ketorolac, 0.5% [Acular], or diclofenac, 0.1% [Voltaren], both four times daily). If the edema does not improve over a 1-month course, or resolves but then recurs, exchange of the anterior-chamber IOL should be strongly considered. Improvement may occur by moving the IOL to another fixation site, such as a peripheral iris suture fixation or transscleral fixation of a posterior-chamber IOL, for the best long-term results. Should IOL exchange be necessary, the surgeon must perform atraumatic surgery if the fragile cornea is to remain compensated. Dispersive OVD can help decrease the damage to the endothelium. Secondary IOL implantation is reviewed in Chapter 41. Management of intraocular inflammation is discussed in Chapter 15. For cases of persistent corneal edema related to an anterior-chamber IOL where decompensation occurs centrally and does not improve with intensive steroids treatment, a combined or staged endothelial keratoplasty (EK) with IOL exchange can be considered. The best type of replacement IOL remains undetermined in regard to both short-term complications and long-term graft survival and recovery of vision.

CORNEAL TRANSPLANTATION

Restoration of vision in an eye with irreversible corneal edema requires either a posterior lamellar endothelial transplant (i.e., Descemet-stripping endothelial keratoplasty [DSEK], Descemet-stripping automated endothelial keratoplasty [DSAEK], Descemet membrane endothelial keratoplasty [DMEK], or pre-Descemet's endothelial keratoplasty (PDEK). In

cases in which the anterior stroma is abnormal or scarred, a full-thickness penetrating keratoplasty (PK) can resolve both the opacity and endothelial dysfunction. It can take several months for a cornea to stabilize and as such the decision to proceed with EK or PK should be deferred until the corneal is stable and had adequate time to attempt healing.

FUTURE THERAPEUTICS

Preliminary research on rho-associated kinase (ROCK) inhibitors, such as ripasudil and netarsudil, which were initially approved for clinical use in glaucoma and ocular hypertension, have shown promise in the regeneration and rehabilitation of endothelial cells. ROCK inhibitors appear to promote cultured endothelial cell proliferation and reduce donor corneal graft endothelial cell apoptosis.[52,53] This preliminary research suggests ROCK inhibitors may contribute meaningfully to future therapies targeted at promoting endothelial cell health in novel ways.

SUMMARY

Clinically significant corneal edema is a well-known, but uncommon, postoperative complication after cataract surgery. It is important to recognize many factors that can contribute to edema, and appropriate preoperative evaluation can identify patients at increased risk. Tailoring corneal edema management to each patient's specific underlying mechanism can increase the likelihood of a desirable patient outcome and increase overall patient satisfaction.

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Glaucoma After Cataract Surgery

Manjool Shah

CONTENTS

KEY POINTS

- Clear corneal phacoemulsification generally reduces intraocular pressure (IOP) in glaucoma and ocular hypertensive eyes.
- A list of differential diagnoses should exist in the minds of all cataract surgeons when evaluating patients with elevated IOP after cataract surgery.
- Immediate postoperative IOP spikes can be common, especially in glaucoma patients, and can be mitigated using specific medical agents.
- Warning signs and risk factors for the development of intraoperative or postoperative malignant glaucoma should be identified.
- The timing of and features of steroid response should be considered, especially in patients with preexisting glaucoma.

INTRODUCTION

Although modern cataract surgery has become exceedingly safe and predictable, unique challenges remain with regards to postoperative development of elevated intraocular pressure (IOP). Increasing evidence suggests that cataract surgery tends to reduce IOP in patients with glaucoma or ocular hypertension.[1,2] Several causes of increased IOP shortly after cataract surgery should be considered, and they can be easily differentiated based on timing of presentation, examination findings, and response to therapy. These etiologies are as follows:

- Retained ophthalmic viscosurgical device (OVD) in the anterior segment
- Malignant glaucoma
- Steroid response
- Overfilled anterior chamber
- Post Nd:YAG capsulotomy

An additional cause of a relatively late development of glaucoma after cataract surgery is the development of uveitis-glaucoma-hyphema (UGH) syndrome.

Rare causes of elevated IOP after cataract surgery need not be discussed in detail and include postoperative inflammation, potentially with associated pupillary seclusion and pupillary block, retained lens material, hyphema, capsular bag distension syndrome, vitreous block, tight-closure techniques, suture compression, and edema mechanically distorting the angle and compromising aqueous outflow in traditional extracapsular surgery (generally not seen in modern scleral tunnels, manual small-incision cataract surgery, and clear cornea phacoemulsification techniques).

CAUSES

The main causes of glaucoma or elevated IOP after cataract surgery can be broken down based on timing and examination findings.

Retained OVD

Insufficient irrigation and aspiration of OVD at the conclusion of cataract surgery can result in an elevated postoperative IOP. This typically results in an IOP elevation shortly after surgery, with peak incidence within the first 1 to 2 postoperative days. Often, these IOP elevations can be identified within hours of surgery. In a study of glaucoma patients undergoing cataract surgery, 17% of subjects experienced at least a 50% increase in IOP compared with their preoperative baseline.[3]

Risk factors for this sort of early postoperative IOP spike include underlying glaucoma diagnosis, as evidenced by known examination findings, elevated preoperative IOP, use of antiglaucoma medications, or history of laser trabeculoplasty. Furthermore, eyes with a longer axial length were noted to be at higher risk for early postoperative IOP spike.[3]

Examination of eyes with retained OVD can often be unremarkable. Because this is a relatively early postoperative issue, expected postoperative edema and inflammation may be evident. However, the retained OVD may result in a relatively static appearance to the anterior chamber cells caused by the greater viscosity of OVD relative to aqueous humor.

Malignant Glaucoma

Malignant glaucoma (MG) is a relatively rare cause of postoperative IOP increase. This condition is characterized by an axial shallowing of the anterior chamber in the absence of choroidal effusions.

- This condition should be distinguished from fluid misdirection syndrome, in which intraoperative irrigation fluid crosses the zonular plane and hydrates the vitreous body, thus causing anterior chamber shallowing.
  - Although fluid misdirection is a self-limited process as the excess fluid is reabsorbed, MG can progressively worsen unless managed.
- The pathophysiology of MG remains debated. Popularly known as *aqueous misdirection*, there has been no evidence of truly misdirected aqueous humor, and such a mechanism would require a one-way ball valve to exist in the eye. Instead, MG is thought to be incited by an expansion of the choroidal volume, often because of transient intraoperative hypotony of the anterior chamber. This choroidal expansion causes a relative increase in the pressure of the posterior segment and resultant compaction of the vitreous body. This compaction causes inability of this increased posterior segment pressure to be transduced across the anterior vitreous, thus resulting in an axial shallowing of the lens and iris. IOP ultimately increases when this axial shallowing results in angle closure.[4]
- Clinical presentation of postoperative MG can be subtle in its early stages. A myopic refractive surprise is often identified. On clinical examination, the distance between the IOL and the iris may appear smaller than usual (Fig. 51.1).
- With progression of the underlying pathophysiology, further axial shallowing can occur, and gonioscopy can reveal closed angles with an elevated IOP. Importantly, IOP may not increase until angle closure develops, but the underlying process should be identified nevertheless.
- In a series of 20 eyes developing MG after cataract surgery, presentation occurred at 5.8 ± 7.1 weeks after surgery. All eyes had narrow or closed angles preoperatively and were often hyperopes.[5]

Steroid Response

Steroid response is a relatively common cause of IOP elevation, especially in patients who have underlying glaucoma or are glaucoma suspects. However, steroid response can occur in patients without this underlying predisposition as well.[6] This phenomenon typically presents 1 to 3 weeks after initiation of steroids after surgery.

IOP elevation has been reported in more novel depot and sustained delivery steroid technologies at a variable rate, so clinical suspicion should remain high regardless of the drug, dose, or method of application.[7,8]

Eyes with a steroid response are often rather unremarkable on examination. Because steroid therapy has been used, the eyes are generally free of inflammation. The IOP elevation is also often slow, and so patients may be asymptomatic.

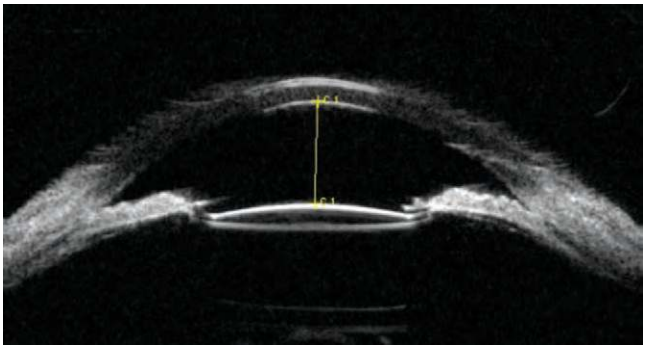

Fig. 51.1 Anterior segment ultrasound biomicroscopy (UBM) demonstrating an axial anterior shift of the intraocular lens and capsule complex, with resultant angle closure.

Uveitis-Glaucoma-Hyphema Syndrome

UGH syndrome was initially described in 1977 by Ellingson as a complication of anterior chamber IOL placement.[9] A classic triad of intraocular inflammation, IOP elevation, and hemorrhage have been associated with implant material rubbing on uveal tissue. However, it is not necessary that all three of these components be present to recognize that an implant is malpositioned and therefore resulting in pathology. Additional sequelae of implant-related chafe include corneal decompensation, eye pain, pigment dispersion, and cystoid macular edema.

UGH syndrome is typically identified years after the original inciting event (IOL implantation) and has been described for implants in the capsular bag, in the ciliary sulcus, in a bag/sulcus position, or in the anterior chamber. It is well understood that single-piece acrylic IOLs should never be placed in the ciliary sulcus, as the large haptics are not well suited for this small space.[10]

COMORBIDITIES

In general, risk factors for the development of any of the above causes of IOP elevation after cataract surgery include extremes of axial lengths, underlying diagnosis of glaucoma or glaucoma suspect status, and occurrence of intraoperative complications.

MANAGEMENT CONSIDERATIONS

The management of all causes of IOP elevation after cataract surgery is typically based on medical intervention because nonsurgical approaches are often sufficient for these conditions to stabilize. Unique considerations based on etiology will be discussed below.

Retained OVD and Early Postoperative IOP Spikes

In patients with a known history of glaucoma, a history of early postoperative IOP spike in the fellow eye, or other risk factors associated with IOP spikes as discussed previously, perioperative prophylactic therapy should be considered. Intracameral carbachol, immediate pre- or postoperative oral or intravenous acetazolamide, and topical aqueous suppressant therapy have all demonstrated efficacy in mitigating early IOP spikes (Table 51.1).[11] Furthermore, newer studies have suggested that the adjunctive utilization of microinvasive glaucoma surgeries, or MIGS, can reduce the likelihood of IOP elevation in the early postoperative period.[12,13]

An additional interventional option in this situation is to perform an anterior chamber paracentesis. After applying topical anesthetic and antibiotic drops, a 25- or 30- g needle can be used to gently depress the posterior lip of the paracentesis incision to express a small amount of aqueous and retained OVD. Care should be taken to ensure that then

TABLE 51.1 Number of Patients Developing an IOP ≥ 30 mm Hg After Use of Various Agents

Agent	4 hours	8 hours	24 hours	Total
Miostat	3	0	0	3
Timoptic	0	4	0	4
Pilopine Gel	5	7	1	13
Diamox	5	8	2	15
Betagan	3	10	5	16
Betoptic	12	15	1	28
Control	10	9	4	23
Iopidine	11	11	3	25

Reproduced from Fry.[11]

anterior chamber remains deep. Particular attention should be given to the character and viscosity of the expressed fluid: the more viscous it is, the higher the concern for persistently retained OVD. Postprocedure topical antibiotics can then be applied.

Malignant Glaucoma

Prevention of MG should be considered in patients who are at risk, specifically in patients with eyes with smaller axial lengths and preoperative closed angles. Specifically, care must be taken to avoid sudden decompression of the anterior chamber, as this can result in a choroidal expansion as described above. When removing the phaco or irrigation/aspiration handpiece, either a balanced salt solution or an appropriate OVD should be infused through a sideport to maintain the pressurization of the anterior segment.

- A stepwise approach to the management of postoperative MG has been described by Varma et al.[5] Initial therapy is medical, with topical cycloplegics such as atropine with potential concomitant aqueous suppression.
- If medical therapy is not able to fully reverse the process, steps must be taken to create a unicameral eye.
  - Nd:YAG laser iridozonulohyaloidotomy can be performed to achieve a channel for pressure equalization between the anterior and posterior segments.
  - As a last resort, surgical iridozonulohyaloidotomy and vitrectomy through either a pars plana or anterior chamber-based approach combined with posterior synechialysis and goniosynechialysis as needed should be considered (Video 51.1).

Steroid Response

Often, the management of steroid response is self-evident. The use of antiglaucoma medications can be considered based on the magnitude of IOP elevation and the relative risk for the IOP elevation causing optic neuropathy. In an otherwise normal patient without any evidence of glaucomatous optic neuropathy, a mild and transient IOP elevation can be tolerated. However, in patients with underlying disease, additional medical management should be considered. In all cases, tapering of the steroid therapy should be performed, and the use of a topical NSAID can assist in the management of residual postoperative inflammation.

Uveitis-Glaucoma-Hyphema Syndrome

The first step in the management of UGH syndrome is recognition of the problem. Evidence of implant-related chafing can be corroborated using ultrasound biomicroscopy (UBM) when available. Based on the specific relationship of the implant to the uveal tissue, implant repositioning or surgical exchange may be advisable. Considerations for choosing between repositioning and exchange include the degree of malposition, the stability of the zonular/capsular complex, and the patient's current and desired refractive status. In certain cases, reverse pupillary block can result in UGH syndrome, particularly in myopic eyes with sulcus IOL placement; these cases can be treated with the placement of a laser peripheral iridotomy.[14] Axial myopes with sulcus IOLs are prone to IOL instability, and so optic capture should be considered when an intracapsular IOL implantation is not an option in these eyes.[15]

POTENTIAL COMPLICATIONS

Unchecked elevated IOP can result in potentially severe consequences for patients, although the incidence of such issues is relatively rare. It is well understood that severe or prolonged elevation in IOP can result in glaucomatous optic neuropathy caused by injury or death of retinal ganglion cells. Furthermore, in eyes at risk for anterior ischemic optic neuropathy, IOP elevation can exacerbate this underlying predisposition. Even in eyes with an underlying history of glaucoma, it is rare that an IOP spike will require surgical intervention. Careful preoperative history and examination can identify underlying risks.

LASER AND SURGICAL PEARLS FOR MANAGING MG

- Nd:YAG laser can be used to create a peripheral iridotomy using standard settings of 3–5 mJ per spot.
  - The laser can then be focused more posteriorly to create an opening in the peripheral capsule or zonules and the anterior hyaloid face.
  - Alternatively, Nd: YAG posterior capsulotomy with anterior hyaloid disruption can be considered.
- Surgical iridozonulohyaloidotomy with vitrectomy (IZHV) can be performed through an anterior or posterior approach.
  - Anterior IZHV: Use a vitreous cutter to create an iridectomy, then advance the cutter for 2–3 mm along the plane of the sclera with the cutter facing posteriorly.
  - Posterior IZHV: Enter the globe via a pars plana entry 3–4 mm posterior to the limbus, and use the cutter to perform a limited pars plana vitrectomy. Then advance the cutter with port facing anteriorly through the peripheral zonules and iris until the cutter is visualized in the anterior chamber.

SUMMARY

- Identify preoperative risk factors for the development of postoperative IOP issues: extremes of axial length, underlying glaucoma history, and fellow eye history.
- Consider perioperative medical therapy to prevent early postoperative IOP spikes.
- Medical management is often sufficient to correct IOP elevation after cataract surgery, but specific interventional techniques should be considered on a case-by-case basis.

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Video 51.1 Surgical video demonstrating iridozonulohyaloidotomy and vitrectomy to treat malignant glaucoma through an anterior surgical approach.

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Retinal Complications of Cataract Surgery

Avni P. Finn and Rahul N. Khurana

CONTENTS

KEY POINTS

- It is important for the cataract surgeon to assess for preoperative and intraoperative risk factors for retinal complications.
- The anterior segment surgeon can take several key steps during and after surgery to maximize visual outcomes despite the occurrence of a retinal complication.
- Prompt diagnosis and management, usually in conjunction with a retinal specialist, is essential.

INTRODUCTION

Cataract surgery may have complications. Although the evolution of surgical techniques, including clear corneal incisions along with phacoemulsification, has increased the efficiency and lowered the ocular trauma associated with cataract surgery, the surgeon must be aware of the acute and late complications of cataract surgery that may affect the vitreous and retina. Although these retinal complications are infrequent, timely management in conjunction with a retinal specialist is crucial to maximizing visual outcomes. The most common complications are discussed in this chapter.

PSEUDOPHAKIC CYSTOID MACULAR EDEMA/ IRVINE-GASS SYNDROME

Cystoid macular edema (CME) is the most common cause of visual loss after cataract surgery.[1] This entity, also referred to as Irvine-Gass Syndrome, was first described by Irvine in 1953, and the fluorescein findings were later detailed by Gass.[2,3] The incidence of CME varies; however, it is much lower since the advent of phacoemulsification and small-incision cataract surgery. Clinically significant macular edema affects anywhere from 0.1% to 11% of eyes after uneventful cataract surgery.[1,4–9] The incidence as measured by optical coherence tomography—the most sensitive modality for detecting macular edema—may be as high as 30% to 41%.[1,6,10]

The pathogenesis of pseudophakic CME is multifactorial. Inflammatory mediators are upregulated in both the aqueous and vitreous after surgery. The increased inflammation leads to the breakdown of the blood-retinal barrier and increased vascular permeability.[11] This increased permeability, in turn, contributes to fluid accumulation within the retina. Macular edema occurs about 4 to 12 weeks after surgery, reaching a peak incidence at about 4 to 6 weeks postoperatively.[5–7,11] In cases of clinically significant CME, patients present with blurry vision, metamorphopsia, or central scotoma. The funduscopic exam will reveal retinal thickening and loss of the foveal depression. Severe cases may appear to have pseudohole formation.

Risk Factors

- Vitreous loss
- Retained lens fragments/vitrectomy
- Iris trauma
- Posterior capsular rupture
- Intraocular lens dislocation
- Anterior chamber intraocular lens or iris fixated lenses
- History of previous treatment for diabetic macular edema[12]
- Previous history of epiretinal membrane, uveitis, retinal vein occlusion, diabetic retinopathy, and retinal detachment repair[13]

Imaging Studies

Optical coherence tomography demonstrates (Fig. 52.1) the following:

- Loss of foveal depression
- Retinal thickening
- Cystic hyporeflective spaces within the macula in the outer plexiform and inner nuclear layers
- Subretinal fluid (severe cases)

Fluorescein angiography demonstrates (Fig. 52.2) the following:

- Leakage from perifoveal capillaries (early frames)
- Classic "petaloid" pattern of leakage (late frames)
- Optic nerve leakage is commonly seen and helps distinguish from other etiologies such as diabetic macular edema

Treatment

To reduce the risk for postoperative CME, all preexisting retinal conditions should be controlled before cataract surgery. Eyes with diabetic

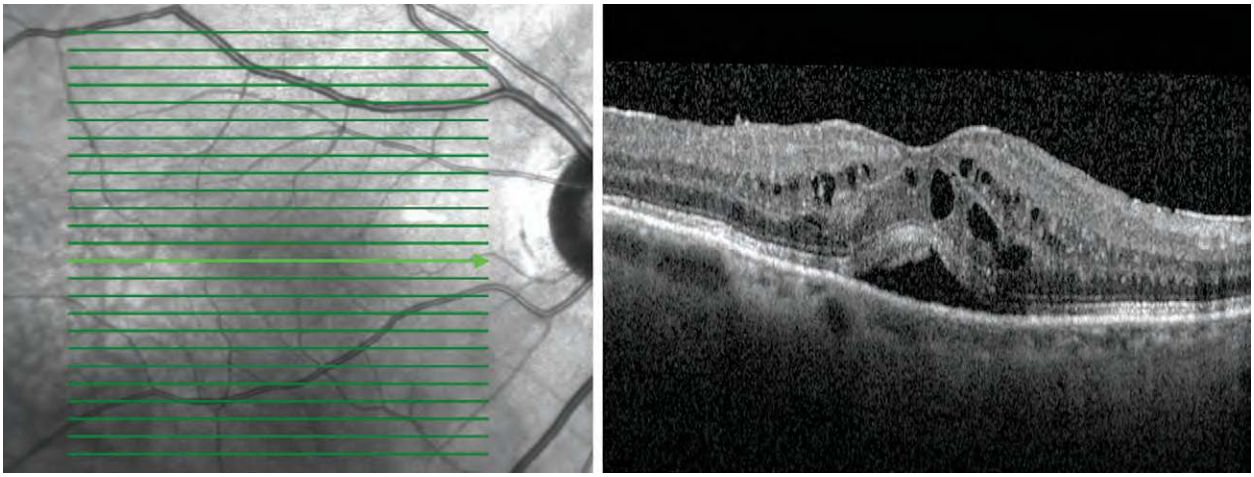

Fig. 52.1 Optical coherence tomography demonstrating macular edema with marked intraretinal and subretinal fluid.

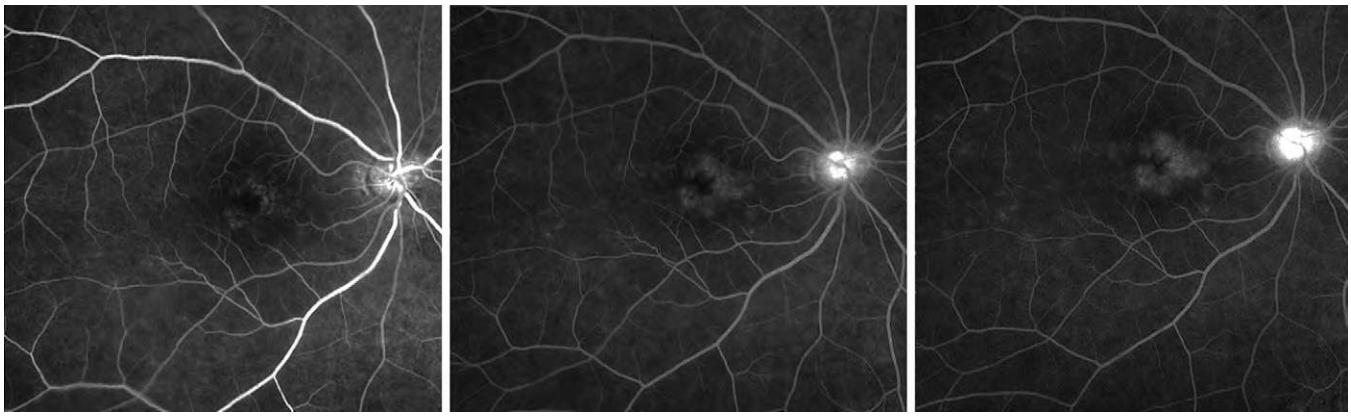

Fig. 52.2 Fluorescein angiography in a patient with pseudophakic cystoid macular edema shows petaloid leakage in the macula and late leakage of the disc.

retinopathy should be evaluated and treated as appropriate.[14] For uveitis, the general recommendation is adequate control of intraocular inflammation for at least 3 months before cataract surgery.[6]

Topical nonsteroidal antiinflammatory drugs (NSAIDs) are the mainstay of perioperative prophylaxis. NSAIDs are potent inhibitors of prostaglandins, one of the key mediators in the development of CME. These medications are approved for the treatment of postoperative inflammation and are commonly used off-label for prophylaxis against pseudophakic CME. Several studies have demonstrated the efficacy of NSAIDs in preventing pseudophakic CME.[9,15–17]

The more commonly used NSAIDs are as follows:

- Ketorolac 0.4% (Acular, Allergan, Irvine, CA)
- Diclofenac 0.1% (Voltaren, Bausch & Lomb, Tampa, FL)
- Bromfenac 0.09% (Xibrom/Bromday, Ista Pharmaceuticals, Irvine, CA)
- Nepafenac 0.1% (Nevanac, Alcon, Fort Worth, TX)

Combination use of topical corticosteroids along with NSAIDs is the most frequently used treatment for pseudophakic CME. Data suggest that the medications work synergistically, and studies report superior visual acuity outcomes when combination therapy is compared with monotherapy treatment with either agent. A small, randomized control trial showed 3.8 lines improvement in Snellen visual acuity with combination treatment with prednisolone and ketorolac compared with only 1.1 to 1.6 lines with prednisolone or ketorolac alone.[18]

CME Refractory to Topical Treatment

Periocular corticosteroids may be given sub-Tenon's, subconjunctival, or intravitreal for CME that is refractory to topical therapy.[19–21] Similarly, drug delivery systems, such as the dexamethasone implant (Ozurdex, Allergan, Irvine, CA) and the fluocinolone acetonide implant (Retisert, Bausch + Lomb, Quebec, Canada), may be used in refractory and recurrent cases.[22] Side effects of periocular and intravitreal corticosteroids include elevated intraocular pressure, so use should be carefully considered in eyes with ocular hypertension or glaucoma.

Antivascular endothelial growth factor (anti-VEGF) intravitreal injections have been used in patients with chronic pseudophakic CME refractory to other treatments.[23–25] Vascular endothelial growth factor is well-known as a key mediator of angiogenesis, but in cases of macular edema it may be upregulated in the midst of increased inflammation and lead to the increased vascular permeability causing CME. A multicenter retrospective study showed 72% of eyes with refractory CME treated with intravitreal bevacizumab showed improvement in visual acuity and central macular thickness at 1 year.[24]

Surgical Treatments

If medical therapy with both topical and injectable treatments is ineffective, surgical intervention may be considered. Nd:YAG vitreolysis is used when abnormal vitreous adhesions or incarcerations at the cataract incisions may be contributing via vitreous traction. Pars plana

vitrectomy may be considered if there is vitreomacular traction or a significant epiretinal membrane.

RETAINED LENS FRAGMENTS

Retained lens fragments are an uncommon occurrence after cataract surgery, with incidence varying from 0.18–1.1%.[26–30] Nevertheless, retained lens fragments may result in significant vision loss and complications, and the timing of medical and surgical treatment and involvement by both anterior segment and vitreoretinal surgeons is important in managing this condition. The goal of management is to ensure the best possible long-term visual acuity and decrease the risk for complications.

