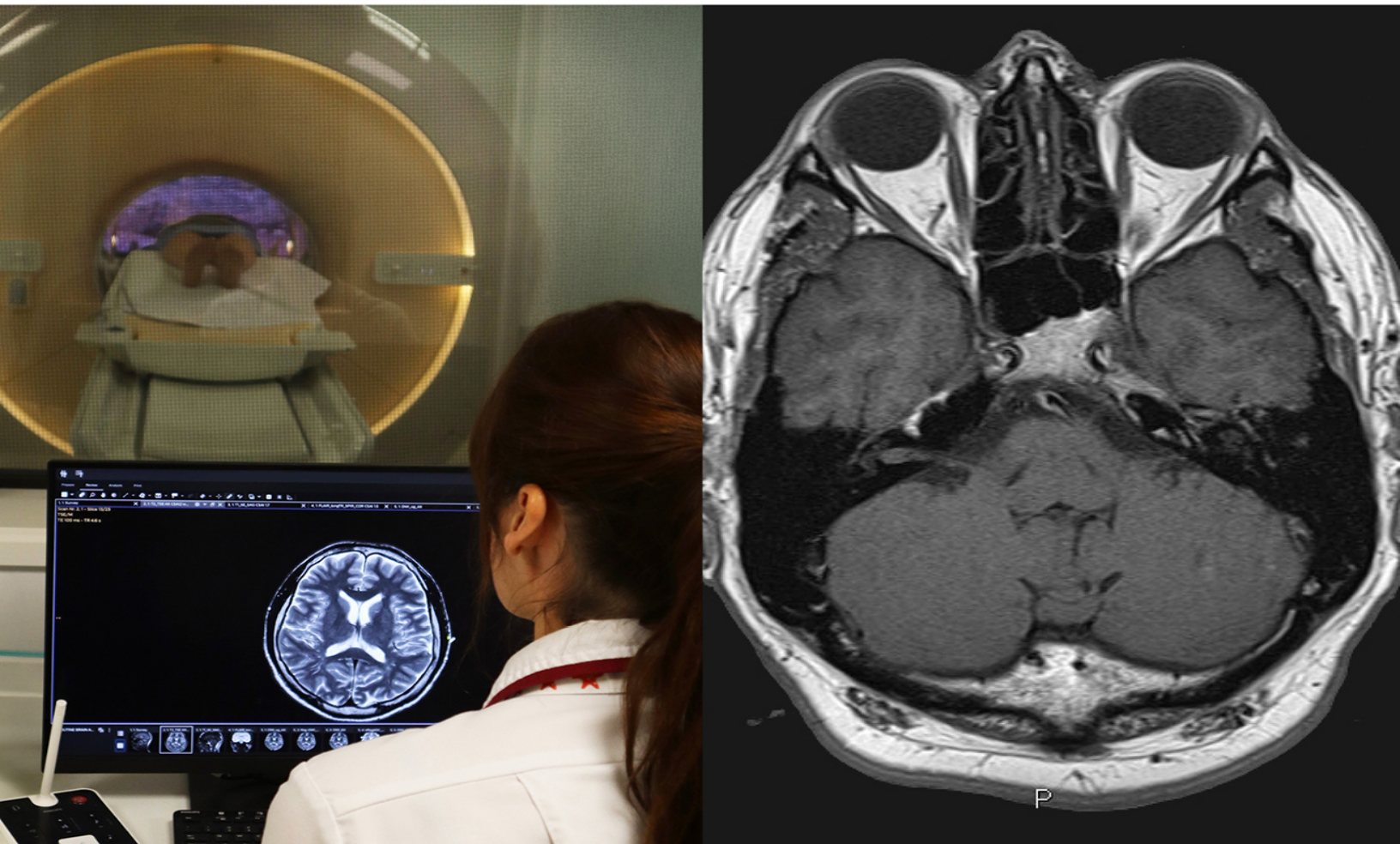


CLARK'S

ESSENTIAL GUIDE TO MRI IN CLINICAL PRACTICE