Recommendations for the anterior segment surgeon for management of retained lens fragments include the following:

- Identify potential risk factors preoperatively (e.g., history of trauma, zonular dehiscence, pseudoexfoliation, high myopia, prior eye surgery, history of retinopathy of prematurity, brunescent cataract, tamsulosin use, prior vitrectomy, multiple prior intravitreal injections[31–34]).
- Identify posterior capsular ruptures during surgery promptly.
- Minimize vitreous prolapse and perform anterior vitrectomy when needed.
- Insert an intraocular lens if safe and possible.
- Do not attempt to remove material in the vitreous cavity.
- Suture all incisions.
- Minimize corneal edema and preserve media clarity for potential future surgery.
- Refer promptly for retinal evaluation.

Complications related to retained lens fragments include the following:

- Glaucoma/elevated intraocular pressure
- Intraocular inflammation
- Corneal edema
- Cystoid macular edema
- Retinal detachment

Depending on the case, retained lens fragments can be managed medically or surgically. In a retrospective review of patients managed medically versus surgically, there was no statistical significance in the final visual acuity or intraocular pressure 1 year out in eyes in either group.[35] However, each case must be assessed on a case-by-case basis as the severity of inflammation, amount and type (nuclear vs. cortical) of retained material, and intraocular pressure may influence the type of management.

Medical Management

The mainstay of medical management is aggressive topical treatment to control the inflammation and intraocular pressure while allowing lens fragments to dissolve on their own. Corticosteroids can be used to treat inflammation, which is usually related to the amount of retained lens fragments. As such, smaller lens fragments (e.g., 5%–10% of the total lens volume) have been shown to be associated with decreased inflammation.[36] Topical and oral agents are used as necessary to manage intraocular pressure, with over 50% of cases with retained lens fragments having elevated pressure.[37–39] NSAIDs may be used concurrently with corticosteroids in cases of macular edema.

Surgical Management

Surgical treatment for retained lens fragments is pars plana vitrectomy. Fortunately, the overall outcomes of vitrectomy for retained lens fragments are quite good, with 44% to 83% of patients achieving 20/40 vision or better.[38–42] Those patients with poorer outcomes (<20/200 vision) were associated with absence of anterior vitrectomy at time of cataract surgery, absence of sulcus lens, concurrent ocular disease, and development of glaucoma.[27,38]

There is no consensus on the timing of vitrectomy for the removal of retained lens fragments. Some situations—such as uncontrolled intraocular pressure or concurrent retinal detachment—may require more urgent intervention. Several studies have compared early versus delayed vitrectomy (more than 1 week out) and have found no relationship between the timing of vitrectomy and final visual outcome.[35, 38,42,43] Most retina specialists would suggest that vitrectomy within 2 to 3 weeks can help improve overall outcomes and reduce risks of chronically elevated intraocular pressure. However, delaying surgical intervention may be necessary if there is insufficient media clarity such as significant corneal edema, which must be treated before being able to perform a safe vitrectomy. Topical treatment is initiated in these cases to treat inflammation and intraocular pressure, allowing time for the corneal edema to resolve.

Despite favorable outcomes after surgery for retained lens fragments, vitrectomy for retained lens fragment may be associated with potential postoperative complications including glaucoma (2%–25%), CME (3%–27%), and retinal detachment (6%–12%).[26,33,34,44,45] Patients with a history of retained lens fragments should be followed by a retinal specialist for development of delayed visual loss from complications such as macular edema or retinal detachment.

RETINAL DETACHMENT

Among the rare complications after cataract surgery, retinal detachment is one of the more frequent sight-threatening events that could occur (Fig. 52.3). Fortunately, the advent of extracapsular cataract extraction and phacoemulsification has led to a significant decline in the incidence of pseudophakic retinal detachment.[46] Large studies have estimated the risk for retinal detachment after cataract surgery to be 0.4% to 1%, which is an approximately 7 to 10 times increased risk relative to the rate of rhegmatogenous retinal detachment in the overall population.[46–50] Most studies point to a peak incidence of postcataract retinal detachment occurring a few months after surgery.[51]

Risk factors for retinal detachment occurring after cataract surgery include[46,49,50] the following:

- Younger age
- Male sex
- Longer axial length (e.g., high myopia)
- Intracapsular cataract extraction

Fig. 52.3 A fundus photos showing a macula-off rhegmatogenous retinal detachment in a patient 3 days after complicated cataract surgery.

- Posterior capsule rupture
- Vitreous loss
- Anterior vitrectomy at the time of phacoemulsification

Pathogenesis

The leading hypothesis is that vitreous changes occurring after cataract surgery lead to the development of a posterior vitreous detachment (PVD) and increased risk for retinal tear or detachment. One study found that over 75% of patients without a history of PVD or lattice degeneration before cataract surgery developed a PVD after cataract surgery.[52]

If a retinal tear or detachment is suspected, an initial examination should include the following:

- Visual acuity
- Visual fields
- Evaluation for "tobacco dust" or pigmented cells in the anterior vitreous (Schaffer's sign)
- Note the presence of a vitreous detachment of Weiss ring
- Careful dilated examination of the peripheral retina for any tears or detachment
- If a detachment is noted, the extent of the detachment and whether there is macular involvement
- Optical coherence tomography may help document extent of macular involvement
- If there is no view or a limited view caused by corneal edema, hemorrhage, or other etiology, a B-scan ultrasound should be used to evaluate the status of the vitreous and retina

Treatment

Symptomatic retinal tears are treated with laser photocoagulation or cryotherapy. These treatments create a chorioretinal scar, limiting fluid spread through the subretinal space and preventing a retinal detachment. This treatment is successful in preventing a retinal detachment in over 90% of cases.[53] However, patients may still be at risk for the development of new breaks and require follow-up with a retina specialist.

Surgical repair is necessary when there is a retinal detachment. Surgery aims at identifying all retinal breaks, relieving vitreoretinal traction, and sealing the breaks. Any of the following three techniques (or a combination of techniques) may be used, depending on the nature of the detachment and the discretion of the surgeon:

1. Pneumatic retinopexy
   a. A less invasive procedure for the repair of select detachments in a clinic or office setting
   b. Involves reattachment of the retina involving the injection of a gas bubble and treatment of the breaks with laser or cryotherapy
   c. Not every detachment may be amenable to a pneumatic procedure
2. Pars plana vitrectomy
   a. Involves removal of the vitreous by cutting the vitreous strands
   b. The retina is flattened during the intraocular surgery and laser is applied to seal any breaks
   c. An intraocular tamponade such as gas or oil is then used to aid in retinal reattachment
3. Scleral Buckle
   a. A silicone band is permanently placed around the outside of the globe under the extraocular muscles
   b. The band creates an indentation and relieves any traction and supports areas of retinal tears
   c. This procedure is combined with retinopexy, usually with cryotherapy
   d. A gas bubble may or may not be injected depending on the location and extent of the detachment

Recommendations

- Any suspicious lesions noted before cataract surgery should be evaluated by a retina specialist.
- Any retinal tears noted before cataract surgery should be treated.
- Any patients with new onset of flashes and floaters after cataract surgery should be examined for the development of a new PVD, retinal tear, or detachment.
- A dilated examination should be considered for all patients within a month after cataract surgery.
- Patients should be educated on signs and symptoms of a retinal tear or detachment including:
  - Flashes of light in the periphery
  - New floating spots in their vision
  - A shadow or curtain in their vision

ENDOPHTHALMITIS

Postoperative endophthalmitis is a cause of severe and potentially irreversible vision loss caused by infection manifesting with inflammation in both the anterior and posterior segments of the eye. The incidence of endophthalmitis after cataract surgery ranges from 0.04 to 0.2%.[30,54–57] The patient typically notices a sudden increase in pain 1 to 7 days after cataract surgery, accompanied by decreased vision.

Clinical exam may reveal the following features:

- Diffuse conjunctival injection
- Variable degrees of corneal edema
- Cell and flare in the anterior chamber
- Hypopyon in the anterior chamber (Fig. 52.4)
- Fibrin (may adhere to the IOL)
- Blunting of the red reflex
- Vitreous cell in the posterior segment and potentially sheets of vitreous debris
- Retinal periphlebitis
- With severe disease, there may be a limited view of the posterior segment

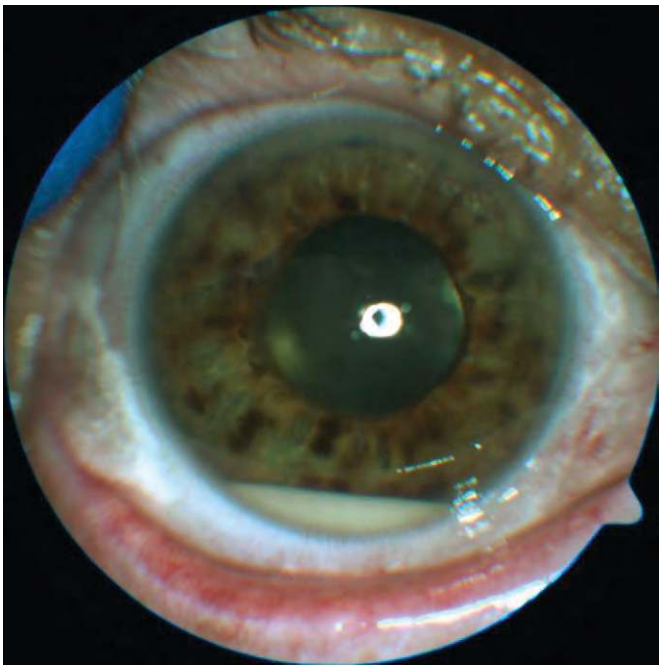

Fig. 52.4 An eye with endophthalmitis showing layered hypopyon in the anterior chamber and fibrin covering the intraocular lens. (Courtesy Mohsin H. Ali, MD)

Various risk factors have been identified at the time of cataract surgery including[30,58] the following:

- Prolonged surgery
- Posterior capsular rupture
- Vitreous loss
- Secondary IOL
- Wound leak/ hypotony
- Vitreous incarceration
- Concurrent or recent nasolacrimal duct surgery
- Combined surgery (e.g., glaucoma tube placement and cataract surgery)

It is important to differentiate an infectious etiology such as endophthalmitis from other etiologies. The differential diagnosis for endophthalmitis includes:

1. Retained lens material causing intraocular inflammation
2. Toxic anterior segment syndrome (TASS)
   a. Presents with more rapid onset (12–24 hours after surgery)
   b. Does not present with vitreous involvement
   c. Responds to corticosteroids
3. Chronic, dehemoglobinized vitreous hemorrhage

The clinical evaluation in a patient with suspected endophthalmitis involves the following:

- Evaluating for a wound leak (Seidel test)
- Grading the anterior chamber inflammation and vitritis
- Measuring the height of the hypopyon if present
- If there is a limited view of the posterior segment, perform B-scan ultrasonography (Fig. 52.5) to assess for the status of the retina, dispersed opacities in the vitreous, choroidal thickening, and choroidal detachment

Most cases of acute endophthalmitis manifest within 3 to 5 days after surgery and are bacterial in origin. In more than 75% of reported culture-positive cases, the causative organism is gram-positive.[59–61] Delayed-onset or chronic endophthalmitis is rare but may present several weeks or months after cataract surgery. The presentation differs in that pain or discomfort may be absent, hypopyon is often absent, keratic precipitates may be present, and there may be white plaques present on the lens or capsule. The organisms isolated in these cases are less virulent bacterial or fungal organisms, with Propionibacterium acnes accounting for the majority of the cases (41–63%).[62]

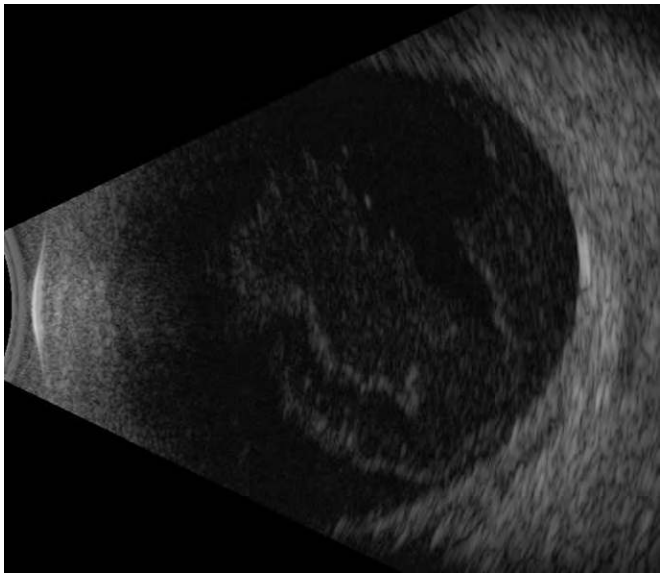

Fig. 52.5 B-scan ultrasonography of a patient with endophthalmitis shows dense vitreous debris and choroidal thickening. The retina appears attached. (Courtesy Mohsin H. Ali, MD)

Most common pathogens for acute and chronic infectious endophthalmitis include the following:

Acute-onset endophthalmitis	Delayed onset/chronic endophthalmitis
Coagulase negative staphylococci	Propionibacterium acnes
Staphylococcus aureus	Staphylococcus epidermidis
Streptococcus	Fungal: Candida species most often; others include Aspergillus, Fusarium
Gram negative bacteria	

Treatment

Patients with suspected endophthalmitis should be referred emergently to a retinal specialist for evaluation and treatment. After a careful examination, a vitreous tap is typically performed, and the vitreous fluid is sent for gram stain, culture, and sensitivities. This is followed by injection of intravitreal antibiotics: vancomycin 1 mg/0.1 cc for gram positive coverage and ceftazidime 2.25 mg/0.1 cc or amikacin 0.4 mg/0.1 cc for gram negative coverage. For patients with light perception vision at presentation, emergent surgery with pars plana vitrectomy may be recommended according to data from the Endophthalmitis Vitrectomy Study (EVS).[59,61] EVS was a study of the largest series of endophthalmitis occurring after cataract surgery and showed that patients with light perception vision at presentation had better visual outcomes with initial pars plana vitrectomy. Those patients in EVS with hand motions or better vision achieved equal outcomes with vitreous tap and inject versus pars plana vitrectomy. There was no benefit when adjunctive systemic antibiotics were added. An important distinction to note is that the study included only cases of endophthalmitis occurring after extracapsular cataract extraction, so current clear corneal incision phacoemulsification techniques were not included.[59]

Prophylaxis

Several steps can be taken to decrease a patient's risk for postoperative endophthalmitis.

1. Povidone-iodine
   a. The single most effect method of preoperative antisepsis is the application of 5% povidone-iodine solution to the corneal, conjunctival sac, and periocular surface before the commencement of surgery.[63–65] A 3-minute exposure time before initiating surgery has been shown to be effective.[66]
2. Topical antibiotics
   a. Topical antibiotics are widely used for surgical prophylaxis, though there have been no randomized control trials.[54,67]
3. Intracameral antibiotics
   a. The European Society of Cataract and Refractive Surgeons performed a prospective randomized study of patients receiving intravitreal cefuroxime at the end of surgery and saw a nearly fivefold increased risk for postoperative endophthalmitis in patients not receiving intracameral antibiotics.[68] A large, retrospective study performed at Aravind Eye Hospital showed a nearly sixfold decrease in endophthalmitis rates with phacoemulsification with the use of routine intracameral moxifloxacin.[69]
   b. Cefuroxime is the most commonly used intracameral antibiotic in Europe, though it is used less commonly in the United States.[70]

Outcomes

Visual prognosis is guarded in these patients. Severity at the time of presentation, time to treatment, and type of organism causing the endophthalmitis all play an important role in the final outcome. A recent IRIS Registry study showed the mean visual acuity of eyes with endophthalmitis 3 months after cataract surgery was about 20/100 compared with 20/40 in eyes without endophthalmitis.[30] Another large study of Medicare beneficiaries demonstrated that 34% of patients achieved a final visual acuity of 20/200 or worse.[71] 43% to 44% of eyes in both studies were able to achieve 20/40 vision or better.[30,71] Understanding risk factors for infection and timeliness to appropriate treatment are imperative to maximizing visual outcomes.

HEMORRHAGIC OCCLUSIVE RETINAL VASCULITIS

Hemorrhagic occlusive retinal vasculitis (HORV) is a rare, devastating complication of cataract surgery occurring after the use of vancomycin. Patients present with severely decreased visual acuity, retinal hemorrhages, and vascular nonperfusion, with reported cases occurring with some delay after the use of vancomycin (Fig. 52.6).[72,73]

Pathophysiology

Limited pathology evidence is available; however, most hypothesize the role of a T-cell mediated type IV hypersensitivity reaction to vancomycin involving intravascular thrombosis in these eyes with evidence of necrotizing retinal vasculopathy.[74]

Clinical Characteristics of HORV

- Normal undilated examination on postoperative day 1
- Delayed onset of sudden painless decreased vision
- Visual acuity often poor at presentation (may be normal in mild cases[75])
- Mild to moderate anterior chamber and vitreous inflammation without a hypopyon
- Sectoral intraretinal hemorrhages in areas of nonperfusion
- Peripheral retinal involvement in all cases
- Sectoral retinal vasculitis and vascular occlusion on fluorescein angiography

Prognosis

These eyes have an overall poor prognosis and rapid progression to neovascular glaucoma. In a report of 26 eyes with HORV, 22 eyes (61%) were 20/200 or worse, and 8 eyes (22%) were no light perception.[76]

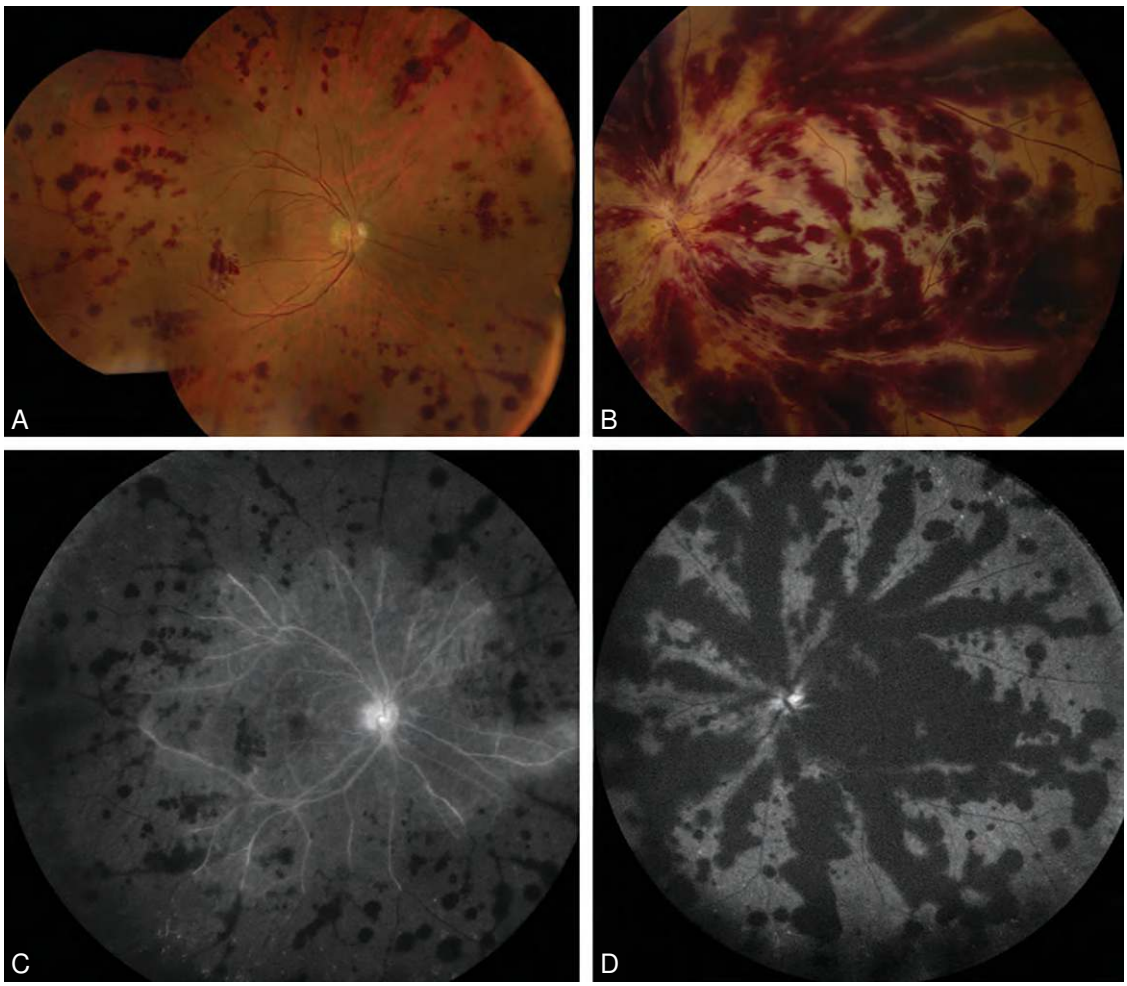

Fig. 52.6 Fundus photos (A and B) of a patient with hemorrhagic occlusive retinal vasculitis showing retinal hemorrhages in the left eye worse than in the right eye. Fluorescein angiography (C and D) demonstrates severe vascular nonperfusion in the left eye greater than in the right eye. (Courtesy J. Michael Jumper, MD)

Therapy with additional intravitreal vancomycin after surgery is associated with especially poor outcomes, and avoiding this therapy is important if HORV is suspected.

Recommendations for Management of HORV

- Consider an ocular or systemic workup for other etiologies if the diagnosis is ambiguous.
- Treat with aggressive systemic and topical corticosteroids; consider periocular or intraocular steroids.
- Early anti-VEGF treatment and panretinal photocoagulation may prevent neovascular glaucoma, a common complication in these eyes.
- Avoid intravitreal vancomycin if HORV is suspected.

SUMMARY

- Assess each patient for preoperative risk factors for retinal complications.
- Many retinal complications may be managed successfully with medical therapy but some will require surgical intervention.
- Prompt diagnosis and timely management of complications usually results in the best visual outcomes.

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53

Subluxated Intraocular Lenses

Shana Sood and Soosan Jacob

CONTENTS

KEY POINTS

- Detailed ocular examination in patients with subluxated IOLs is a must, including undilated gonioscopy and dilated slit lamp evaluation to reveal the status of the zonules, capsular bag, and any endocapsular device in situ.
- Subluxated IOLs may result from missed systemic entities. Hence, complete evaluation including family history and general examination is a must in all cases.
- It is important to rule out any trauma to the eye or ocular appendages in the remote past, which the patient might find trivial, because this helps anticipate various intraoperative challenges like zonular dialysis.
- Subluxated IOLs may present with lenticular astigmatism, monocular diplopia, and glare and halos caused by IOL edge effect.
- Investigations like anterior segment OCT (ASOCT), B scan, and ultrasound biomicroscopy (UBM) can help precisely localize a subluxated/ dislocated IOL or parts like missing haptic/ optic.
- Subluxated IOLs can be classified as in-the-bag IOL subluxation and out-of-the-bag IOL subluxation.
- In-the-bag IOL subluxation with intact capsular bag can be managed with endocapsular devices like capsular tension ring, glued capsular, hook and paperclip capsule stabilizer.
- Out-of-the-bag IOL subluxation can be managed with various methods of scleral fixated IOLs like glued IOL.
- Eyes with subluxated IOLs are more prone to develop complications like cystoid macular edema, pseudophakic bullous keratopathy, and secondary glaucoma.

INTRODUCTION

What Is Subluxation of IOL?

Subluxation of intraocular lens (IOL) is defined as partial displacement of the IOL away from its physiologic position. It can be classified based on the capsular bag-IOL relation:[1]

- **In-the-bag IOL subluxation**: IOL is subluxated but still in the capsular bag (Fig. 53.1). This is commonly seen in cases of zonular dehiscence for (e.g., pseudoexfoliation syndrome). It is important to make note of any previously implanted endocapsular devices that support the bag in such cases (Figs. 53.2 and 53.3)
- **Out-of-the-bag IOL subluxation**:
  - This can arise in two different situations:
    1. *IOL is subluxated with haptic/optic or both parts lying out of the capsular bag*. This is common in cases with posterior capsular compromise/tear. Fibrosed or shrunken capsular remnants may be seen (Fig. 53.4).
    2. *IOL is subluxated with no/absent remnants of capsular bag*. This is very rare and is usually seen in cases of nonphaco cataract surgeries (small-incision cataract surgery [SICS] or extracapsular cataract extraction [ECCE]) wherein the mature cataractous nucleus was accidentally delivered with the capsular bag around it or sometimes also after complicated phacoemulsification. In such cases, the primary IOL is usually an anterior chamber IOL/iris fixated IOL or scleral fixated IOL, which may subsequently get subluxated as a result of improper fixation/support.

What Is Dislocation/Luxation of IOL?

Complete displacement of IOL from its physiologic position is known as *dislocation* or *complete luxation* of the lens. IOL can be dislocated in the following ways:

1. Anteriorly: IOL may lie in the anterior chamber leading to iris chafing, glaucoma, and pseudophakic bullous keratopathy.
2. Posteriorly: IOL may drop through a posterior capsular tear or may drop within the bag to lie in the vitreous or on the retina, causing vitreous traction and damage to the retina.

INCIDENCE AND ETIOLOGY

Subluxation and dislocation of IOL have an overall incidence of 0.05% to 3% of cataract surgeries.

The etiology can be classified as shown in Table 53.1.

Preoperative

Primary

This includes congenital causes predisposing to subluxation caused by zonular weakness/dehiscence/absence. These cases usually present

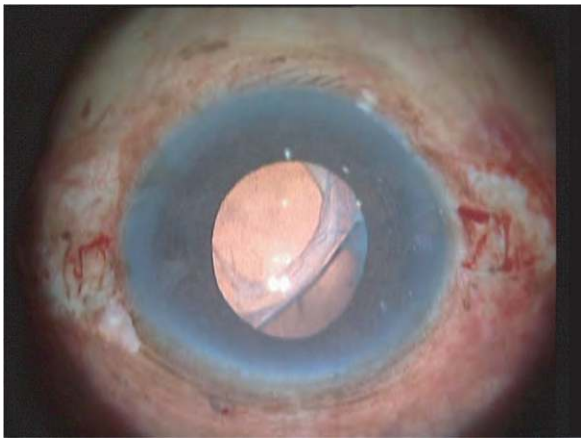

Fig. 53.1 In-the-bag IOL subluxation. IOL subluxation noted with fibrosed capsular bag.

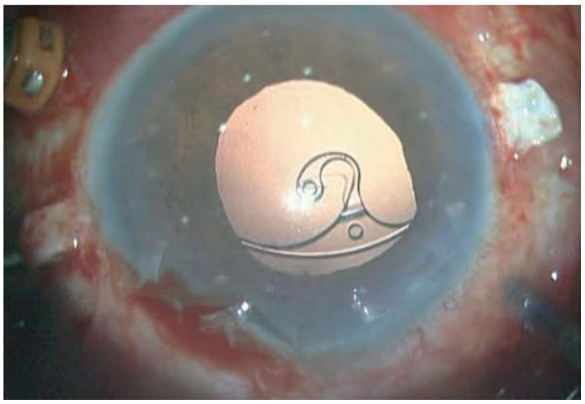

Fig. 53.3 Subluxated sutured Ahmed segment with broken suture.

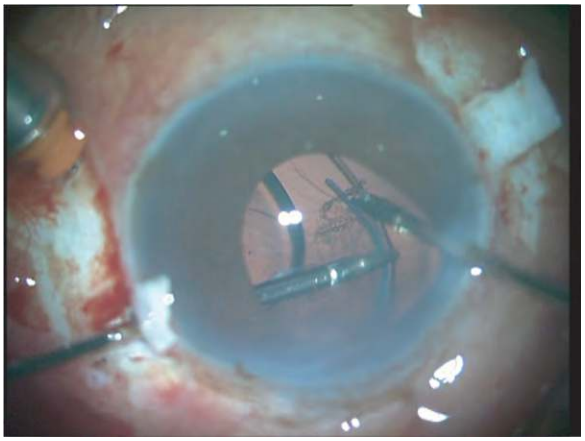

Fig. 53.2 In the bag IOL subluxation with capsular tension ring (CTR) in situ.

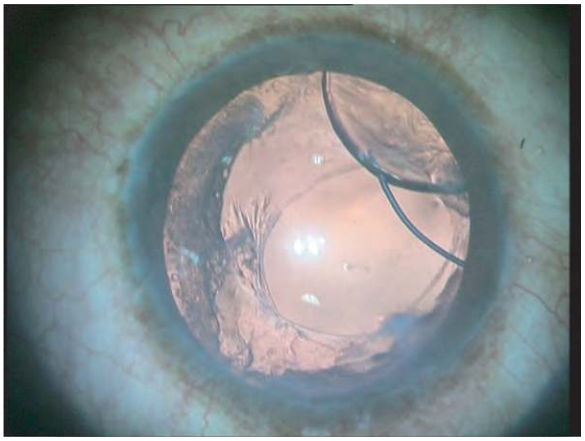

Fig. 53.4 Out-of-the-bag IOL subluxation with posterior capsular rent (PCR).

TABLE 53.1 Etiologic Classification of Subluxated/Dislocated IOL

Preoperative	Intraoperative	Postoperative
Primary causes: High myopia, Marfan's syndrome, Ehlers Danlos syndrome, Weil Marchesani, homocystinuria, hyperlysinemia,aniridia, lens coloboma,familial ectopia lentis **Secondary causes:** Pseudoexfoliation, trauma, uveitis, angle closure glaucoma	Damage to capsular bag or zonules during various steps of cataract surgery or vitreoretinal surgery.	Capsular fibrosis and shrinkage caused by pseudoexfoliation, diabetes mellitus, uveitistrauma (unrelated to surgery). Suture disintegration of primarily suture fixated IOL

with bilateral subluxated IOLs. Examination of the other eye and syndromic associations aid in diagnosis of such entities.

- High myopia
- Marfan's syndrome
- Weil-Marchesani
- Ehlers Danlos syndrome
- Homocystinuria
- Hyperlysinemia
- Aniridia
- Familial ectopia lentis
- Lens colobomas

Secondary

This includes acquired causes of zonular dehiscence/weakness.

- Pseudoexfoliation
- Trauma
- Angle closure glaucoma

Intraoperative

Damage to zonules or capsular bag during various steps of cataract or vitreoretinal surgery can lead to immediate or late IOL subluxation/dislocation. Common causes include the following:

- Incomplete hydrodissection of the nucleus leading to zonular damage while attempting to rotate the nucleus

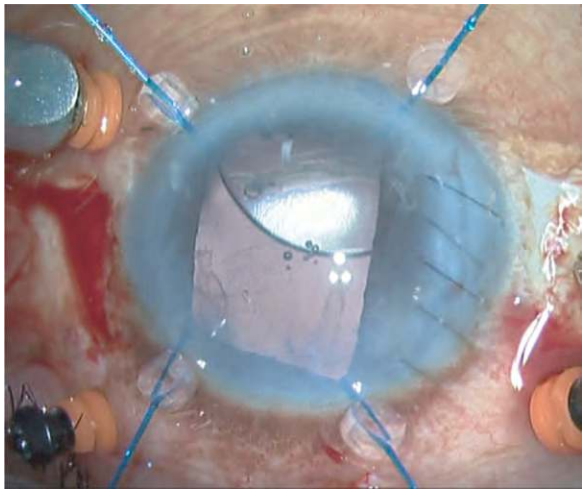

Fig. 53.5 Out-of-the-bag IOL subluxation with posterior capsular rent.

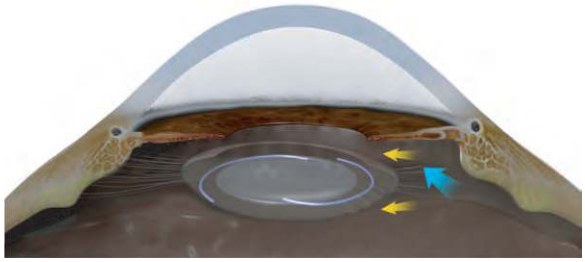

Fig. 53.6 Capsular shrinkage causing stress on zonules and dehiscence. The capsule has anatomic attachment of the zonules, hence shrinking of the capsule causes stress on zonules, weakening them leading to zonular dehiscence and disruption and subluxation of the IOL.

- Excessive stress on zonules while sculpting or chopping
- Accidental capsular aspiration during aspiration of cortex causing traction on zonules
- Posterior capsular rent / compromise at any step of surgery (Fig. 53.5)
- A large capsulotomy or rhexis runaways also increase the chance of compromise on zonules.

Postoperative

Intraoperative/secondary causes usually present as postoperative IOL subluxations.

- Capsular shrinkage and fibrosis[2] (in pseudoexfoliation, diabetes mellitus, and uveitis) (Fig. 53.6)
- Trauma to the eye with blunt objects/sports related injury.
- Suture disintegration of sutured scleral fixated IOL[3]

SYMPTOMS AND SIGNS

Patient with IOL subluxation may be asymptomatic or present with various complaints, symptoms being specific for various scenarios that may be associated with the entity.

- *Glare/halos exaggerated while observing lights in poor lighting*: this is common in mild to moderate subluxated IOLs caused by the edge effect of the IOL rim. Astigmatism, along with prismatic and higher order aberrations, set in and induce halos/glare around a light.
- *Monocular diplopia* is seen in moderate to severe cases because of double refraction of the light via the aphakic and pseudophakic area of the pupil. There can also be perception of *shaky/ shaking images* because of associated pseudophakodonesis.
- *Constant blurred vision* may be caused by astigmatism or induced aberrations.
- *Metamorphopsia* may be caused by associated cystoid macular edema.
- *Redness with pain and cloudy vision* point toward early onset of pseudophakic bullous keratopathy, uveitis, or rise in intraocular pressure caused by secondary glaucoma.

PATIENT EVALUATION

Stepwise evaluation is a must to diagnose the cause of subluxation and avoid missed diagnosis or findings in such cases.

Step 1: *Detailed undilated slit lamp examination* can reveal information on the location of the IOL. Pupillary margin may show pseudoexfoliative material indicating PXF syndrome or other tell-tale signs like sphincter tears in cases of trauma. Examination should also be done in the lying-down position because this may sometimes reveal the true degree of subluxation.

It is important to examine the limbus and sclera carefully to note any suture or scleral fixated techniques of IOL fixation attempted previously. *It is also important to evert the lid*. In cases of trauma, the IOL may lie in the subconjunctival space and present as a pseudophacocoele.

Status of the capsular bag, zonules and previously implanted endocapsular devices is better evaluated after complete dilatation. In cases where the IOL is absent from the pupillary area, a single haptic may sometimes be seen hooked on to the margins of the pupil or fibrotic capsule through which the IOL is suspended in the posterior cavity.

Step 2: *Measure intraocular pressure* to rule out secondary glaucoma.

Step 3: *Gonioscopy* is a must to assess the angle structures. Capsular tension rings may be visualized with this method.

Step 4: *Dilatation* is then initiated and complete dilatation is attempted.

Dilated slit lamp examination helps in grading of the subluxation of IOL/cataract, along with status of capsular bag and zonules (Fig. 53.7). A dilated fundus examination is necessary in all cases. It is not uncommon to find an intact IOL or broken haptic in the posterior cavity along with localized vitreous traction. Associated retinal tears or macular edema should be ruled out. Careful disc evaluation is necessary to note any glaucomatous damage caused by sustained raise in IOP.

Step 5 *Investigations*: In case of poor view as a result of advanced bullous keratopathy, limited pupillary dilatation, or any other cause,

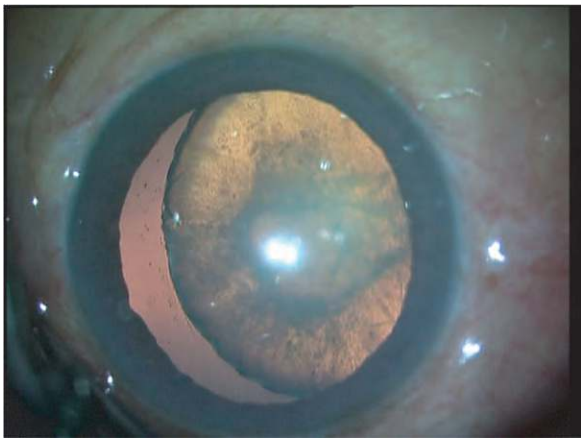

Fig. 53.7 Dilated slit lamp examination is a must in all cases of subluxated cataract/ IOL for grading of severity.

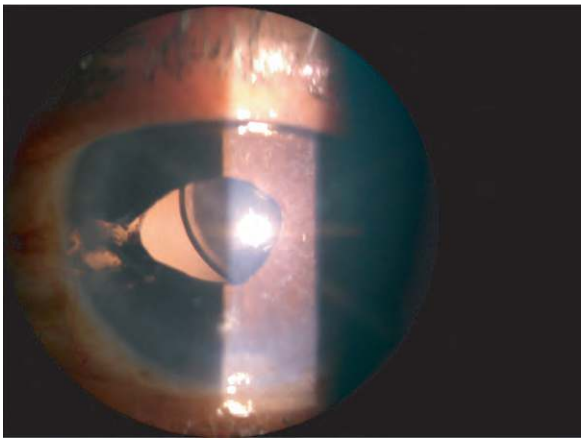

Fig. 53.8 Case with corneal astigmatism (caused by corneal tear) and lenticular astigmatism (caused by subluxated IOL).

investigations such as ASOCT (anterior segment optical coherence tomography), UBM (ultrasound biomicroscopy), and B scan can help localize anterior and posterior dislocated IOLs.

MANAGEMENT

Conservative Management

Glasses can be prescribed in minimal to mild cases of subluxation. Such patients usually have lenticular astigmatism because of associated tilt of IOL. Usually, the major component of refractive astigmatism comes from corneal astigmatism. However, lenticular astigmatism can be present in scenarios like subluxated lens, subluxated IOL, and altered curvature of the lens (lenticonus) (Fig. 53.8). The magnitude of lenticular astigmatism can be determined by comparing corneal and refractive astigmatism. Certain imaging devices also can detect and measure "internal" astigmatism, which includes posterior corneal and lenticular astigmatism.

SURGICAL MANAGEMENT

Indications

1. Symptomatic patient with monocular diplopia
2. Visual phenomena that hamper the lifestyle
3. Moderate and severe subluxation
4. Dislocated IOLs in anterior chamber causing iris chafing, damage to angle structures, glaucoma, and pseudophakic bullous keratopathy
5. Dislocated IOLs in posterior chamber with vitreous traction, retinal tears, and recalcitrant macular edema.

The Surgical Management of Subluxated IOLs Includes an Organized Approach to a Wide Range of Decision Making

For the purpose of better understanding, it is important that we familiarize ourselves with the following two terms:

- ***Primary IOL***: This is the subluxated/dislocated IOL present in situ when a patient presents for the first time for examination. This IOL can be retained in the patient's eye in the same position, or refixed in a different position. For example, a posteriorly dislocated intact IOL can be explanted from the vitreous cavity, and the same IOL can be repositioned by method of scleral fixation.
- ***Secondary IOL***: In case where the primary IOL is not suitable for reposition, a secondary IOL is implanted in the eye after careful IOL power calculation. Pseudophakic/aphakic mode of biometry is decided based on the presence/absence of the IOL in the pupillary aperture. In cases where biometry of the affected eye is not possible, it is performed on the other eye of the patient for IOL power calculation. It is important to note that the IOL power derived from biometry is suitable for in the bag implantation, necessary adjustments need to be made in other methods of fixation. As the position of IOL is moved anterior to the bag, the IOL power should be reduced, it is usually deducted by 0.5D for sulcus placement.

Decision 1: Reposition Primary IOL versus Primary IOL Explantation and Secondary IOL Implant (Fig. 53.9)

***Reposition and refix the primary IOL*:** Primary IOL can be retained in cases where there is an

- intact IOL that
- provides optimal postoperative refractive outcome and
- is suitable for chosen approach of repositioning/ refixation.

This is possible in most case scenarios.

***Primary IOL explantation with secondary IOL implantation*:** It is indicated in cases where

- Primary IOL is damaged (broken or twisted haptic, weak junction)
- IOL opacification

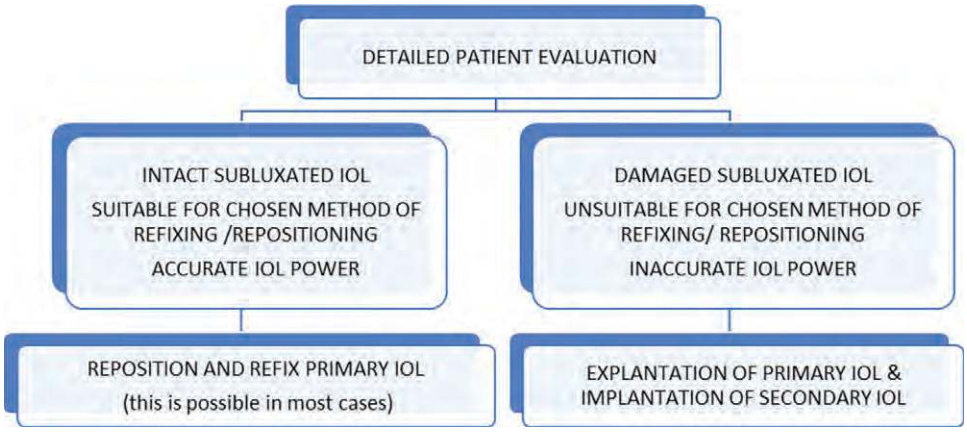

Fig. 53.9 Decision-making tree. Reposition primary IOL versus primary IOL explantation and secondary IOL implant.

- Poor postoperative refractive outcome
- Type of primary IOL is not suitable for technique of implantation (for example, a three-piece IOL is necessary for scleral fixated/Glued IOL)

Primary IOL Repositioning Techniques

Before refixing the primary IOL it is important to bring it to desired surgical plane (sulcus/iris) and release any adhesions. There are two techniques to reposition the primary IOL.

Anterior Dislocated IOL (IOL Present in Anterior Chamber)

Anterior dislocated IOLs are usually secondary to posterior capsular rent/compromise and an unintentionally/sometimes intentionally wrongly placed IOL. Anterior chamber entry is made, and viscoelastic is injected to prevent prolapse of vitreous. The IOL is then checked for adhesions/vitreous traction followed by anterior vitrectomy. Once the IOL is free of any attachments, it can be repositioned to the desired plane (behind the iris or sulcus) for refixing.

Posterior Assisted Levitation (PAL) of Posterior Dislocated IOL:[4]

This technique is performed for posteriorly dislocated IOL. Viscoelastic agent is injected in the anterior chamber to protect the cornea and prevent prolapse of vitreous. This is followed by creation of pars plana sclerotomy incisions through which instruments (e.g., spatula, sleeveless extrusion cannula-ECAL)[5] are directed into the posterior chamber to assist in levitation of the dislocated IOL lying suspended in the anterior vitreous. The same sclerotomy routes can be used for limited vitrectomy for bands/vitreous adhesions around the subluxated IOL so that all traction is released before mobilizing the IOL. The IOL is levitated into the anterior chamber through the posterior capsular rent and then prepared for refixation.

Primary IOL Explantation Techniques

There are two techniques for primary IOL explantation:

Anteriorly Dislocated IOL (IOL Present in Anterior Chamber)

In this technique, AC entry is made followed by injection of viscoelastic to prevent further prolapse of vitreous. Dislocated IOL is checked for any adhesions/vitreous traction, anterior vitrectomy is performed if needed, and the dislocated IOL is explanted (as a whole) after enlarging the incision or via a small-incision after transection with IOL cutting scissors.

Posterior Assisted Levitation (PAL) of Posteriorly Dislocated IOL

This technique is similar to PAL as discussed above; however, for explantation after the IOL is levitated, it may be explanted as described previously.

In both cases, anterior vitrectomy to clear any prolapsed vitreous, and any other anterior segment reconstructive procedures are carried out, followed by secondary IOL implantation.

Decision 2: Method to Refix the Primary IOL (Or Implant a Secondary IOL)

The next decision making involves choosing the method of primary IOL refixing. Decision making with regards to this depends on the status of capsular bag and zonules.

Subluxated IOL Because of Zonular Weakness (Intact Capsular Bag)

Subluxated IOLs with intact capsular margin are usually managed with endocapsular devices though a direct suturing technique may also be used.

Direct suturing: A double-armed polypropylene (9-0) or polytetrafluoroethylene (PTFE, Gore-Tex) suture is brought out ab interno through a scleral groove with one needle passing above and one below the haptic or CTR and also through the bag. Tying the knots down pulls the bag-IOL complex into position.

Endocapsular devices can provide stability to the bag by two different methods:

1. *By providing skeletal support to the capsular bag*: Owing to the innate circular shape of the capsular bag, most endocapsular devices are in the shape of a **complete capsular tension ring or smaller segments of a ring (e.g., Ahmed segment)**. These devices stretch out the capsular bag at its margins and help in reinforcing the framework of the bag (Fig. 53.10ab).
2. *By centering the capsular bag and anchoring it to the sclera*: This is performed very well by devices that are shaped like **hooks/anchors or paperclips**. One end of such a device is used to engage the

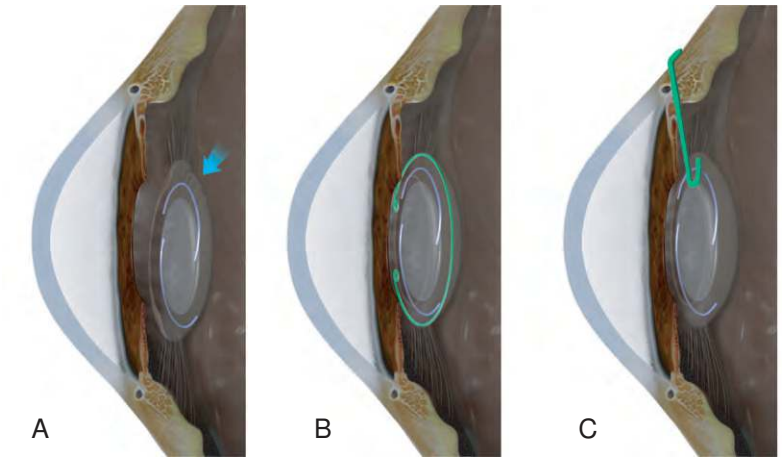

Fig. 53.10 Mechanism of support with endocapsular devices. (A) Subluxated IOL with zonular dialysis and posterior capsule wrinkling. (B) Endocapsular device reinforcing capsular bag framework like Capsular tension ring. (C) Capsular device (Jacob glued capsular hook technique) anchoring capsular bag to sclera.

TABLE 53.2 Classification of Endocapsular Devices

Temporary	Permanent
These devices are used temporarily for intraoperative fixation of the capsular bag to aid in easier surgical maneuvering. They are explanted at the end of the procedure and not retained in the eye.	These devices are implanted during the surgical procedure and are retained in the eye or sutured/glued into place to provide postoperative stability of IOL and the capsular bag complex.
Example: Capsular hooks	Example: Capsular tension ring, Cionni's ring, glued capsular hook, and paperclip capsule stabilizer techniques

TABLE 53.3 Technique of Secondary IOL Implantation/Primary IOL Repositioning in Zonular Dialysis With Intact Capsular Bag

Degree of Zonular Dialysis	Choice of Management
Zonular dehiscence of 3–4 clock hours	CTR
Zonular dehiscence of 4–6 clock hours	Cionni ring (modified CTR) with single loop. Ahmed's ring segment, Assia anchor, Jacob paperclip capsule stabilizer, Jacob glued capsular hook
Zonular dehiscence of 6–9 clock hours	Cionni ring (modified CTR) with double loop, double placement of glued capsular hook, paperclip capsule stabilizer, Ahmed segments or others
Zonular dehiscence of 9–12 clock hours	Scleral or iris fixated IOL (see details in Table 53.4); alternatively, scleral fixation at multiple points may be tried.

anterior capsular margin and center the capsular bag, and the other end is fixed to the sclera to hold it in place (see Fig. 53.10c).

Cionni's modified capsular tension ring and Ahmed segments support the capsular bag by both mechanisms to varying degrees; the ring supports the framework of the bag, whereas the eyelet on the loops help anchor the device to the sclera via a suture.

Endocapsular devices can also be classified as[6] Table 53.2.

Temporary: These devices are used temporarily for intra operative fixation of the capsular bag to aid in easier surgical maneuvering. They are explanted at the end of the procedure and not retained in the eye. It includes various forms of capsular hooks that are available commercially.

Permanent: These devices are implanted during the surgical procedure and are retained in the eye or sutured/glued in place to provide postoperative stability of IOL and the capsular bag complex. Intrascleral haptic fixation of the capsular bag through glued capsular hooks have been described as permanent method to stabilize subluxated IOLs by one of the authors (SJ). Other techniques include the paperclip capsule stabilizer, also described by the author (SJ).[7]

Choice of Endocapsular Devices Largely Depends on Degree of Subluxation/Zonular Dialysis (Fig. 53.11) (Table 53.3)

Zonular Dehiscence Up to 3 to 4 Clock Hours (90 degrees)

1. Capsular tension rings (CTR) with in the bag IOL implantation:
   These provide skeletal framework to the bag by providing support at the equator and stretching the posterior capsule to avoid wrinkling. At each end of the ring are small holes that help in engaging the device for surgical positioning in the bag (Fig. 53.11a).
   Modified versions of the plain CTR include[8] the following:
   a. Iris plates for cases of partial (see Figs. 53.11d, 53.11e)/total aniridia (see Fig. 53.11f)
   b. Improved structural design (e.g., Ophtec CTR with smooth ski tip to prevent capsular margin damage caused by entanglement)
   c. Henderson's modified capsular tension ring: It has indentations to allow easy removal/aspiration of cortex in case of primary surgery done for subluxated cataracts.

Zonular Dehiscence of 3 to 6 Clock Hours (90–180 Degrees)

1. Cionni's modified CTR with single loop and in the bag IOL implantation:
   Cionni modified the conventional CTR with an additional internal loop and eyelet on one side. This loop helps anchor the implant to the sclera via a suture passed through the eyelet, thus providing better bag stability and support to the IOL.[9] The single loop model (see Fig. 53.11b) is used for lesser degrees of zonular dialysis whereas, the double loop model (see Fig. 53.11c) is used in cases of increased zonular dehiscence. The Malyugin-Cionni CTR is an injectable version of the conventional Cionni ring. See Chapter 34.
2. Ahmed capsular tension segments and in the bag IOL:
   This is a modified segment of the Cionni ring with a single loop. One segment stabilizes smaller zonular dialysis, and two segments can be used for higher degrees of zonular dialysis. (see Fig. 53.11g). See Chapter 34 for additional description and video.
3. Assia Anchor with in the bag IOL:
   The anchor is made of PMMA and is composed of a central rod and two lateral prongs on either side (see Fig. 53.11h). One set of lateral prongs is internalized to engage the anterior capsular rim, while another set is externalized to anchor the device with a suture to the sclera.[10] The internal set of lateral prongs are place under the anterior capsulorrhexis edge. The tips of the prongs extend to the capsule equator and provide firm support. See Chapter 34 for a fuller description with video.
4. Jacob Paper Clip Capsule stabilizer with in the bag IOL:
   This is a small endocapsular device made of blue PMMA. It has a paper clip component and a tail-like segment (see Fig. 53.11I). The paperclip component engages the capsulorrhexis margin and helps center the bag, whereas the tail-like haptic is exteriorized and tucked into the Scharioth tunnel to be glued under scleral flaps (Fig. 53.12) (Video 53.1). This device allows a sutureless method of stabilizing the capsular bag, and its small size decreases the needed manipulation for inserting it into fibrosed capsular bags. More than one device can be used for higher degrees of zonular dialysis[11] (Fig. 53.13).
5. Ambati Capsular Tension Segments with in the bag IOL:
   The Ambati Capsular Tension segment is a PMMA segment with 2 eyelets (instead of 1). This allows a uniform distribution of tension along the anterior capsular rim and prevents damage to anterior capsule caused by pinpoint areas of stress. A single segment stabilizes zonular dehiscence of up to 180 degrees, and double segments can be used for zonular dehiscence of >180 degrees.[12]
6. Jacob Glued Capsular Hook with in the bag IOL:

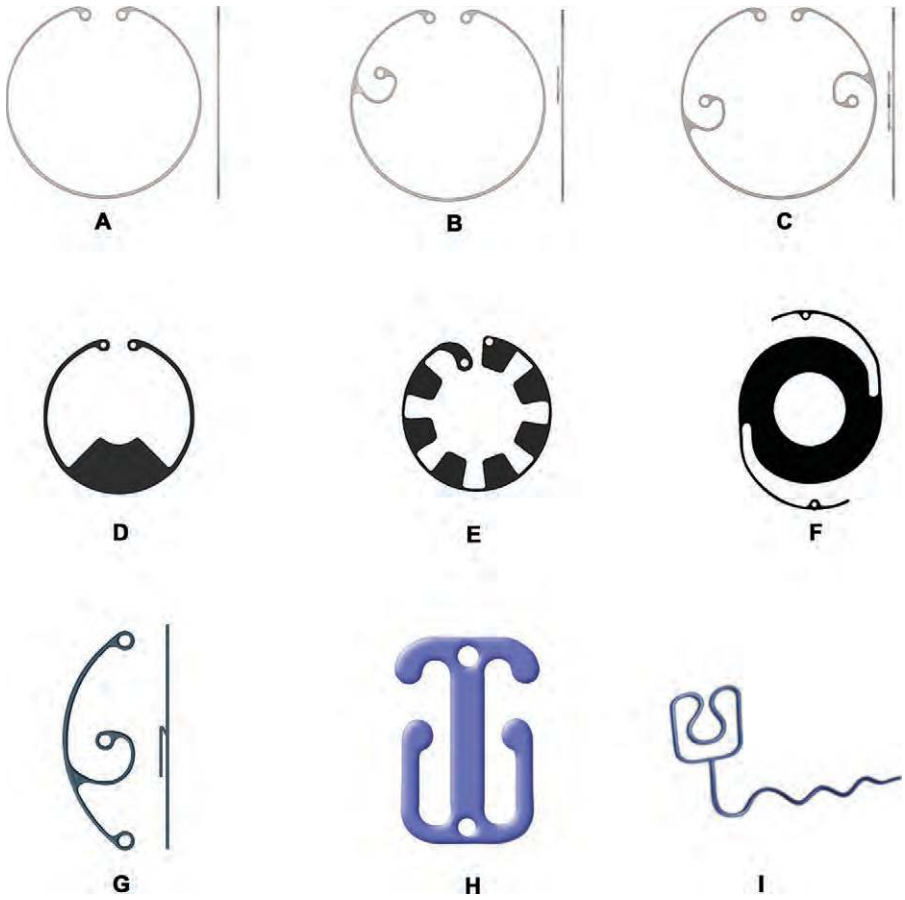

Fig. 53.11 Endocapsular devices. (A) Capsular tension ring. (B) Cionni ring with single loop. (C) Cionni ring with double loop. (D) Capsular tension ring with iris plate. (E) Capsular tension ring with iris plates. (F) IOL for aniridia. (G) Ahmed ring segments. (H) Assia anchor. (I) Jacob paperclip capsule stabilizer.

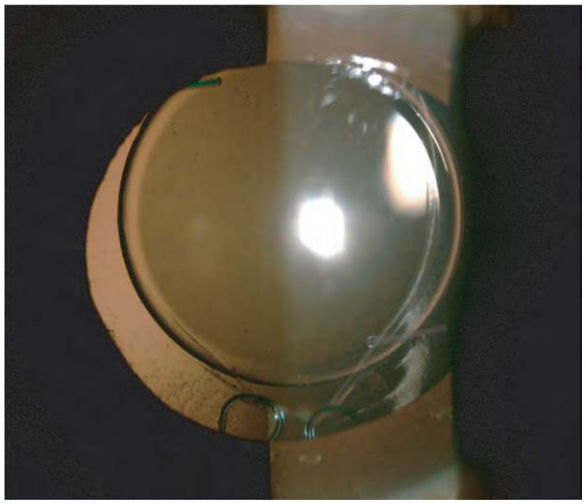

Fig. 53.12 Dilated examination showing Jacob paperclip capsule stabilizer as permanent method of IOL fixation for in the bag IOL subluxation.

This technique described by one of the authors (SJ) uses the hook shaped endocapsular device that is conventionally implanted temporarily for intraoperative stability of lens for permanent fixation of the bag in cases of subluxation of more than 3 to 4 clock hours.[13]

A capsular hook is modified to have a bend in its tail, these are crimped closer together (Fig. 53.14). The hooked end is implanted through sclerotomy opening under a scleral flap, and it is used to engage the anterior capsular rim to center the capsular bag, whereas the tail haptic that is passing through the sclerotomy is trimmed and tucked under a scleral tunnel (Fig. 53.15). The plane of passage is below the iris and above the anterior capsule. The scleral flap is then sealed with glue, thereby avoiding the need for sutures. The glued capsular hook can also be used in combination with other rings/segments to provide additional stability in the presence of large degrees of subluxation (Video 53.2).

Zonular Dehiscence of 6 to 9 Clock Hours (180–270 degrees)

1. Cionni ring with double loop and in-the-bag IOL implantation.
2. Dual or more placement of other devices such as glued capsular hooks, paperclip stabilizer, Ahmed segments etc.

Management of Subluxated IOL With Damaged Capsular Bag and Discontinuity in Capsular Margins (Posterior Capsular Compromise, Rhexis Run Away, Can Opener Rhexis) (Table 53.4)

1. **Optic Capture:** With a centered rhexis that is smaller in size than the optic, the IOL haptics may be placed in the sulcus and the optic

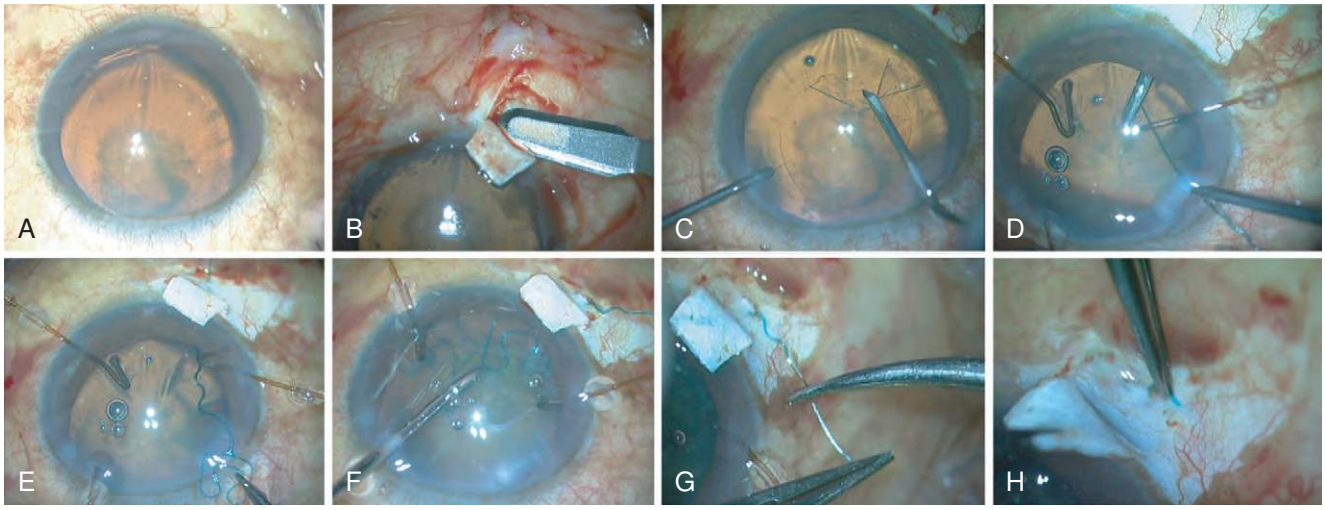

Fig. 53.13 Jacob paperclip capsule stabilizer: Steps of surgery. (A) Area of zonular dialysis is noted after complete dilation of pupil. (B) Scleral flap with Scharioth tunnel are fashioned adjacent to the area of zonular dialysis. (C) Capsulorrhexis is performed. (D and E) The tail-like haptic is inserted via the main port incision and exteriorized through the scleral flap using microforceps. (F) The paperclip component engages the capsulorrhexis margin and helps center the capsular bag. (G and H) The trailing haptic is tucked into the Scharioth tunnel to be glued under scleral flaps.

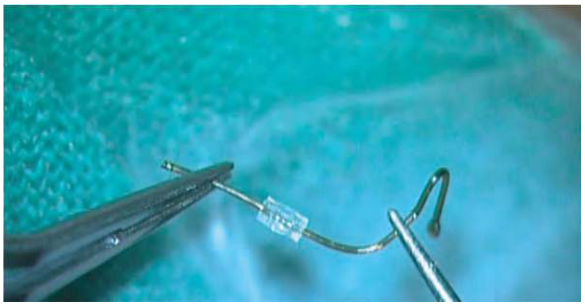

Fig. 53.14 Glued capsular hook (Jacob et al.).

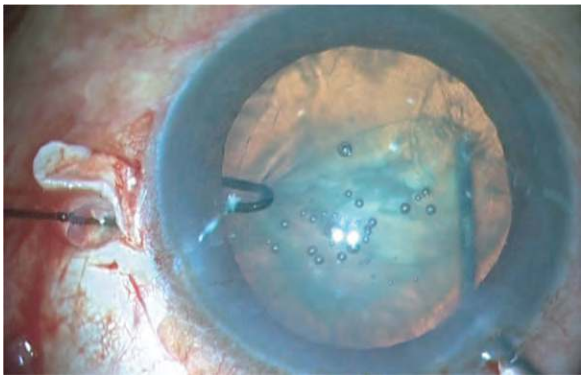

Fig. 53.15 Glued capsular hook. The hooked end is implanted through a sclerotomy opening under a scleral flap, and it is used to engage the anterior capsular rim and center the capsular bag. The tail (haptic) that is passing through the sclerotomy is trimmed and tucked into an intrascleral Scharioth tunnel.

pushed below the rhexis margins to be captured by the rhexis. With an IOL that is subluxated posterior to the rhexis, a reverse optic capture may be done.

2. **AC IOL (Anterior Chamber IOL):** This is discussed in Chapter 41: Secondary IOL Implantation.

TABLE 53.4 Technique of Secondary IOL Implantation/Primary IOL Repositioning With Damaged Capsular Bag or Zonular Dehiscence of More Than 9 Clock Hours

Location of Fixation	Method of Fixation	IOL Specifications
Anterior Chamber	**Iridocorneal angle supported**	These are rigid/semiflexible IOL with open loop haptic and footplates for three-/four-point angle fixation.
Iris Fixation	**Suture iris fixated**	Posterior angulated three-piece IOL
	Iris claw lens	IOL with claw like haptics that pinch iris tissue for fixation
Scleral Fixation	**Sutured scleral fixated IOL**	Three-piece IOL with one eyelet on each haptic (e.g., Alcon CZ70BD and Bausch and Lomb 6190B). Opsia Grenat IOL has two eyelets on each haptic
	Scharioth intrascleral tunnel	Standard three-piece IOL with haptic size of 13.5 mm
	Glued IOL	Three-piece IOL (PMMA/foldable) (preferable haptic material is PMMA/PVDF (polyvinylidene fluoride)/polyamide)
	Yamane transconjunctival fixation	Three-piece IOL with PVDF (polyvinylidene fluoride) haptics that are amenable to cautery -CT Lucia 602 (Zeiss)
	CM T Flex Foldable IOL	Hydrophilic foldable IOL; 13.75 mm diameter, posterior angulation of 10 degrees and specialized T-shaped haptics

3. **Iris Fixated IOL:**
   a. *Sutured*: See Chapter 41 Secondary IOL Implantation for full description of this technique.
   b. *Iris Claw Lens*: These are IOL with specially designed haptics that act like claws to pinch iris tissue between them. These IOLS can be fixed anterior to the iris (prepupillary) or posterior to the iris (retro-pupillary) (Fig. 53.16).[14]
4. **Scleral Fixated IOLS:** In absence of capsular bag, PMMA three-piece IOLs can be used. The optics are centered behind the pupil, whereas the haptics are placed below the iris and exteriorized via anterior sclerotomies to be fixed to the sclera via various techniques.
   a. *Sutured scleral fixated IOL*: See Chapter 41 Secondary IOL Implantation for description of technique (10-0 or 9-0 Prolene or 8-0 PFTE can be used). Various modifications have been made to the suturing techniques in scleral fixated IOL. These include change in suturing techniques like the modified sewing machine technique[15] and the modified Siepser knot.[16] Modifications also vary with regards to the part of IOL anchored to sclera.
   b. *Scharioth intrascleral haptic fixation and the glued IOL*: In 2007, Scharioth et al.[17] introduced the technique of ISHF by externalizing IOL haptics through two ab externo straight sclerotomies made 180 degrees apart from each other and tucking the haptics into limbus-parallel tunnels starting from the sclerotomies. Later, a variation of this technique was introduced by Agarwal et al.[18] where sutureless intrascleral haptic fixation of the IOL is aided with scleral flaps and fibrin glue (Fig. 53.17; Video 53.3). Both techniques can be performed with rigid and flexible IOLs. The glued IOL technique of ISHF has been used in children and also in combined surgeries and special situations, such as aniridia and multifocal IOLs.[19]

Scharioth's Intrascleral Tunnel Technique and Glued IOL (Key Points)

- Both techniques are somewhat similar. Dissimilarities have been highlighted below.

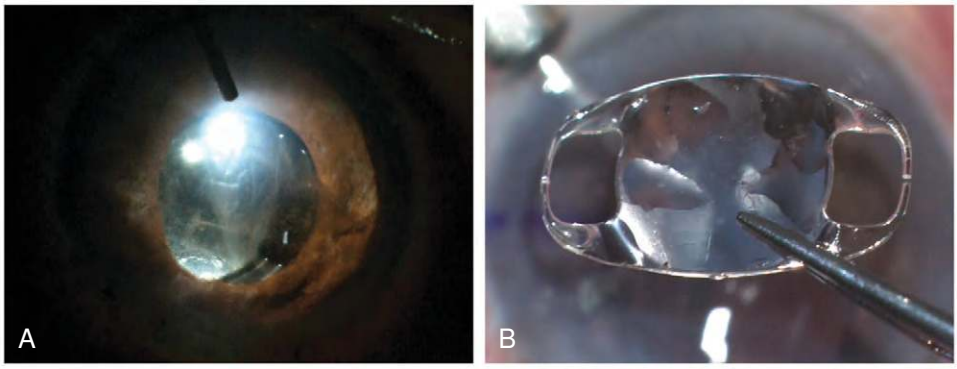

Fig. 53.16 (A) Subluxated retro-iridal claw IOL pinching the iris posteriorly at the 3 o'clock position. (B) Intact iris claw IOL after explantation.

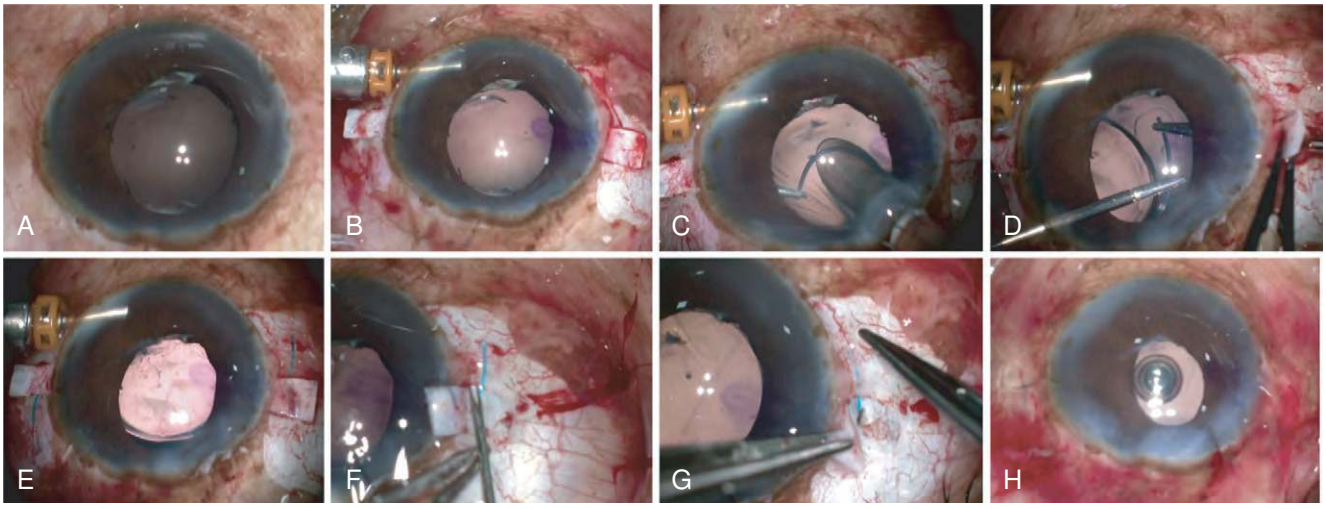

Fig. 53.17 Glued IOL: Steps of surgery. (A) Anterior vitrectomy is performed to clear prolapsed vitreous and free any vitreous adhesions. (B) Partial thickness scleral flaps are created 180 degrees apart after surgical marking followed by sclerotomies with a 23 G needle 2 mm from the limbus. The anterior chamber is maintained using an AC maintainer/ trocar anterior chamber maintainer or a 23 G pars plana trocar infusion cannula. (C) The secondary IOL is loaded and injected through a clear corneal incision (in case of foldable IOL). (D and E) The leading haptic is grasped via 25 G microforceps and exteriorized from under the iris plane through the adjacent sclerotomy to under the scleral flap; similarly, the trailing haptic is exteriorized under the scleral flap on the opposite side. (F) Intrascleral tunnels (Scharioth tunnels) are fashioned using a 26 G needle at the edge of both flaps. (G) This is followed by intrascleral tuck of the haptics and sealing of the partial thickness scleral flaps with fibrin glue.

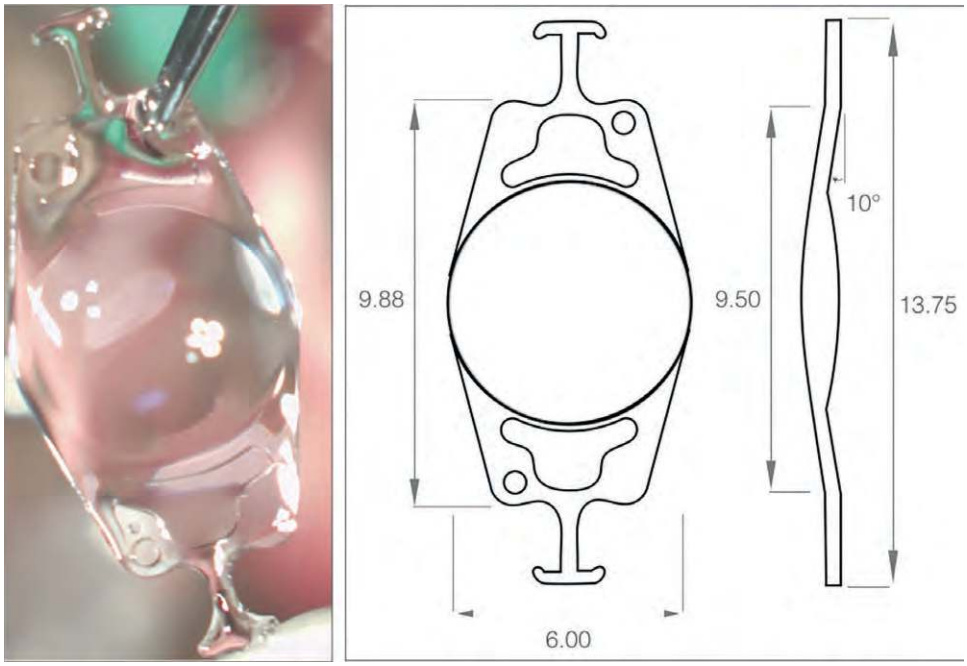

Fig. 53.18 CMT flex foldable IOL.

- In case of glued IOL, lamellar scleral flaps are created 180 degrees apart, centered on the pupil. The anterior chamber is maintained using an AC maintainer/ trocar anterior chamber maintainer or a 23 G pars plana trocar cannula infusion. Anterior vitrectomy is performed to clear prolapsed vitreous and free any vitreous adhesions. Ab externo sclerotomies are created under the lamellar flaps about 1.5 to 2 mm from the limbus with a 23 or 24 G needle.
- With the Scharioth technique, two ab externo sclerotomies are created directly without creating scleral flaps. The same cannula is used to create intrascleral Scharioth tunnels parallel to the limbus, near the sclerotomies. Glued IOL technique uses 26 gauge cannulas to create Scharioth tunnels to obtain a tighter fit of the haptics.
- In both techniques, a three-piece IOL is then loaded to begin injection into the eye through a separate clear corneal incision.
- As the leading haptic exits the injector, it is grasped with a specially designed 25 G Scharioth's forceps that is inserted through the adjacent sclerotomy. The haptic is then pulled out and exteriorized. The leading haptic may be temporarily held in place via forceps by the surgical assistant or by using silicon tires from iris retractors while the trailing haptic is being exteriorized.
- The same technique is repeated for the trailing haptic.
- Both haptics are then tucked in the intrascleral tunnel. Vitrectomy is done at the sclerotomy site to remove any prolapsed vitreous. In the glued IOL technique, the scleral flap and conjunctiva are glued down using fibrin glue so that no part of the haptic is exposed. This also aims at decreasing the risk for endophthalmitis and wound leaks.
  a. **The supracapsular glued IOL[20] technique:** This was described by one of the authors (SJ) and may be used in situations where an out-of-the-bag three-piece subluxated IOL is present with intact and stable anterior and posterior capsular remnants. The same IOL may be translocated and haptic externalized via a plane above the anterior capsule so that the capsular remnants act as a support and a scaffold. This is especially useful when combining with endothelial keratoplasties as it gives a more stable air tamponade in the postoperative period and helps to maintain a nonmigrating air bubble.
  b. **Yamane's flanged technique for sutureless fixation:** See Chapter 41 Secondary IOL Implantation for a full description of this technique.[21]
  c. **CMT Flex Foldable IOL:** This is a new IOL (Appasamy Associates, Chennai, India) with specially designed T shaped haptics to allow easier scleral fixation (Fig. 53.18). Two partial-thickness scleral flaps are created 180 degrees apart; 23 G sclerotomies are then designed to perform vitrectomy. The IOL is implanted through a 2.5 mm clear corneal incision, and the specially designed T-shaped haptics are externalized to be fixed with fibrin glue under the scleral flaps.[22]

SUMMARY

Subluxation and dislocation of IOL is a recognized complication of cataract surgery, which most cataract surgeons are bound to encounter in their practice. Detailed evaluation is a must to diagnose the etiology and assist in correct decision making with regards to management. Careful intervention with a word of caution is necessary while planning surgery in the other eye too.

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Video 53.1 Paperclip capsule stabilizer.
Video 53.2 Glued capsular hook.
Video 53.3 Glued IOL.

54

Neodymium:Yttrium-Aluminum-Garnet Laser Applications in the Cataract Patient

Lauren E. Chen, Ken Y. Lin, and Matthew Wade

CONTENTS

KEY POINTS

- Posterior capsular opacification is very common after cataract extraction. Nd:YAG laser capsulotomy is the treatment of choice.
- Nd:YAG laser can also be used to perform laser peripheral iridotomy and anterior hyaloid vitreolysis to address pupillary block glaucoma.
- For patients with vitreous strands associated with cystoid macular edema after cataract extraction, Nd:YAG laser vitreolysis may be helpful.

INTRODUCTION

The neodymium:yttrium-aluminum-garnet (Nd:YAG) laser is a short, high-power pulse that generates ionization and plasma formation, causing shock and acoustic waves-that disrupt intraocular structures.[1] This chapter focuses on the most common applications of Nd:YAG laser in the postcataract extraction patient.

PROCEDURE SPECIFICS

An explanation of the procedure and informed consent should be obtained before using the Nd:YAG laser. Ocular Nd:YAG laser procedures are contraindicated if significant corneal scarring, edema, or irregularities preclude adequate visualization of the target aiming beam or degrade the Nd:YAG laser beam optics. Patients who cannot fixate adequately are not ideal candidates because of the threat of inadvertent damage to adjacent intraocular structures. Children who can tolerate a slit lamp exam may be good candidates, but sedation may be needed.

Additional relative contraindications to Nd:YAG posterior capsulotomy include patients with a glass intraocular lens (IOL), known or suspected cystoid macular edema (CME), active inflammation, or a high risk for retinal detachment. Nd:YAG laser peripheral iridotomy (LPI) is relatively contraindicated in patients with active uveitis or very shallow anterior chambers. For Nd:YAG vitreolysis, patients should understand that the procedure often requires more than one session.

ND:YAG LASER CAPSULOTOMIES

Posterior Capsule Opacification (PCO)

Fibrotic PCO may present as broad wrinkles that are rarely visually significant or as fine wrinkles that cause marked optical disturbance (Fig. 54.1). PCO can also appear as small Elschnig pearls and bladder cells (Fig. 54.2).

Anterior Capsule Contracture

After cataract surgery, the remaining anterior capsule can contract, opacify the visual axis, and even rupture zonular support (Fig. 54.3). Depending on the severity of contracture, early Nd:YAG laser anterior capsulotomy can improve visually significant capsular contraction.

Negative Dysphotopsia

Negative dysphotopsia describes the perception of a crescentic temporal shadow in the visual field.[2] Although the cause of negative dysphotopsia is debated, the interface between the nasal anterior capsule and the anterior IOL surface is thought to be a contributing factor. Nd:YAG laser anterior nasal capsulectomy may be helpful in some cases.[3,4]

Considerations

Postcataract Extraction Timing of Nd:YAG Posterior Capsulotomy

Ample time should be given postoperatively for the capsule to shrink tightly around the IOL and stabilize it, especially when the capsulotomy opening is larger than the optic. Early Nd:YAG posterior capsulotomy with an unstable IOL poses the risk for IOL movement and vitreous prolapse.

For patients with a history of uveitis, Nd:YAG posterior capsulotomy may be delayed until disease is quiescent for 3 months and may be supplemented by preoperative and postoperative courses of steroids.[5]

Multifocal IOLs

Multifocal IOLs may be less tolerant to PCO.[6] It is important to verify that decreased visual quality and patient dissatisfaction is because of

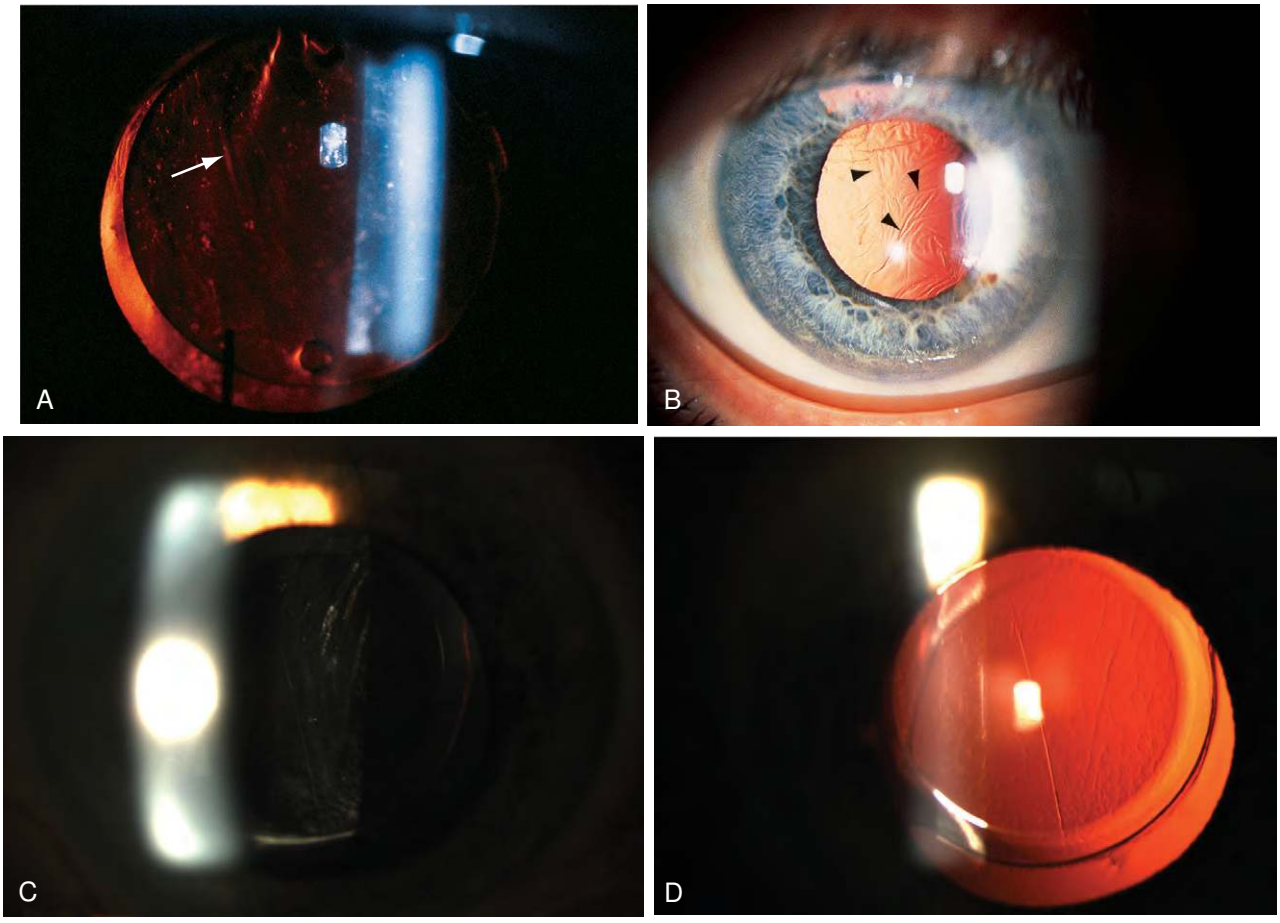

Fig. 54.1 (A) Broad wrinkles of the clear posterior capsule (*arrow*) are seen on red reflex, with numerous small epithelial pearls. (B) Fine wrinkles in the posterior capsule are evident on red reflex (*arrowheads*). These wrinkles alone can be visually disturbing and can reduce acuity by several lines or cause Maddox rod light streaks. (C) and (D), Posterior capsule opacification viewed directly via slit lamp and indirectly via red reflex view, respectively. (From Steinert RF, Puliafito CA: The Nd:YAG laser in ophthalmology: Principles and clinical applications of photodisruption Elsevier, 1985.)

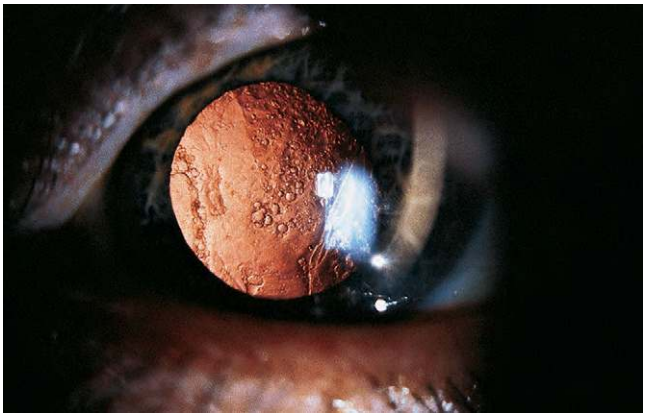

Fig. 54.2 Red reflex view shows formation of multiple small epithelial pearls after anterior epithelial cells migrate centrally from peripheral areas of apposition of anterior capsular flaps to the posterior capsule. (From Steinert RF, Puliafito CA: The Nd:YAG laser in ophthalmology: Principles and clinical applications of photodisruption Elsevier, 1985.)

PCO and not secondary to the multifocal optics, as IOL exchange after a Nd:YAG laser posterior capsulotomy is more difficult.

Accommodative IOLs

Accommodative IOLs rely on the pliability of the haptic optic junction to shift their shape with ciliary muscle movement. Accommodative IOLs may be particularly sensitive to opacification and fibrosis of the capsule.

Nd:YAG capsulotomy may be used to treat Z-syndrome, a rare condition where capsular contraction causes the haptics of an accommodative IOL to tilt in a "Z" formation (Fig. 54.4).[7]

Capsular Bag Distension Syndrome (CBDS)

Capsular bag distension syndrome (CBDS) describes the presence of transparent or milky fluid within the capsular bag that displaces the IOL axially, presenting with unexpected myopia and poor visual acuity after cataract extraction. Etiologies include intraoperative rapid hydrodissection, inadequate cleaning of the cortex resulting in remnant LECs, retained ocular viscoelastic devices, and sequestration of bacteria such as Propionibacterium acnes.[8] Nd:YAG laser posterior capsulotomy is an accepted effective standard treatment for CBDS.[8]

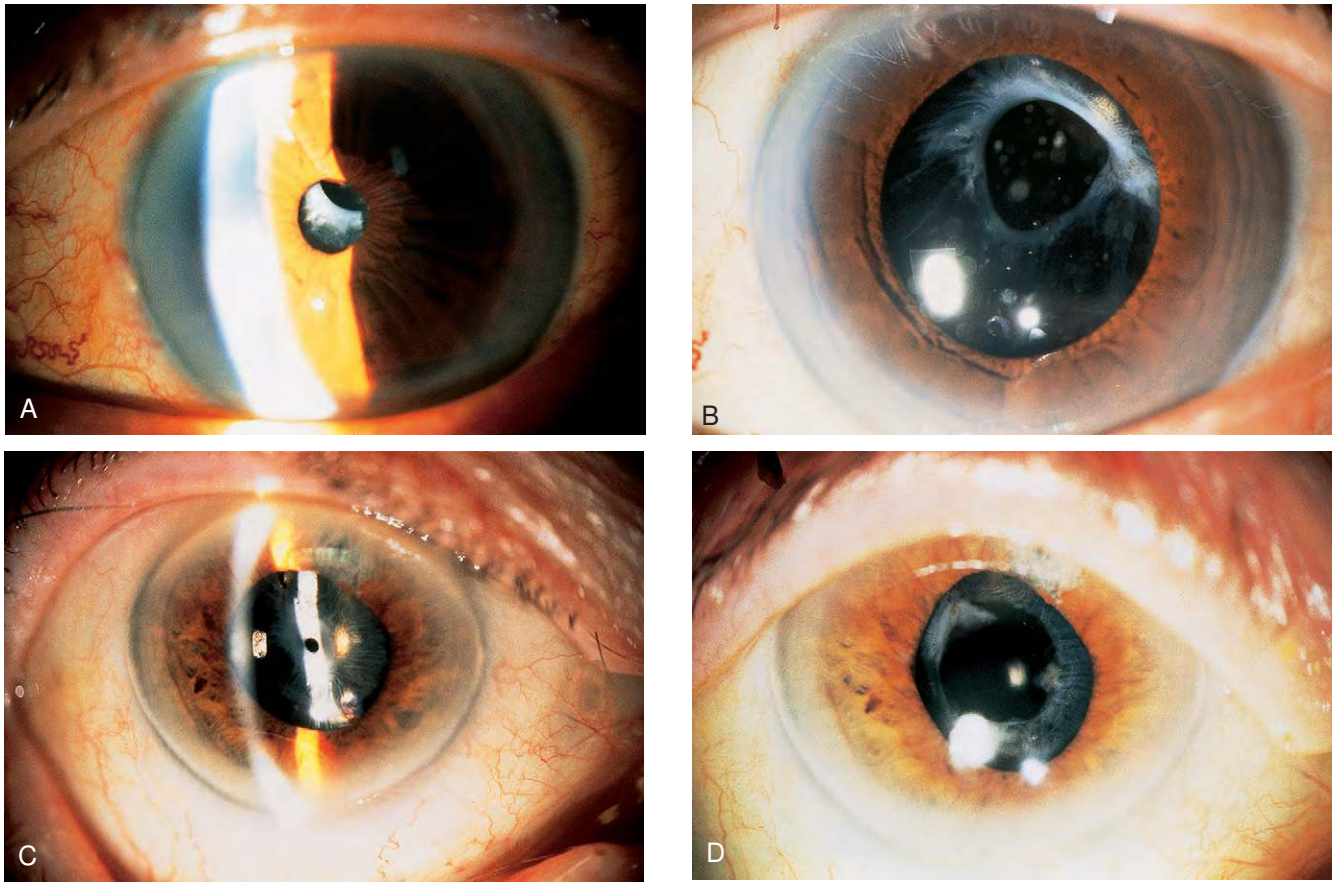

Fig. 54.3 (A) Contracture of the anterior capsule inferiorly has nearly occluded the optical zone. (B) Dilated view of same eye: Nd:YAG laser cutting of the inferior capsule adhesion will restore an adequate visual axis. (C) Symmetric contracture of the anterior capsulorrhexis leaves an inadequate visual axis. (D) Photodisruption of the anterior capsulotomy edge restores an adequate visual axis.

Preoperative Management

Careful dilated assessment is necessary to be certain that PCO is causing decreased visual acuity. A contact lens such as the Peyman or central Abraham lens is recommended to stabilize the eye, prevent eyelid closure, improve the laser beam optics, and facilitate accurate focusing.

Nd:YAG Laser Posterior Capsulotomy

The capsulotomy should be sufficiently large enough to reduce glare, typically larger than 4 mm.[9,10] Differences in IOL design or multifocal focusing area diameters may be considered as well.

The most commonly performed patterns are cruciate and circular, followed by an inverted U pattern (Fig. 54.5). Although the circular and inverted U patterns avoid centrally placed laser shots, both can result in a capsular remnant that may float into the visual axis. The cruciate pattern does not generate flaps and typically can be performed with fewer pulses and less energy. However, the central laser shots pose the risk for IOL pitting in the visual axis.

Laser-induced IOL damage is fairly uncommon.[11] In clinical practice, mild IOL pitting is not typically visually significant,[12] but severe IOL damage can cause sufficient glare and image degradation to warrant explantation.[13] Box 54.1 summarizes techniques to minimize IOL laser marks.

The visible focusing laser and the invisible Nd:YAG lasers are aligned. The focusing laser can be programmed with an anterior or posterior offset from the treatment laser.

Use of a condensing lens such as the Abraham Nd:YAG lens increases the laser convergence angle, which decreases the focus spot size at the posterior capsule. Fig. 54.6 demonstrates how a condensing contact lens narrows the range of high energy density surrounding a target, thereby increasing the precision of optical breakdown and mitigating damage to surrounding tissue.

Nd:YAG Posterior Capsulotomy for Posterior Capsule Opacification

Box 54.2 contains key surgical pearls for this procedure, and Video 54.1 demonstrates the procedure with a few examples.

- Step 1: Set the energy level to 1 to 2 mJ and consider a posterior laser offset of 100 to 200 um.
- Step 2 Cruciate Pattern:
  - Manually focus at the 12 o'clock position and progress to the 6 o'clock position. If visualization is poor, start in an area of high capsule opacification.
  - From the middle edge of the capsule opening, progress laterally toward 3 and 9 o'clock positions.
- Step 2 Circular Pattern:
  - Manually focus at the 12 o'clock position and progress in a circular pattern.
- Step 3: Any flaps that remain in the pupillary space may be cut radially with the laser; these flaps typically retract.

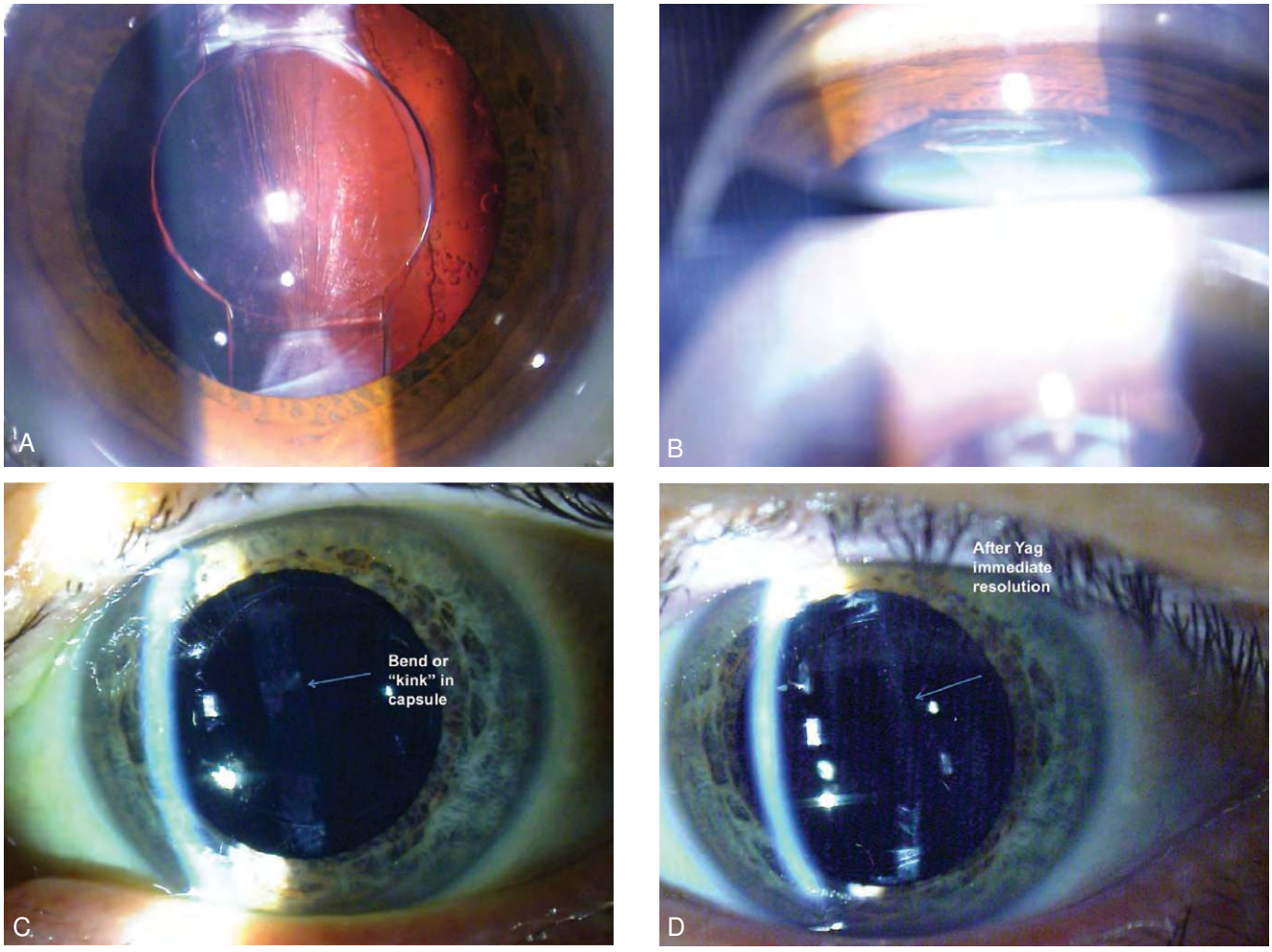

Fig. 54.4 Z-syndrome secondary to tilting of the accommodative intraocular lens may have visible features of (A) capsular guitar string like folds or (B) forward bending of the intraocular lens. (C) Bending or kinking of the capsule secondary to Z-syndrome that resolved (D) after Nd:YAG laser treatment. (Courtesy Steven G. Safran, M.D. safran12@comcast.net.)

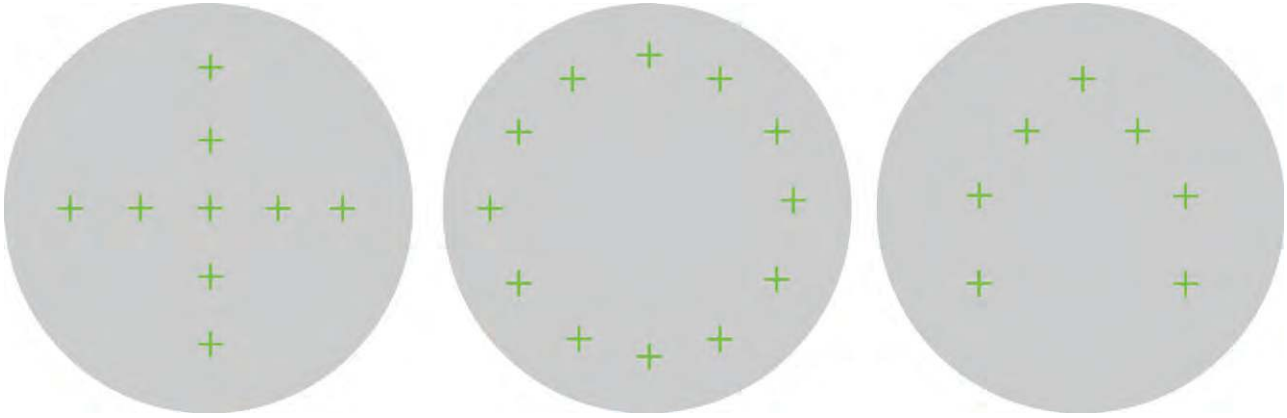

Fig. 54.5 Common patterns of Nd:YAG laser posterior capsulotomy include cruciate, circular, or inverted U shapes.

ND:YAG ANTERIOR CAPSULOTOMY FOR CAPSULAR CONTRACTION SYNDROME

- Step 1: Set the energy level to 1 to 2 mJ; increase energy as needed to cut the fibrotic anterior capsule.
- Step 2: Aim at the margin of the capsulorrhexis edge. Manually focus and consider an anterior laser offset of 100 to 200 um or manually focus slightly anteriorly.
- Step 3: Aim to transect the round edge into at least four quadrants in a spoke-like fashion with approximately 1 mm radial nicks in the contracted capsule annulus.

Postoperative Management and Complications

Postoperative follow up and treatment vary. Follow-up is typically between 1 to 4 weeks if indicated.

Postoperative steroids and/or cycloplegic agents are not typically indicated. Patients at higher risk for inflammation include those with CBDS, history of uveitis, communication between the vitreous cavity and the anterior chamber after Nd:YAG, and those at risk for CME. When indicated, steroids are used for 1 week and then discontinued or tapered as needed.

Rates of intraocular pressure (IOP) elevation after Nd:YAG are relatively low, and IOP lowering medications are not routinely necessary.[15]

The incidence of CME after Nds:YAG capsulotomy has been reported to be between 0.7 and 4.9%.[15] Prospective studies after Nd:YAG laser posterior capsulotomy found no CME at 4 to 10 weeks follow up.[16,17] Rates of CME are lower when there is in-the-bag IOL placement and delayed Nd:YAG posterior capsulotomy.[15]

Historically, the reported risk for retinal detachment after Nd:YAG was 0.5-3.6%, with risk factors of high myopia, lattice degeneration, and previous detachment.[15] However, recent rates have been reported to be 0.0% to 1.59%.[18]

Cases of IOL backward movement or displacement, endophthalmitis from release of sequestered bacteria within the capsule, and macular hole development are rare but have previously occurred.[15]

BOX 54.1 Minimizing Intraocular Lens Laser Marks During Capsulotomy

- Use the minimum necessary energy.
- Use a condensing contact lens.
- Use a slight manual defocus away from the IOL.
- Offset the treatment laser posteriorly (for posterior capsulotomies) or anteriorly (for anterior capsulotomies) from the aiming beam.

ND:YAG LASER IRIDOTOMY

Laser iridotomy may be performed using primarily Nd:YAG or after pretreatment with argon laser.

Preoperative Management

Nd:YAG laser peripheral iridotomy (LPI) is relatively contraindicated in patients with active uveitis or very shallow anterior chambers.

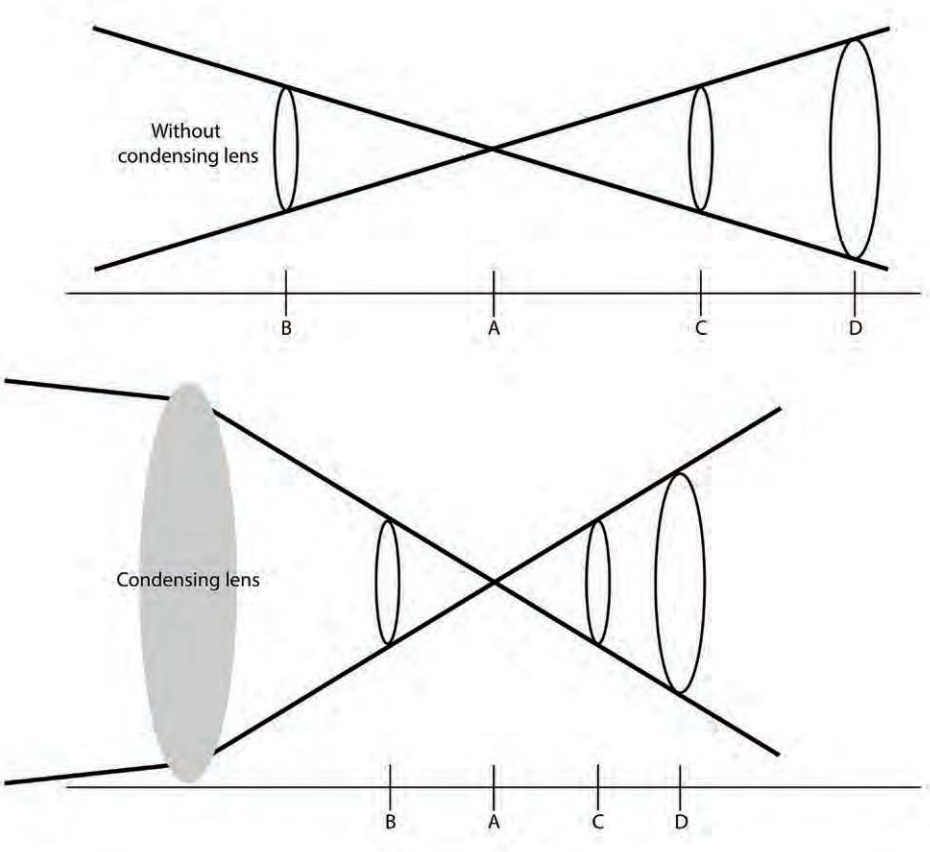

Fig. 54.6 A condensing lens narrows the axial range of energy density sufficient to cause tissue interaction (point B to C), minimizing the risk for damage to surrounding structures around point A. (Figure adapted from Ophthalmic Microsurgery.[14])

The pressure may rise after Nd:YAG LPI, for which IOP-lowering medications such as apraclonidine or brimonidine can be applied 1 hour prior the procedure and immediately after. This is especially important in the setting of acute angle closure crisis.

If the patient has not already been treated maximally with miotic agents, application of a miotic agent such as pilocarpine 2% is advisable to place the iris on maximal stretch.

Corneal edema may be cleared by topical glycerin 10%, systemic acetazolamide, intravenous mannitol, or oral hyperosmotic agents. An Abraham iridotomy contact lens may be applied to stabilize the eye and increase the convergence of the laser beam.

Nd:YAG Laser Peripheral Iridotomy

Ideal iridotomy targets are areas of iris crypts or thinning in the periphery but central to any arcus senilis. Location preference for superior, supranasal, supratemporal, nasal, or temporal iridotomy placement is debated and varies by surgeon experience.

LPIs should be full thickness and patent. Transillumination may occur in nonpatent iridotomies, so patency should be confirmed by visualization of lens zonules and posterior to anterior flow of iris pigment mixed with aqueous.

Perforating a hole in the iris, ideally in one pulse, provides an alternative pathway for aqueous flow, and relieves pupillary block. It is important to note that LPI specifically alleviates pupillary block and may not fully treat other causes of narrow angle, such as plateau iris or anterior rotation of the ciliary body.

Nd:YAG Iridotomy for Pupillary Block Glaucoma

Box 54.4 contains key surgical pearls for Nd:YAG iridotomy and Video 54.2 demonstrates the procedure

- Step 1: Set the energy level to 4 to 8 mJ.
- Step 2: Assess for a thinned iris crypt. Manually focus on the peripheral iris stroma and avoid vessels.

ND:YAG ANTERIOR HYALOID VITREOLYSIS FOR MALIGNANT GLAUCOMA

On rare occasions, malignant glaucoma may occur after intraocular surgeries, particularly glaucoma surgeries. These patients often present with elevated IOP and a diffusely shallow anterior chamber, sometimes rendering malignant glaucoma difficult to discern from pupillary block. However, in malignant glaucoma, anterior rotation of the ciliary body causes a posterior diversion of aqueous. As such, malignant glaucoma is also known as ciliolenticular block. In the presence of a large iridectomy where visualization of the ciliary processes is possible, an argon laser photocoagulation of the ciliary body can be attempted to break the malignant glaucoma. However, more commonly, in aphakic or pseudophakic eyes, Nd:YAG laser can treat malignant glaucoma by disrupting the anterior hyaloid face or the posterior lens capsule and hyaloid face.

Postoperative Management and Complications

Postoperatively, topical steroid therapy such as prednisolone acetate 1% or dexamethasone 0.1% is used four times daily or more as inflammation requires. Cycloplegics are helpful to decrease synechia formation if inflammation is present.

Intraocular bleeding during laser treatment is a common complication and may be treated with pressure from a contact lens for 45 to 60 seconds to achieve hemostasis. Usually, hyphemas resolve spontaneously. Avoidance of vessels during the procedure and pretreatment with argon laser for its coagulative properties, especially in darkly pigmented eyes, may decrease risk for hyphema. Studies show no differences in hyphema incidence or severity with stopping anticoagulant or antiplatelet medications prior to Nd:YAG iridotomy.[19]

IOP may rise as a result of the release of iris pigment, blood, and debris from Nd:YAG iridotomy.[20–22] Before discharge, a postoperative IOP check may be performed. If questionable patency is achieved or IOP rises soon after the procedure, the patient should be closely evaluated for elevated IOP, patency, and inflammation, and treated appropriately. Higher laser energy, number of pulses, and shallower central anterior chambers seem to correlate with increased rates of IOP spike 1 hour postoperatively.[21]

Endothelial cell counts can also be affected depending on the proximity of the laser pulse to the cornea.[23–25]

ND:YAG LASER VITREOLYSIS

Preoperative Management

Vitreous strands adherent to the cataract extraction wound can cause CME.[26,27]

Strands are usually best seen on slit-lamp examination with a narrow slit beam in a darkened room. Careful gonioscopy may be necessary to visualize the strand, particularly if the vitreous enters the anterior chamber through the area of a peripheral iridectomy.

Fig. 54.7 illustrates the three most common configurations of vitreous to the wound:

1. A small discrete strand
2. A broad band
3. A band with either adhesions to the iris or iris entrapment behind the band

The most favorable cases for Nd:YAG laser vitreolysis are those with relatively discrete strands under tension. Broad bands are more difficult to fully transect, and amorphous vitreous herniations are extremely difficult to cut with the laser. The larger the amount of vitreous involvement, the more consideration should be given to pars plana vitrectomy for definitive removal of all pathologic vitreous.

Fig. 54.8 demonstrates subtle pupillary peaking, indicating a vitreous strand coming around the pupil that is less obvious after vitreolysis. Permanent changes in the iris stroma are frequent in cases of long duration.

Nd:YAG Laser Anterior Vitreolysis

When the vitreous strand passes through the pupil, using pilocarpine 2% preoperatively puts the strand on stretch and makes it easier for the laser to cut.

Aiming of the laser can be performed along two different pathways (inset within Fig. 54.7).

Pathway 1: The most reliable landmark for vitreolysis is the internal surface of the cataract wound, which can be visualized using a gonioscopy lens.

Pathway 2: If the cornea is clear near the limbus and the vitreous strand can be visualized with clearance from the iris stroma, direct cutting without a contact lens or with a peripheral button Abraham lens may successful. Because of the proximity to the iris, pigment may be liberated obscuring the surgeon's view. Misfocused shots can cause local damage to the underlying or overlying stroma.

Successful treatment releases the tension and converts a discrete strand to an amorphous gelatinous appearance. Observation of the change and any iris deformation is the best indicator of a successful release of tension. Hundreds of shots over several treatment sessions may be necessary for large bands. Postoperatively, visual acuity improvement of at least two lines of vision has been reported to be 40% to 89%.[28]

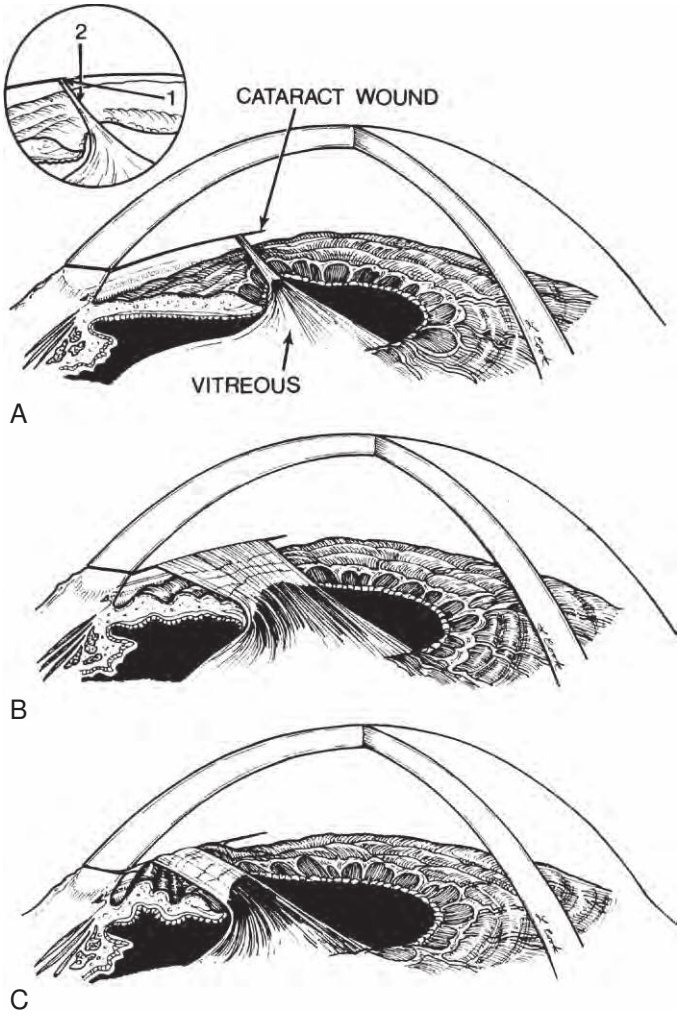

Fig. 54.7 (A) A narrow vitreous strand to a cataract wound. The inset shows possible laser pathways for vitreolysis: (1) a gonioscopic approach, directed at the cataract wound – the location at which the vitreous strand is often the most discrete and (2) a direct approach near the limbus. (B) A broad vitreous band at the wound. (C) Iris pulled upward in a tentlike configuration and entrapped by the vitreous incarceration in the wound. (Adapted from Steinert RF, Puliafito CA: The Nd:YAG laser in ophthalmology: Principles and clinical applications of photodisruption Elsevier, 1985.)

Nd:YAG Laser Anterior Vitreolysis

- Step 1: If the vitreous strand passes through the pupil, administer pilocarpine 2% every 10 min, for three or four drops preoperatively to put the iris on stretch.
- Step 2: Set the energy level to 4 to 8 mJ (Abraham lens) or 6 to 12 mJ (gonioscopy lens).
- Step 3: Depending on visualization and approach, aim at a vitreous strand under tension along one of the pathways.

Postoperative Management and Complications

Topical corticosteroids such as prednisolone acetate 1% or dexamethasone 0.1% and topical nonsteroidal antiinflammatory drugs can be used postoperatively, typically at four times per day until the vision improves and inflammation and CME are resolved.

Much of the literature on Nd:YAG laser anterior vitreolysis in the postoperative cataract patient is case series that report few or no postoperative complications.[28–31] IOP elevation after vitreolysis has not been well documented. A beta-blocker or brimonidine drop at the time of treatment may provide adequate prophylaxis, if there is concern for high risk for IOP elevation.

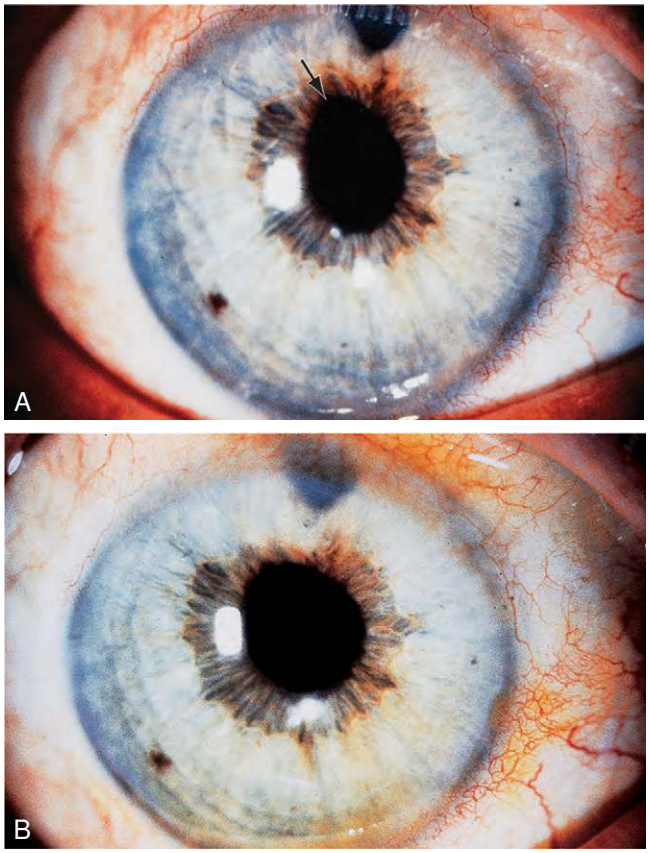

Fig. 54.8 (A) Fine vitreous strand caused mild peaking of the pupil (*arrow*). Gonioscopy showed a fine vitreous strand to the wound. (B) After laser vitreolysis, less peaking is present, but chronic change in the sphincter prevents a completely normal pupillary contour. (From Steinert RF, Puliafito CA: The Nd:YAG laser in ophthalmology: Principles and clinical applications of photodisruption Elsevier, 1985.)

BOX 54.2 ND:YAG POSTERIOR CAPSULOTOMY SURGICAL PEARLS

- Inform the patient to expect to hear small clicks or pops during and stress the importance of staying still during the procedure.
- If a patient cannot be fully dilated, have them look up, down, right, and left to create a large enough capsulotomy.
- If the patient is anxious, consider starting in the periphery outside of the visual axis.
- Fully truncated circular pattern capsulotomies can leave a large fragment that may not sink away from the visual axis.

BOX 54.3 ND:YAG ANTERIOR CAPSULOTOMY SURGICAL PEARLS

- Capsule will contract and eventually resume a round appearance.
- Avoid free-floating fragments, which may settle in the anterior chamber and obscure vision, such as circular patterns.

BOX 54.4 ND:YAG IRIDOTOMY SURGICAL PEARLS

- Use a minimum amount of energy as possible, although more energy may be required for dark thick irides.
- Pretreatment with argon laser may be beneficial to more easily penetrate thick dark irides and to decrease the risk for bleeding.
- If cornea edema or anterior chamber flare is present, higher energy levels may be required for optical breakdown.
- Unlike Nd:YAG capsulotomy, laser offset focusing techniques are not helpful for iridotomy.
- Transillumination of an LPI is insufficient to confirm patency; direct visualization is often needed.
- If shots disperse pigment and cloud the iridotomy site, one may move to another site or wait for a few minutes for pigment to clear.

BOX 54.5 ND:YAG VITREOLYSIS KEY SURGICAL PEARLS

- Aiming at the cataract wound (pathway 1) is the most reliable landmark.
- Use caution when aiming directly at a vitreous strand when it passes the pupil margin.

SUMMARY

- Nd:YAG laser is a safe, effective, and reliable tool to treat a variety of conditions that arise in the postcataract extraction patient: posterior capsule opacification, anterior capsular contraction syndrome, negative dysphotopsia, Z-syndrome, CBDS, aphakic and pseudophakic glaucoma with iridotomy, and vitreolysis of vitreous strands.
- Emphasis on understanding the use of both manual and laser settings for focusing is instrumental to successful Nd:YAG laser procedures.
- For each Nd:YAG laser procedure, strive to use a minimum amount of energy as possible.

The authors of this chapter sincerely acknowledge the late Dr. Roger F. Steinert, the original author of Chapters 51 and 52 discussing Nd:YAG laser posterior capsulotomy and Nd:YAG in the management of postoperative complications of cataract surgery within the third edition of this textbook.

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Video 54.1. Nd:YAG posterior capsulotomy for posterior capsular opacification.
Video 54.2. Nd:YAG laser peripheral iridotomy..

55

Management of Dysphotopsia

Samuel Masket, Nicole R. Fram, Zsofia Rupnik, Ananya Jalsingh, Stephen Kwong, and Don Pham

CONTENTS

KEY POINTS

- Dysphotopsias (positive, negative, and diffractive optic) represent undesirable subjective optical phenomena that may occur after uncomplicated, seemingly "perfect" cataract surgery.
- They are, in part, related to IOL design and IOL position.
- Positive dysphotopsia (PD) is described by patients as light streaks, light arcs, flashes, and starbursts that are all induced by an external light source.
- Negative dysphotopsia (ND) is manifest as a temporal arc-shaped or linear dark shadow that is typically stimulated by temporally oriented light sources (Figs. 55.1–55.3).
- Diffractive optic dysphotopsia (DD) relates to the better understood optical side effects of diffractive optic rings and the splitting of light energy (Fig. 55.4).
- Because the varying dysphotopsias seemingly have different causes, patients may experience more than one type; a given patient may experience all three types.

It has been suggested that dysphotopsia is a leading cause of patient dissatisfaction after cataract surgery, as reported by Tester et al.[1–5] Indeed, they indicated that 49% of their cases had some form of dysphotopsia after surgery, and Bournas et al. reported that 19.5% of patients complained of dysphotopsia on the first postoperative day.[5,6]

POSITIVE DYSPHOTOPSIA

Positive dysphotopsia (PD) is described by patients as light streaks, light arcs, central flashes, and starbursts that are induced by an external light source (Fig. 55.2).

- PD must be distinguished from entoptic light flashes caused by vitreoretinal traction, noted under dark conditions, whereas PD requires an external light source as a stimulus in order to be realized by the patient.
- Also, PD must be distinguished from a Maddox rod effect that is caused by posterior capsule striae and generated by a point source of light; this condition may be managed by Nd:YAG laser posteriorly capsulotomy as indicated by patient symptoms (Fig. 55.5).

The etiology of PD is reasonably well understood, given good correlation between the optical laboratory and the clinical findings. IOL edge design, index of refraction of the optic material, and overall optic design have all been implicated as causative factors. Truncated or square edge design of ovoid intraocular lenses (IOL) was first reported as a source of undesired optical images by Masket et al.[7] They used ray tracing and reflectometry to demonstrate that light of oblique incidence (between 40 and 70 degrees) may strike the truncated square edge of the IOL and reflect onto the retinal surface, inducing PD symptoms.[7] In the era before foldable IOLs, rigid PMMA (poly methylmethacrylate) was essentially the only IOL optic material available, and oval PMMA IOLs were manufactured by truncating parallel edges of a round optic, reducing the diameter in one meridian (from 6.0 to 5.0 mm) so that the IOL could be implanted through a smaller incision. The Masket et al. investigation found a nearly 4-fold greater likelihood for PD symptoms with oval versus round IOLs, owing to the squared edge of the truncated side of the optic.[7] Supporting this finding, the work of Holladay revealed that square-edged IOLs concentrate stray light into an arc that is projected onto the retina opposite the image of the light source, while round-edged IOLs disperse stray light over a larger portion of the retina, thus reducing PD symptoms.[8] Franchini et al. also found that square edge design is associated with halos, rings, and arcs of light, and they suggested that rounding the anterior edge of a square-edged IOL could be beneficial.[9] All of that stated, the square edge of an IOL can have a significant impact on the retardation and/or reduction of PCO, as the posterior square edge of the optic inhibits lens epithelial cell migration from the equator of the capsule bag onto the posterior capsule (Fig. 55.6).[10] As such, it is unlikely that square edge design will be removed from the marketplace, despite its causal relationship to PD.

- In addition to the square edge of the optic, existing evidence also implicates high index of refraction (I/R) of the IOL optic material as another cause for PD.
- This is particularly true if the optic is designed with a relatively flat anterior radius of curvature as has been reported by Erie et al.[11] Their work revealed that high I/R when combined with a flat anterior radius of curvature was a key cause of patient-reported central

Fig. 55.1 Reference image for street scene on a cloudy day without direct sunlight. (Courtesy Drs. Geunyoung Yoon and Scott MacRae, University of Rochester, all rights reserved.)

Fig. 55.2 Reference photo with superimposed white arc simulating positive dysphotopsia. (Courtesy Drs. Geunyoung Yoon and Scott MacRae, University of Rochester, all rights reserved.)

Fig. 55.3 Reference photo with superimposed temporal dark arc simulating negative dysphotopsia. (Courtesy Drs. Geunyoung Yoon and Scott MacRae, University of Rochester, all rights reserved.)

light flashes from reflection off the back of the flat anterior surface of the optic.

- Other authors found that PMMA IOLs and round-edge silicone IOLs were associated with a decreased incidence of PD.
- These studies also suggest that square edge design is associated with a higher incidence of PD irrespective of IOL material.[12,13]
- I/R also plays a major role in the reflectivity of the optic material, impacting both patient symptoms and the "cat's eye" phenomenon

Fig. 55.4 "Spider web" pattern around headlights of diffractive optic dysphotopsia. (Courtesy Drs. Geunyoung Yoon and Scott MacRae, University of Rochester, all rights reserved.)

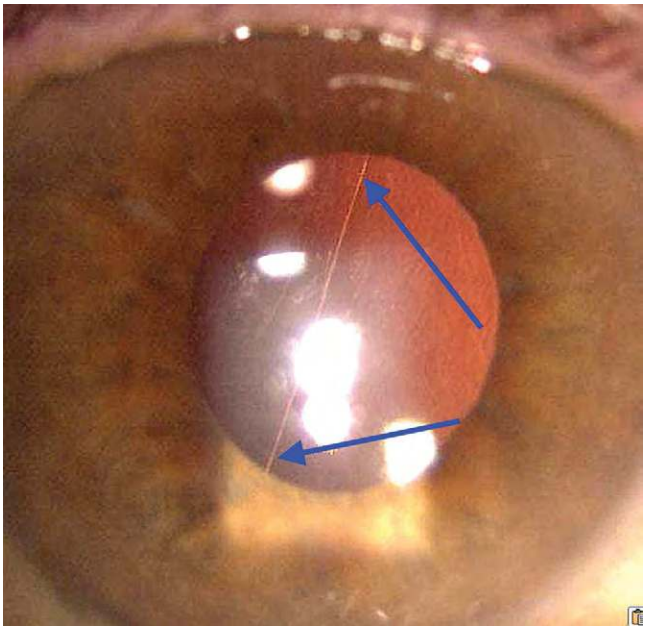

Fig. 55.5 Stria in posterior capsule (delineated by arrows) that induce a Maddox rod effect with point sources of light.

of an accentuated 3rd Purkinje image from the anterior surface of the IOL.

- Table 55.1 lists the material, I/R, and design of several IOLs in use in the United States that are associated with PD.

Given a good overall understanding of the causes, the ophthalmic IOL industry has addressed PD by rounding the anterior portion of the optic's edge, reducing square-edged IOL thickness, leaving the IOL edge unpolished, and moving the IOL optical power more to the anterior rather than the posterior optic.[14] Although these logical improvements have helped, the incidence of PD is still significant in large part because of the square edge of the optic. Unless and until better means for preventing or retarding PCO are developed, PD will persist as an undesired subjective postsurgical phenomenon.

NONSURGICAL MANAGEMENT OF PD

Although not well studied, unlike ND (see below), it appears that there is no meaningful neuro-adaptation to PD, and highly symptomatic cases require treatment in some fashion. Conservative management

methods for PD include correction of any refractive error, treatment of any coexisting ocular surface disease, treatment of posterior capsule opacification (PCO), and pharmacologic miosis. The latter may be accomplished with pilocarpine 0.5% or brimonidine 0.15%. Regarding PCO and laser capsulotomy, the clinician must be certain that the posterior capsule is the offending agent; otherwise its opening could complicate future attempts at IOL exchange, should it be necessary.

- As a rule of thumb, if the patient was asymptomatic early after surgery (perhaps other than the Maddox rod effect) and developed symptoms later as PCO evolved, capsulotomy may be helpful.

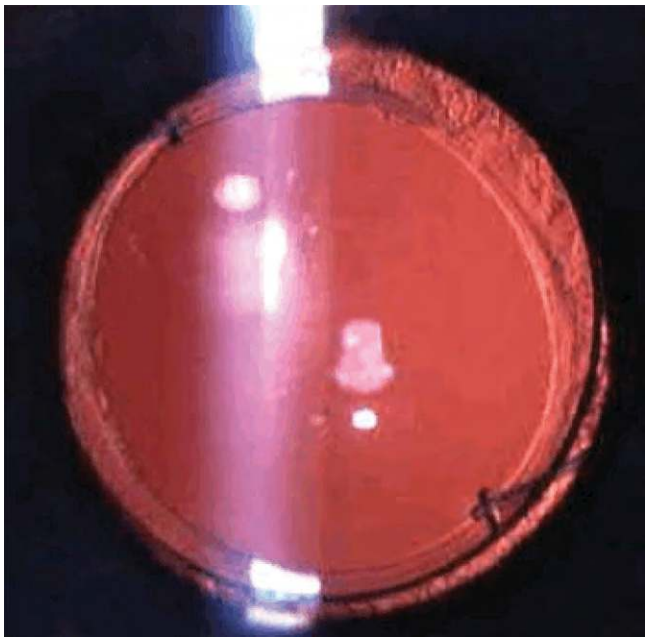

Fig. 55.6 Square-edged IOL (AcrySof, Alcon Labs, Ft. Worth Texas) with extensive posterior capsule opacification peripheral to the IOL but minimal opacity behind the optic, indicating that the optic edge retards lens epithelial cell migration onto the posterior capsule.

- On the other hand, if the patient was symptomatic with PD immediately after surgery when the capsule was clear, it is unlikely that capsulotomy will improve PD symptoms.
- Moreover, posterior capsule openings, once made, should be generous in size, as the edges of a small capsulotomy can be the source of additional light induced symptoms, particularly at night.

Should conservative measures fail and patients remain significantly symptomatic, IOL exchange can be considered as the most definitive step (see below).

NEGATIVE DYSPHOTOPSIA

Negative dysphotopsia (ND) is reported by patients as an arc-shaped dark shadow or line in the temporal periphery after otherwise uncomplicated cataract surgery (Fig. 55.3).[1] One of the most frustrating aspects of ND for both patient and surgeon is that it occurs after what surgeons believe to be anatomically "perfect" surgery as it tends not to accompany complicated surgery that may result in malpositioned IOLs, and so forth.

- ND can be very disturbing to some patients and the incidence is reported as high as 15% to 20% early after surgery when patients are specifically queried about presence of the condition.[15,16] However, presumably because of neuro-adaptation, the incidence reduces to approximately 3% at 1-year postoperatively.[15]
- Curiously, and as yet unexplained, the incidence is higher in women and in left eyes.
- Although there are no specific objective testing devices for ND, recent reports demonstrate far peripheral visual field changes on Goldmann kinetic VF testing that are missed with standard 30-degree static Humphrey Visual Field (HVF) testing.[2–4]
  - Interestingly, patient symptoms may appear to exceed what would be expected from the Goldmann visual field changes reported by Makhotkina et al. under monocular testing.[2]
  - More recent **binocular** Goldmann VF testing suggests that the ND scotoma is significantly greater with both eyes open and reduces with contralateral eye occlusion or use of a peripherally opaque contact lens on the contralateral eye, affording an understanding of the depth of some patients' symptoms and

TABLE 55.1 Positive Dysphotopsia Inciting IOLs: Index of Refraction and Edge Design

PCIOL	IOL Material	Manufacturer	Refractive Index	Edge Design
ZCB00	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
ZCTXXX	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
ZMB00	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
ZKB00	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
ZXTXXX	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
ZXR00	Hydrophobic acrylic	Johnson & Johnson	1.47	Frosted, posterior square edge
SN60WF	Hydrophobic acrylic	Alcon	1.55	Square edge
SN6ATX	Hydrophobic acrylic	Alcon	1.55	Square edge
SN6AD1	Hydrophobic acrylic	Alcon	1.55	Square edge
Softec HD0	Hydrophilic acrylic	Lenstec	1.43	Square edge, oval optic
Akreos AO60	Hydrophilic acrylic	Bausch & Lomb	1.6	Square edge
CZ70BD	PMMA	Alcon	1.49	Round thin
AQ2010V	Silicone	Staar Surgical	1.41	Round edge
L161AO	Silicone	Bausch & Lomb	1.41	Square edge
ZA9002	Silicone	Johnson & Johnson	1.46	Rounded anteriorly, square posteriorly
Crystalens	Silicone	Bausch & Lomb	1.43	Square edge
CC4204A	Collamer/Copolymer	Staar Surgical	1.44	Plate haptic
CQ2015A	Hydrophilic acrylic/Copolymer	Staar Surgical	1.45	Rounded anteriorly, square posteriorly

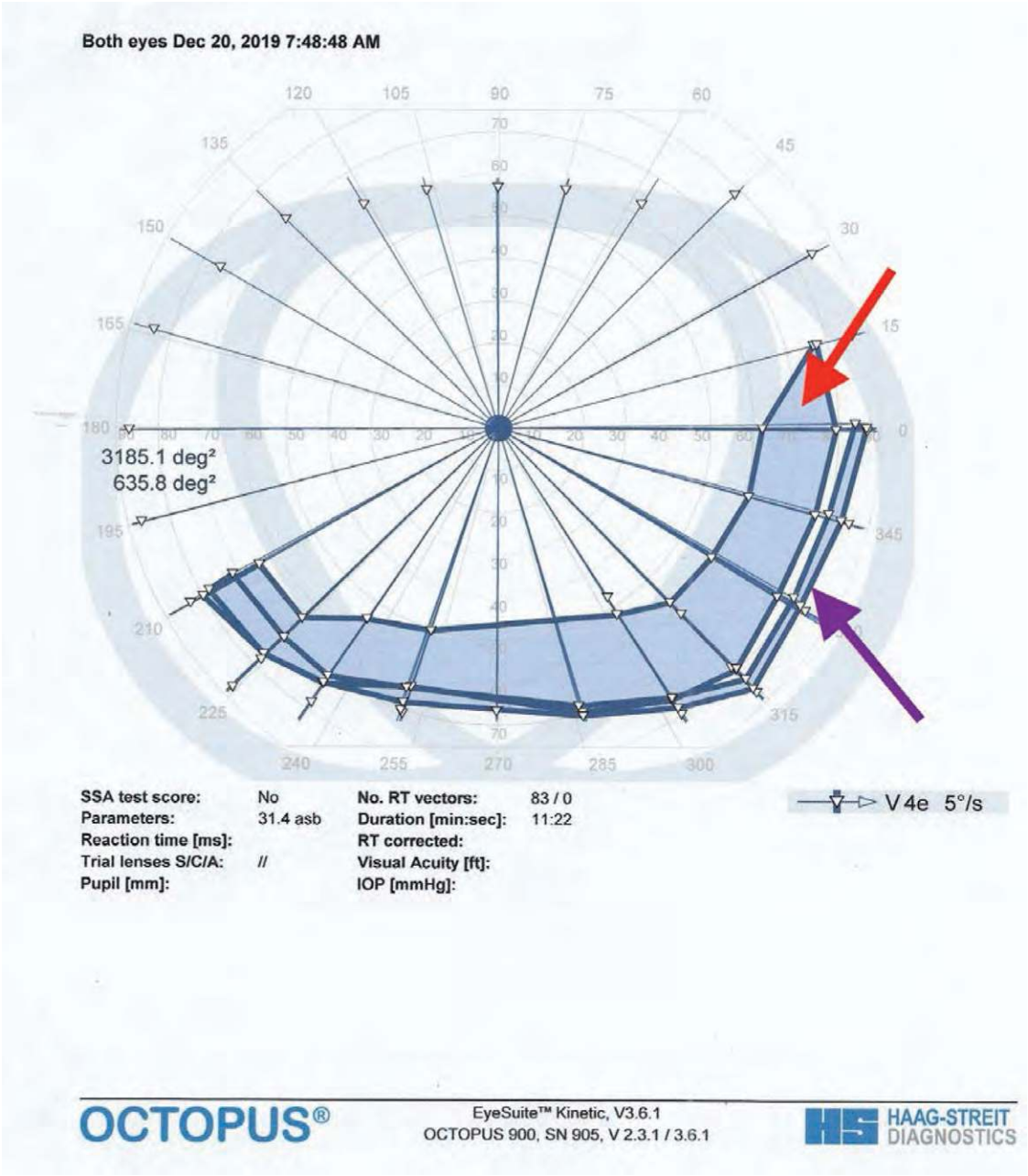

Fig. 55.7 Binocular Goldmann kinetic visual field for patient with negative dysphotopsia right eye. Note the large inferotemporal scotoma (*red arrow*) with both eyes fully open. However, note the markedly reduced size of the scotoma after application of a peripherally opaque contact lens on the fellow left eye (*purple arrow*).

suggesting a central nervous system (CNS) component to ND (Figs. 55.7 and 55.8).[4]

In general, the clinician relies primarily on patient-reported outcomes to determine the presence and course of symptomatic ND. Moreover, there are occasional atypical cases regarding symptoms and course that make diagnosis and understanding even more difficult. Indeed, Olsen and others have suggested that a temporal shimmering effect, reported by some patients, is a manifestation of ND, simulating positive dysphotopsia in some manner (personal communication, 2014).

ND appears to be more enigmatic than PD. However, there seems to be general agreement about certain conditions:

- In the susceptible patient, ND is stimulated by light from the temporal side and improves if the temporal light source is blocked.
- ND symptoms are reduced with pupil dilation and worsened with pupil constriction.
- Despite seemingly similar anatomy, ND may not occur bilaterally, having a greater incidence in the LE.
- ND has not been reported with ciliary sulcus, anterior chamber, or scleral suture fixated IOLs; ND has only been reported with in-the-bag IOLs after what is considered to be anatomically perfect surgery.[17]

Unlike PD, the etiology seems to be less well understood as there appears to be a gap between optical laboratory findings and clinical assessment.

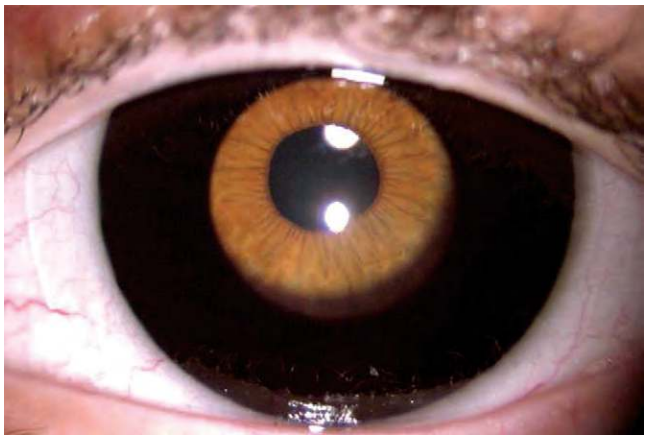

Fig. 55.8 Peripherally opaque contact lens applied to the left eye caused marked reduction of negative dysphotopsia scotoma in the right eye of patient in Fig. 55.7.

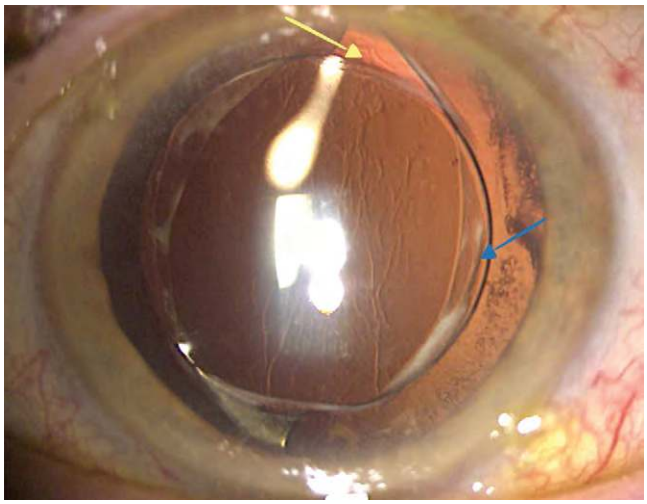

Fig. 55.9 Reverse optic capture in right eye with haptics underneath the anterior capsule (*yellow arrow*) and optic edge above the anterior capsule (*blue arrow*).

- As an example, initial ray tracing studies from Holladay et al. implicated square-edged, high I/R IOLs as likely causal of ND.[18] However, in a clinical analysis of patients requiring secondary surgery for chronic ND (persisting beyond 6 months), it was reported that 13% of cases had low I/R silicone IOLs with round edges.[19] Indeed, in that report virtually all types of IOLs on the U.S. market were noted to be associated with ND.
- Additionally, a report from Burke and Benjamin indicated that high I/R, square-edged IOLs would "cure" ND if the lenses were placed in the ciliary sulcus, rather than the capsule bag.[20] That report, in combination with others, suggests that the final common clinical pathway for ND is an in-the-bag IOL with an overlapping anterior capsulotomy and that material or design of the IOL is less relevant.[17,19–22]
- Indeed, the Masket, Fram, et al. study revealed that 42 of 43 eyes were improved, cured or prevented from ND by placing the optic anterior to the anterior capsulotomy in reverse optic capture fashion, with the haptic supports remaining in the capsule bag (Fig. 55.9).[19]
- Therefore, in clinical terms, ND may occur if the anterior capsule overlies the optic, but if the optic overlies the capsule, ND will be avoided. This phenomenon has not been well investigated in the optical laboratory setting.
- This tenet is furthered by the observation that by removing the nasal capsule edge with the Nd:YAG laser, ND will be improved in the majority of cases.[23,24] Additionally, in one case, the nasal portion of the optic was truncated surgically, successfully eliminating ND and furthering the concept that for ND to occur, the capsule must overlap the optic, in particular on the nasal side.[25]
- These reports also firmly suggest that alteration of posterior chamber depth is not a likely causal factor, given that no movement of the IOL occurs with capsulectomy or optic truncation.[23–25]
  - Further suggesting that varying posterior chamber depth does not contribute to ND is the 2010 report from Vamosi et al. in which they found no difference in posterior chamber depth between a group of cases with ND and an asymptomatic control group.[22]
  - Similarly, Masket and Fram found that reducing posterior chamber depth alone did not reduce ND symptoms.[17]
  - However, working nonclinically with ray tracing analysis in the optical laboratory, Holladay et al. reported that increased depth and volume of the posterior chamber of the pseudophakic eye contributes to ND.[18]

Although there is an apparent disconnect between the clinical findings of ND and what has been garnered from the optical lab, more recent ray tracing analyses describe an "illumination gap" between temporally incident light rays that pass anterior to the IOL optic and those that are refracted by the lens (Fig. 55.10).[26–28] These theoretical reports are widely accepted, seem quite plausible, and possibly offer an understanding of the focal optical mechanism for ND. However, there are clinical findings that cannot be explained by the illumination gap theory: Why should ND occur more frequently in women and in the left eye; why does ND occur in only one of two eyes in many cases; why wouldn't ND occur more frequently with thick, low I/R IOLs as the illumination gap would be wider? Moreover, recent binocular far peripheral kinetic Goldmann VF testing (see above) suggests the possibility that ND has CNS manifestations, confirming that ND is a complex clinical issue that cannot be explained solely by a focal illumination gap.[4]

NONSURGICAL MANAGEMENT OF ND

Given all of the above, how can we best manage patients with existing ND and how can we prevent it? ND is an exclusionary diagnosis in which no observable ocular pathology exists. Therefore a dilated fundus examination and standard VF testing are necessary to rule out a disease condition that could mimic ND, such as retinal detachment or optic neuropathy. Most importantly, patients with ND early after surgery should have a thorough explanation of the condition (as best we understand it), be encouraged that it will likely improve over time, and given support. Also, there are some nonsurgical approaches that may help. Given that temporally incident oblique light appears to be the chief inciting source for ND, use of spectacles with a thick temple piece has been beneficial to some patients and, based on findings from recent investigations, occlusion of the fellow eye with part-time patching or use of peripherally opaque contact lenses on one or both eyes can reduce symptoms and might help patients achieve neuro-adaptation, although the latter is speculative (Fig. 55.8).[4] However, patients with chronic ND, persisting more than 6 months, are unlikely to benefit from nonsurgical approaches, and surgery offers the best opportunity to alleviate symptoms of ND (see below). Our published surgical experience indicates that nearly 100% of cases will have ND prevented or improved with primary or secondary reverse optic capture.[19]

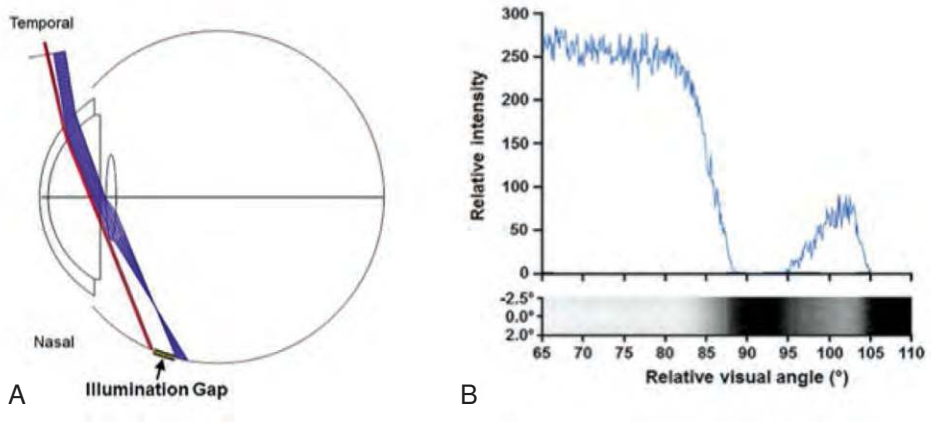

Fig. 55.10 Schematic ray trace demonstrating the proposed illumination gap between the light rays that are incident anterior to the optic and those that are refracted by it (A) and the resultant reduced relative light intensity near 90 degrees temporal (B). (From Erie JC, Simpson MJ, Bandhauer MH. Effect of a sulcus-fixated piggyback intraocular lens on negative dysphotopsia: ray-tracing analysis. *J Cataract Refract Surg* 2019; 45:443–450. Reproduced with permission.)

DIFFRACTIVE-OPTIC DYSPHOTOPSIA (DD)

It is important to recognize that the U.S. experience with presbyopic IOLs is limited compared with the myriad of devices that are available in Europe and other parts of the world. As a result, this section will be less than comprehensive regarding IOLs in this category and will be limited to Alcon and Johnson & Johnson (J&J) diffractive devices. The only refractive multifocal IOLs available at this time in the United States are the Alcon Vivity. By nature of their design, diffractive-optic multifocal IOLs (MFIOLs) and diffractive extended-depth-of-focus IOLs (EDOF IOLs) produce undesired optical imagery that is manifest as concentric circles, "star bursts," or "spiderweb" patterns around point sources of light in addition to glare and halos (Fig. 55.4). As a result, the symptoms tend to be exaggerated by headlights and street lamps during nighttime driving. Although the majority of patients with diffractive-optic IOLs will note these optical effects from the IOLs, over time most find the side effects tolerable and an acceptable trade-off for reduced spectacle dependence; moreover, there appears to be a gradual improvement in tolerance, suggesting neuroadaptation. Bear in mind that the effects of diffractive-optic dysphotopsia may be superimposed on PD, ND, or both.

The original MFIOL designs of both manufacturers' products featured a relatively high 4.0 D add power at the IOL plane, producing a 2.5 D to 3.0 D add at the spectacle plane. The theory at that time was that a large separation of the 2 optical images (distance and near) would be better tolerated by the human visual system than if the add power were to be lower and the image separation less disparate. Moreover, the concept of bifocal over multifocal optics was also considered to be easier to tolerate owing to greater image separation with the former. However, clinical practice clearly disagreed with the suggestions from the optical bench. Experience in Europe with lower-add bifocal and trifocal IOLs revealed greater patient tolerance and acceptance than with the original bifocal models. Indeed, with regard to the U.S. Food and Drug Administration (FDA) trials of the original Alcon ReStor +4.0 D add bifocal IOLs, 93% of patients indicated that they would have the same IOL implanted again, despite the fact that the patients were all "best case" and did not pay for the IOL. Contrast that with the more recent investigation of the Alcon trifocal Panoptix where 99% of patients indicated that they would have the same IOL again. On a similar note, with respect to the original J&J +4.0 D add Tecnis MFIOL, 87% indicated that they would have the same IOL implanted again, whereas 96% would have the more recently designed +2.75 D add Tecnis in repeated surgery. Both the Alcon and J&J examples indicate that trifocal and lower-add multifocals are better tolerated than the original MFIOL design. Additionally, much has been learned regarding patient selection for presbyopic IOLs with regard to ocular surface disease, maculopathy, preexisting higher order optical aberrations (HOAs), and so forth, allowing greater success with these devices. All of that notwithstanding, and despite the best information and improved IOL technology, a small but given percentage of patients will be unhappy with the outcome of surgery and require help.

NONSURGICAL MANAGEMENT OF DD

Ametropia has a markedly deleterious effect on the performance of diffractive-optic IOLs (Fig. 55.11).[29,30] Any patient with intolerable optical side effects needs a careful refraction and reevaluation of their symptoms after correction of any optical error with a trial of spectacles or contact lenses. Should optical correction eliminate or markedly improve DD, permanent correction can be offered in the form of laser vision correction, IOL exchange for improved power, or piggyback IOLs should the patient desire. It is my preference to employ wavefront-guided LVC in this situation as wavefront analysis tends to uncover greater degrees of mixed astigmatism than clinical manifest refraction and can also improve higher order aberrations. Indeed, in a large European study, 88% of unhappy trifocal IOL patients were ultimately very satisfied with their surgery and would have the same IOL again after wavefront-guided laser vision correction for ametropia after cataract surgery.[31] Although ametropia may enhance DD, patients who are intolerant of the visual symptoms must also be carefully evaluated for ocular surface disease and maculopathy. As such, there is a growing trend toward extensive presurgical tear film analysis and macular OCT in all cases considered for a diffractive IOL. Additionally, the condition of the posterior capsule also requires careful examination, as even subtle degrees of posterior capsule opacification may enhance DD. However, the surgeon should open the capsule only if there is certainty of its complicity in the patient's symptoms. Nonetheless, DD certainly exists with no demonstrable pathology, as it is inherent to diffractive optic IOLs and, if ametropia and comorbidities are ruled out, IOL exchange (see below) is the only option for the patient with significant

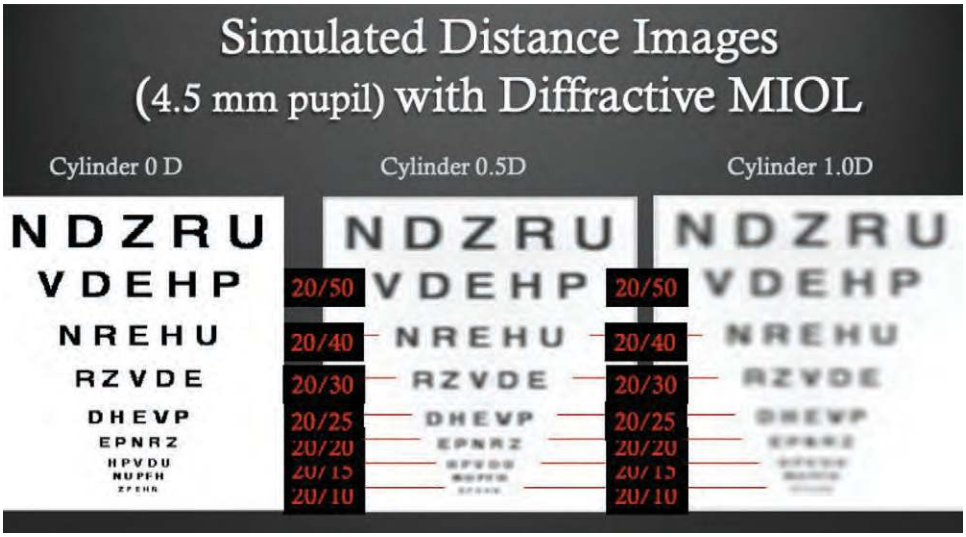

Fig. 55.11 Simulated degradation of image quality at distance with 0.5 D and 1.0 D of uncorrected corneal astigmatism and diffractive multifocal IOL.

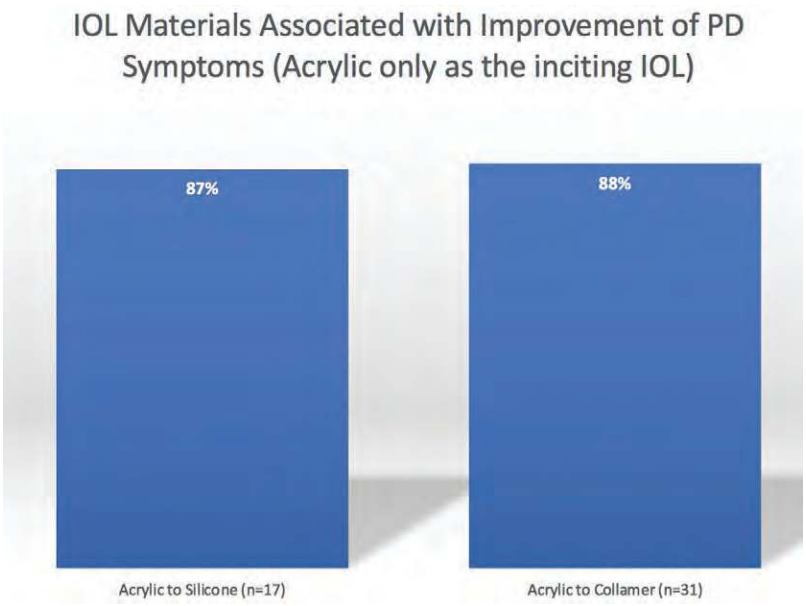

Fig. 55.12 Success rates for improving PD symptoms associated with acrylic IOLs achieved with silicone (*left*) and copolymer IOLs as the exchanged material. (Masket S, Rupnick Z, Fram NR, Kwong S, McLachlan J. Surgical management of positive dysphotopsia: U.S. perspective. *J Cataract Refract Surg*. 2020 Nov;46(11):1474–1479. (Reproduced with permission.)

diffractive-optic dysphotopsia. A recent investigation from our practice (Naids et al. unpublished data presented at the 2019 ASCRS Annual Meeting) determined that, of 34 eyes requiring MFIOL exchange, 18 had comorbid conditions while 16 eyes had no demonstrable ocular pathology. This finding attests to the fact that some patients will not tolerate MFIOLs despite seemingly best-case conditions.

IOLS DESIGNED TO PREVENT DYSPHOTOPSIA

Unfortunately, in the United States there are no foldable IOLs available with round edges, and there are no IOLs that are specifically designed to prevent PD. However, as noted above, modifications to IOL edge design and optic configuration have been made over time in attempt to reduce the incidence of PD. In our practice, we have had success with PD by exchanging for IOLs with a lower index of refraction, hence reduced surface reflectivity. Our surgical experience with 46 eyes requiring IOL exchange for chronic PD suggests an overall success rate between 85% and 90% with either a silicone or copolymer IOL when exchanged for a hydrophobic acrylic IOL (Fig. 55.12).[32] Unfortunately, at this time, round-edge IOLs are available only as PMMA material, and they require large (7.0 mm) incisions.

On the other hand, with regard to specific IOLs and ND, Masket designed an optic (90S IOL, Morcher, Stuttgart, Germany) to mimic reverse optic capture by placing a groove on the optic edge that captures the anterior capsulotomy; in that fashion, there is a portion of the optic over capsule, rather than capsule over optic (Figs. 55.13 and 55.14).[33] In European limited clinical trials, none of the 175 cases with that IOL experienced ND. At present, there are two other IOLs in use

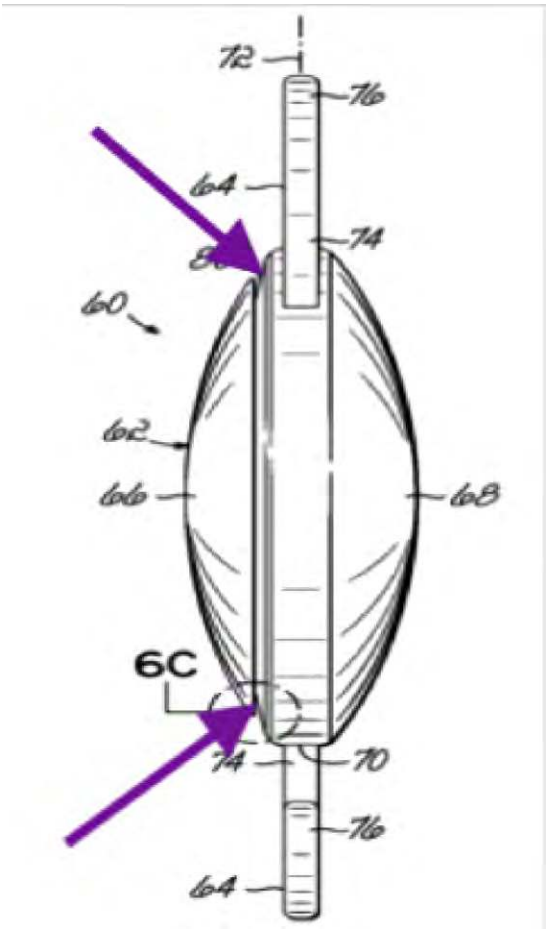

Fig. 55.13 Antidysphotopic IOL design from US Patent drawings (Masket) with groove (*purple arrows*) to accept anterior capsulotomy, simulating reverse (anterior) optic capture. (Masket S, inventor. Antidysphotopsia intraocular lens and method. US patent 8652206. April 11, 2011.)

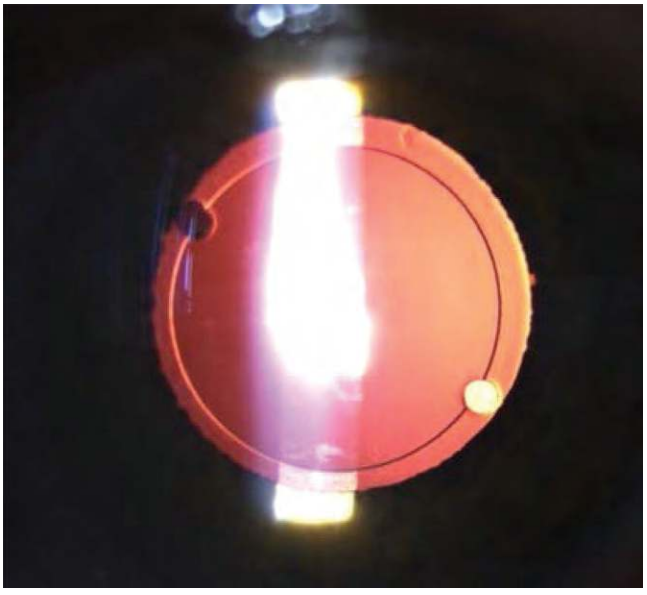

Fig. 55.14 Postoperative clinical photograph of 90S IOL (Morcher) demonstrating excellent centering. Note peripheral groove that accepts the anterior capsulotomy. Also note the two fixation holes. (Courtesy Tobias Neuhann MD)

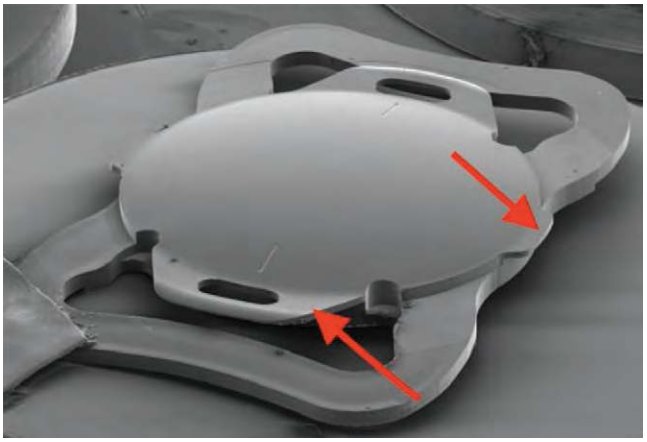

Fig. 55.15 Scanning electron photomicrograph (SEM) of the Femtis (Oculentis) IOL. Note that the optic has 4 tabs (red arrows) that keep the optic edge anterior to the anterior capsulotomy.

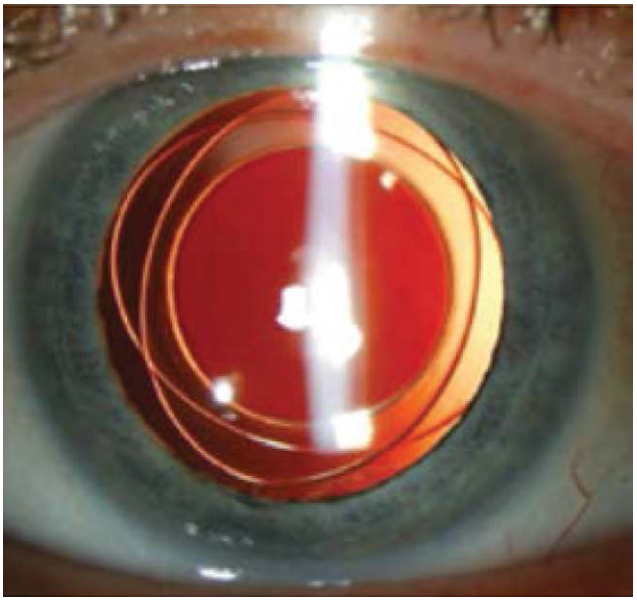

Fig. 55.16 Bag-in-the-lens (BIL) (Morcher) design of Tassignon. This nonhaptic IOL design has opposing ovals with a groove that accepts both anterior and posterior capsulotomies.

in Europe that provide anterior capsulotomy fixation of the IOL, and no cases of ND have been reported with these either, confirming the concept that optic over capsule prevents ND. One device, the Femtis IOL, has also been studied for other facets of anterior capsule fixation, including positional stability and more predictable effective lens positioning (ELP) (Fig. 55.15).[34] Another is the bag-in-the-lens IOL designed by Tassignon (Fig. 55.16); it is a nonhaptic IOL that requires anterior *and* posterior capsulotomies that are captured in the equatorial groove of the IOL.[35] Although not published to date, reportedly none of thousands of cases with that lens have experienced ND, giving further testimony that anterior capsulotomy optic fixation precludes ND. The design strategy of capsulotomy-fixated IOLs has theoretical advantages, other than elimination of ND, that are under investigation. They include absence of rotation of toric IOLs, reduced tilt and decentration of the optic, reduced higher order aberrations with diffractive optic IOLs, absence of capsule contraction, and more predictable and stable ELP.

SURGICAL STRATEGIES FOR MANAGEMENT OF DYSPHOTOPSIA

Surgery is indicated if the dysphotopsia is chronic, if nonsurgical means (see above) have failed, and if the patient is intolerant of the condition. Given that ND, PD, and DD have varied causal mechanisms, their surgical management differs. That said, patients may exhibit more than one type of dysphotopsia, and surgery should address all related problems. Surgical planning is based on a combination of patient symptoms and ocular findings, recognizing and that no single form of treatment will be appropriate for all cases.

- To our understanding, PD appears purely related to the IOL, whether in the capsule bag or ciliary sulcus; position seems to be noncontributory.
- Moreover, it appears that the square optic edge is the chief causal factor, but high index of refraction with high surface reflectivity is also contributory.
- The latter can be addressed by IOL exchange for one of lower I/R, as virtually all foldable IOLs have square edges; only large-diameter PMMA rigid IOLs are available with a round or knife-edge design for exchange.
- Positioning of the new or exchanged IOL depends on the condition of the anterior capsulotomy, the status of the posterior capsule, and the integrity of the zonule.
- Typically, PD has been associated with high I/R hydrophobic acrylic IOLs, and our experience dictates that exchange for either silicone or copolymer (Collamer, Staar Surgical, Monrovia, CA) optic IOLs will bring success in 85% to 90% of cases under that circumstance (Fig. 55.10). [32] Unfortunately, the three-piece copolymer IOL model is no longer manufactured.

On the other hand, clinically, ND appears to be associated with any IOL, irrespective of design, that is within the confines of the capsule bag, generally underlying an intact circular anterior capsulotomy.

- In this situation, change in IOL position relative to the anterior capsule is more significant for reducing symptoms than is a change in IOL design or material.
- Surgical strategies generally require that the optic of the IOL is brought anterior to the anterior capsulotomy either by reverse (anterior) optic capture or sulcus placement.
- Though we prefer the former options, there is good evidence that add-on or piggy-back IOLs also reduce ND but carry added risks of decentration and late iris chafe.[17, 27, 35]

Chronic intolerance to diffractive multifocal or EDOF IOLs almost invariably requires IOL exchange for a monofocal IOL. Position of the optic for the new IOL will be determined by the condition of the capsule remnant. Patients who experience more than one type of dysphotopsia must have all conditions addressed by surgery. Surgical strategies, listed below, are applied as appropriate for the existing dysphotopic condition(s), the status of the posterior capsule, and the size and centration of the anterior capsulotomy. Incision size may vary 2.2 to 7.0 mm depending on the technique required to remove the existing IOL or the IOL to be implanted. For a clear corneal approach, the incision size should range from 2.2 to 3.5 mm. For eyes requiring a scleral tunnel, incisions may be 7 mm or greater. Sutures or wound sealants are used when appropriate.

Bag-to-bag PCIOL exchange: This technique involves the removal of the original IOL and the replacement of a different IOL in the capsular bag. This method is appropriate for patients with isolated PD or DD symptoms; this strategy is NOT to be applied for patients with ND (Video 55.1).

Primary reverse (anterior) optic capture: Either a three-piece or single-piece IOL is placed in the capsule bag after which the optic is prolapsed anteriorly to sit above the capsule, leaving the haptics in the bag. It is key that the nasal portion of the optic overly the anterior capsule edge. This technique is used for the fellow eye of patients who are highly symptomatic with ND in their previously operated eye (Video 55.2).

Secondary reverse (anterior) optic capture: The anterior capsule edge is freed from the anterior surface of the previously placed IOL by blunt dissection, aided by an ophthalmic viscosurgical device (OVD). The optic edge is elevated above the anterior capsule nasally and temporally with a spatula. This requires that the haptics are oriented near 6 o'clock and 12 o'clock. Nontoric IOLs with horizontal or oblique haptic orientation can be rotated into vertical orientation before optic capture. This technique is applicable to patients with persistent ND associated with an in-the-bag IOL (Video 55.3).

IOL exchange with reverse (anterior) optic capture (ROC): This technique requires removal of the originally placed IOL from the capsular bag and replacement with a different IOL (for the PD symptoms) in a reverse optic capture position (for the ND symptoms). This method is applied to patients with both PD and ND symptoms. PD symptoms are addressed by changing the material or design of the IOL, and the ND symptoms are addressed by placing the IOL in the ROC position above the (nasal and temporal) anterior capsule (Video 55.4).

Ciliary sulcus PCIOL placement with iris suture fixation (ISF): An existing bag-fixated IOL is removed from the capsular bag and replaced (for PD or DD) with a three-piece IOL in the ciliary sulcus. This strategy is employed if the posterior capsule is open and not suitable for in-the-bag placement or if the patient also has ND and the capsule cannot accommodate ROC positioning. We opt to use ISF with 10-0 polypropylene for long-term fixation stability. We believe that secondary IOLs should not be placed passively in the sulcus because of the concern of movement or dislocation over time. This technique is used in cases with either PD or combined PD/ND/DD when the condition of the capsule bag so dictates. (Video 55.5)

Ciliary sulcus PCIOL placement with posterior (traditional) optic capture: An existing capsule-bag-placed PCIOL with a previously opened posterior capsule is removed from the capsule bag and replaced with a different 3-piece IOL positioned in the ciliary sulcus and the optic prolapsed behind the anterior capsulotomy, typically after limited vitrectomy. This strategy is applied for PD or DD but not ND. This strategy requires that the anterior capsulotomy is well centered and of appropriate size and the zonule has normal integrity (Video 55.6).

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Video 55.1 Exchange of low power, high Index of Refraction (I/R), square edge acrylic IOL for a round edge low I/R silicone IOL for management of Positive Dysphotopsia.
Video 55.2 Primary reverse (anterior) optic capture of a 3-piece silicone IOL for prevention of Negative Dysphotopsia.
Video 55.3 Secondary reverse (anterior) optic capture of a single piece toric acrylic IOL for management of chronic Negative Dysphotopsia.
Video 55.4 IOL exchange and reverse optic capture for management of combined Positive Dysphotopsia and Negative Dysphotopsia.
Video 55.5 Exchange of an in the bag acrylic IOL for a sulcus placed copolymer IOL with iris suture fixation for management of Positive Dysphotopsia in a case with a previously opened posterior capsule.
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Refractive Enhancements After Cataract Surgery

Kanika Agarwal and Elizabeth Yeu-Lin

CONTENTS

KEY POINTS

- There can be several contributing factors to a refractive surprise after cataract surgery, such as incorrect intraocular lens (IOL) calculations as a result of keratometry and/or axial length measurements, postrefractive surgery eyes, or toric IOL rotation (see Chapter 31).
- Steps that can be taken to correct postoperative refractive surprises beyond spectacle/contact lens correction include laser vision correction (LASIK/PRK), piggyback lens, IOL exchange, or corneal relaxing incisions (see Chapter 31).
- Things to consider when deciding to pursue refractive enhancement include why the error occurred, the patient's symptoms and goals, and the amount of refractive error needing to be corrected.

INTRODUCTION

Refractive surprise after uncomplicated cataract surgery can be daunting. In one large European multicenter database study, refractive outcomes were within 0.50 D for 73% of patients and within 1.0 D for 93%.[1] Although rare, when refractive surprises > 1.0 D occur, patients may be symptomatic and require surgical correction. It is important to consider all factors contributing to the patients' postoperative refractive outcome when trying to determine the next best step. Careful analysis of biometry data, especially keratometry and axial length, prior refractive surgery history, and examination of the patient can clue the surgeon into potential sources of error. Based on the amount of refractive error, corneal versus lens-based surgery can be pursued.

CAUSES

It is important to analyze keratometry and biometry measurements because significant errors in these could lead to large refractive surprises[2]. If picked up preoperatively, many of these can be treated or accounted for to allow for a more predictive refractive outcome.

FACTORS CONFOUNDING KERATOMETRY MEASUREMENTS

- Ocular surface/dry eye disease
- Epithelial basement membrane dystrophy (EBMD) (Fig. 56.1)
- Corneal opacities: scars or Salzmann nodular degeneration
- Pterygium
- Contact lens corneal warpage
- Corneal manipulation during examination such as tonometry and gonioscopy
- Prior laser vision correction (LASIK, PRK, RK)
- Keratoconus

FACTORS CONFOUNDING AXIAL LENGTH MEASUREMENTS

- Poor patient fixation
- Irregularities in globe contour (e.g., staphyloma in a high myope)
- Prior retinal surgery (e.g., silicone oil in vitreous cavity)
- Undiagnosed retinal pathology

LENS-BASED ISSUES

- Wrong lens inserted (mixed up patient calculations/eyes)
- Incorrect formula/calculation
- Lens inserted upside down—depending on type of lens—could cause a myopic shift
- Capsular block causing a myopic shift
- Decentration/tilt of intraocular lens
- Effective lens position, especially in eyes with short axial lengths
- Residual mixed astigmatism caused by toric IOL malposition

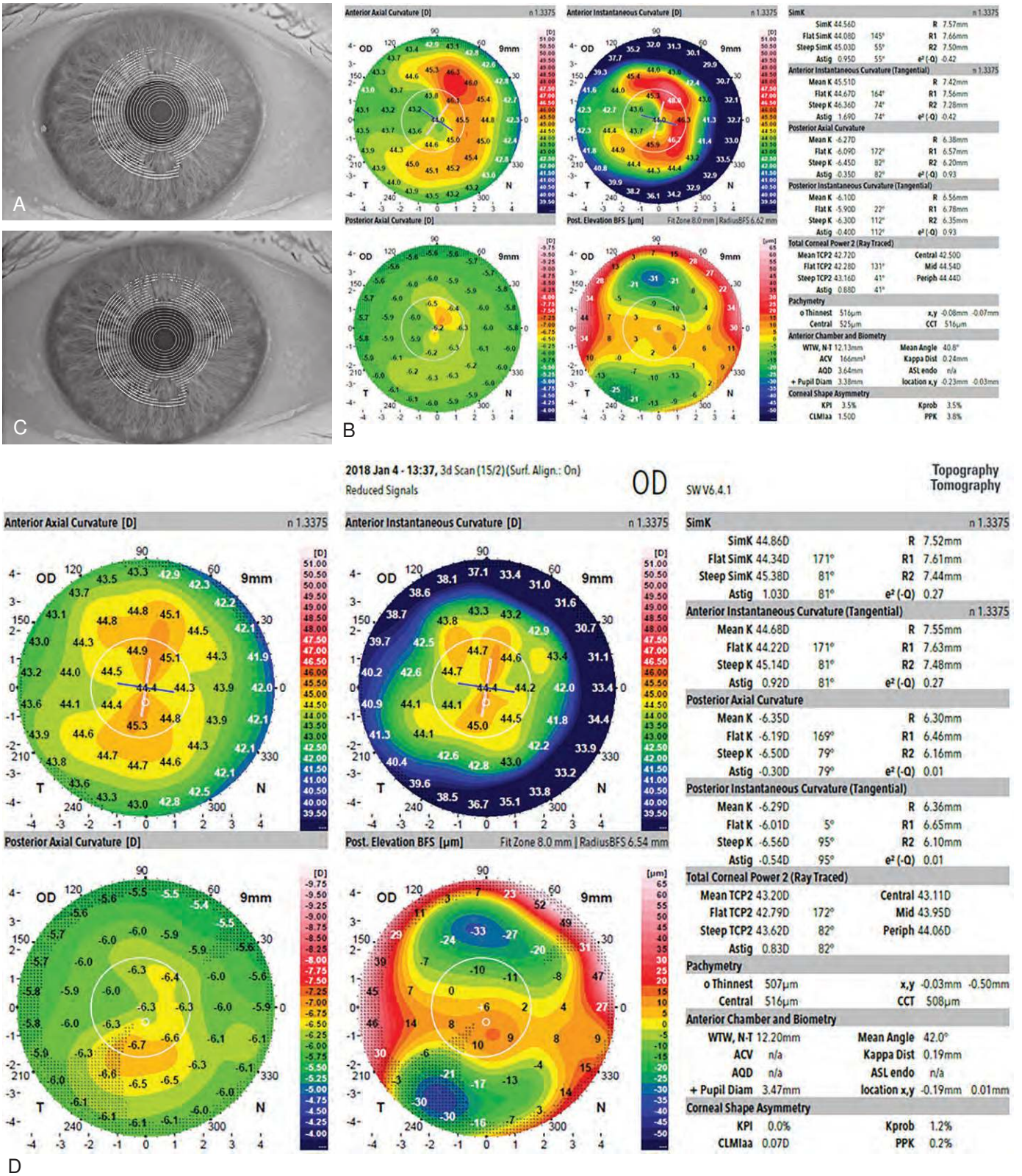

Fig. 56.1 (A) Mires from the dual-Scheimpflug Placido tomographer showing marked distortion (especially superotemporally) in the right eye implanted with a 2D toric IOL, which the surgeon rotated 1 week postoperatively. (B) Color maps show marked irregular astigmatism. (C) Mires 3 months after epithelial debridement, showing marked improvement with minimal irregularity. (D) Color maps now show mild with-the-rule astigmatism of ~ 1 D. Exchange of the toric IOL for a monofocal IOL resulted in uncorrected 20/20 vision. (Images courtesy of Li Wang and Douglas D. Koch.)

EVALUATION

When trying to clinically assess the root cause for refractive error, a stepwise approach should be taken.

1. Review preoperative measurements and refraction.
2. Clinically evaluate the patient for corneal and lens pathology as described above.
3. Obtain OCT-macula, and repeat biometry and topography measurements.
4. Dilate the patient to assess for IOL position. Check for alignment if a toric IOL was placed (see Chapter 31).

SURGICAL MANAGEMENT

After determining the cause for the refractive surprise, if possible, options for surgical correction can be pursued depending on the degree of refractive error and the patient's goals. Spectacle or contact lens correction should be offered to the patient, and surgical correction should only be pursued if the patient desires. A second procedure should be pursued no sooner than 2 to 3 months after the initial cataract surgery to allow the wounds to settle and to verify stability of refraction.

See Chapter 31 for surgical management of mixed astigmatism. Astigmatic keratotomy (AK) options exist, including manual peripheral corneal relaxing incisions (PCRIs) (also referred to as *limbal relaxing incisions*) or femtosecond laser-assisted arcuate incisions. These should be reserved for patients with lower amounts of residual mixed astigmatism: ≥ 1.25 D. Larger AK procedures have their own complications and side effects, including unpredictable refractive outcomes, focal ectasia, dry eye disease, irregular corneal astigmatism, and glare.

CORNEAL-BASED SURGERY

Corneal-based surgery can be pursued if:

- The refractive error is generally no greater than –2 D of myopia and +1–1.5 D of hyperopia.
- There is no underlying corneal pathology such as corneal ectasia, HSV, dry eye, or EBMD.
- The patient has not reported symptoms of glare, haloes, or contrast sensitivity postoperatively.

The decision to pursue LASIK, PRK, or SMILE is often surgeon dependent. Refractive stability is important when planning for an enhancement and should not be performed sooner than 3 months after surgery. Laser vision correction can be done in patients with multifocal lens implants, but it is important to caution patients about the risk for haloes and glare, and to be cautious if they are already symptomatic postoperatively.[3] Laser vision correction is very accurate, with over 90% of patients coming within 0.50 D of their target.[4]

LENS-BASED SURGERY

Lens-based surgery is typically pursued if:

- Refractive error is > 2 D of myopia, 1 to 1.5 D of hyperopia, and 2 D of astigmatism.
- Corneal abnormalities exclude the patient from laser vision correction.
- IOL is the known source of error.
- Patient reports visual phenomena (more common in multifocal intraocular lenses).

Depending on the status of the IOL and capsule, insertion of a piggyback IOL is much less complex than IOL exchange. There may be a higher risk for certain complications with IOL exchanges compared with piggyback lenses (Table 56.1). Complications of IOL exchange include posterior capsule compromise, zonular damage, cyclodialysis, retinal tears, and macular edema. IOL exchange can also be more complex to perform if a Nd:YAG posterior capsulotomy has already been performed.[5]

Advantages of placing a piggyback lens are its increased accuracy compared with IOL exchange, relative ease of procedure, and reversibility. It is intended to be placed in the sulcus, anterior to the original intraocular lens in the capsular bag. Add-on IOLs specifically designed for piggyback IOL implantation that are widely used outside the USA are not available in the United States, nor are three-piece toric IOLs available. There is controversy as to whether or not the piggyback lens should be the same material. Intralenticular opacities can develop if same-material IOLs are both within the bag, but this may not be as much of an issue if the piggyback IOL is within the sulcus.[6] Thus, if opposite material IOLs are being considered, as an example, a sulcus-placed silicone IOL would be preferred if a hydrophobic acrylic IOL in is in the capsular bag. Adequate space is necessary in the sulcus to accommodate the lens and the lens diameter should be > 13.5 mm with an optic size > 6.0 mm. Rounded-edge lens profiles are preferred because they decrease the risk for pigmentary dispersion, iris chaffing, and uveitis-glaucoma-hyphema syndrome, which, along with interface opacification, are the potential long-term complications of piggyback IOLs.[6]

For patients with postoperative residual mixed astigmatism after a toric IOL (see Chapter 31), it is crucial to review the preoperative and postoperative data to determine whether the patient would benefit from rotation of the IOL to a more optimal axis versus a PCRI or PRK/LASIK. Special attention should be given to the current manifest refraction and current axis and power of the toric IOL.

There are several online calculators available to determine the optimal axis to reposition the lens such as astigmatismfix.com and Barrett Rx calculator.[7] The manifest refraction is a critical piece of data used in these calculations, so this should be double-checked for accuracy. Patients with purely mixed astigmatism or residual spherical equivalent < +/– 0.5 D would benefit most from rotation of the IOL to the ideal axis of astigmatism. PCRIs with a diamond blade or femtosecond laser can be done for residual astigmatism <1 D. If the spherical equivalent is > +/–0.5 D, an IOL exchange with potential rotation of the new lens to the optimal axis may be necessary. For large myopic or hyperopic refractive errors with residual astigmatism, LASIK or PRK can be done if they meet the criteria as described above for laser-based surgery.

There are special considerations for performing an intraocular lens exchange, including the status of the capsular bag and zonules, presence or absence of an intact posterior capsule, type of IOL, and the duration that the IOL has been in the eye. Silicone IOLs and hydrophilic IOLs can be thicker and more slippery to grip. Three-piece IOLs have more rigid haptics to manipulate. The various hydrophobic IOLs have a very different consistency, from being tacky, soft, and gummy (like the Alcon Acrysof IOL family), or more rigid (JJV Tecnis and B&L Envista IOL families).

The most important step is to reopen the capsular bag. In the early postoperative period, this is often easy to perform with a blunt 27 g cannula on viscoelastic syringe to bluntly dissect this potential space (see Videos 56.1 and 56.2). Once the anterior capsule has fibrosed or adhered onto the anterior face of the optic, a blunt cannula may not be insufficient to engage in between the capsule and optic. There are specific instruments that are available to help separate this potential space, such as the Donnenfeld Femto Spatula. Otherwise, a 27¼ g needle or Palay cannula on a viscoelastic syringe can be introduced, bevel down, to slide under the anterior capsular edge and slowly inject small aliquots of viscoelastic to spread the potential space of the capsular bag open (see Video 56.2). Once an adequate space has been created

between the anterior face of the optic and the anterior capsule, the needle should be changed to a blunt 27 g cannula on the viscoelastic device, to prevent capsular bag damage from the needle. It is important to open the capsular bag for its entirety of 360 degrees. As the viscodissection proceeds, the capsular bag should be carefully decompressed of the viscoelastic device by pressing down on the optic edge, allowing the viscoelastic to prolapse around the IOL. This will prevent inadvertent damage to an intact posterior capsule.

Regarding the actual explantation of the IOL, the haptics can pose another challenge because they can be entangled with fibrotic bands that attach them to the capsular bag equator. This can be seen even after a few months postoperatively and is more commonly seen with the one-piece IOLs. The haptics should be carefully manipulated to check how freely mobile they are before trying to lift the IOL out of the capsular bag, as incomplete release of the haptic from its adhesions can lead to capsule compromise and/or disinsertion of the adjacent zonules. Sometimes, the haptics will need to be transected from the optic to perform the IOL exchange safely (see Videos 56.1 and 56.2).

A variety of methods can be used for fixating the new IOL, depending on the status of the posterior capsule, anterior capsular opening, and zonules. Video 56.3 shows the method of fixating the haptics of a three-piece IOL using scleral flaps and tunnels.

REFRACTIVE ENHANCEMENTS TO ADDRESS PRESBYOPIA

Various options are available to address presbyopia after IOL surgery. These include the following:

- Monovision via laser vision correction, piggyback IOLs, or IOL exchange
- Presbylasik
- Corneal inlays
- Multifocal add-on IOLs

Discussion of the pros and cons of each is beyond the scope of this chapter, but these approaches should be considered in patients who are dissatisfied with bilateral uncorrected distance vision only after IOL surgery.

FUTURE DEVELOPMENTS

Light-adjustable lenses were FDA approved in 2017 and hold the promise for decreasing the need for a second procedure after cataract surgery. The lens undergoes predictable changes in curvature when exposed to UV light. Up to 2 D of sphere and cylinder can be adjusted in 1 to 3 light treatments. Alio reported that 92% of RxSight patients were within 0.50 D of refractive target and 99.5% were within 1 D of the refractive target.[8] Patients need to be able to dilate adequately for the adjustments postoperatively. The ability to tailor the lens itself after cataract surgery to a patient's refraction can drastically change the need for a refractive enhancement after cataract surgery and eliminate subjecting patients to delayed visual recovery and cost associated with another surgery.

SUMMARY

- Careful retrospective analysis to determine the cause of a refractive surprise is critical.
- The degree of refractive error will determine the type of procedure for which the patient is a candidate.
- Laser vision correction can correct low degrees of refractive error, barring no corneal pathology.
- Piggyback lens placement is a reversible and technically easier surgery to perform than IOL exchange when there is a large refractive error to be corrected.
- Several online calculators are available for residual astigmatism correction and determine optimal axis for a toric IOL.
- Understanding the source of error in the first eye surgery can help better plan for the second eye.[9]

TABLE 56.1 Considerations for Choosing IOL Exchange Versus Piggyback Lens

IOL exchange	Piggyback lens
Refractive error > 2D	Refractive error in average to long axial length
Incorrect IOL initially implanted/IOL is known source of refractive error	Zonulopathy (but worry about IOL decentration if zonulopathy)
Damaged optic	Posterior capsule compromise
Poor quality of vision (multifocal lens)	

Abdelghany AA, Alio JL. Surgical options for correction of refractive error following cataract surgery. Eye Vis (Lond). 2014;1:2. doi:10.1186/s40662-014-0002-2

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Video 56.1 Bag-to-bag IOL exchange of a one-piece multifocal IOL for a toric monofocal IOL approximately 8 months from the original surgery.

Video 56.2 IOL exchange in a patient who had persistent, unremitting debilitating negative dysphotopsia, 2 years after the original surgery. There is a well-centered Nd:YAG-created posterior capsulotomy.

Video 56.3 This patient has a dislocated 1-piece hydrophobic acrylic IOL that is within the sulcus space with only a minimal shelf of capsule still remaining.

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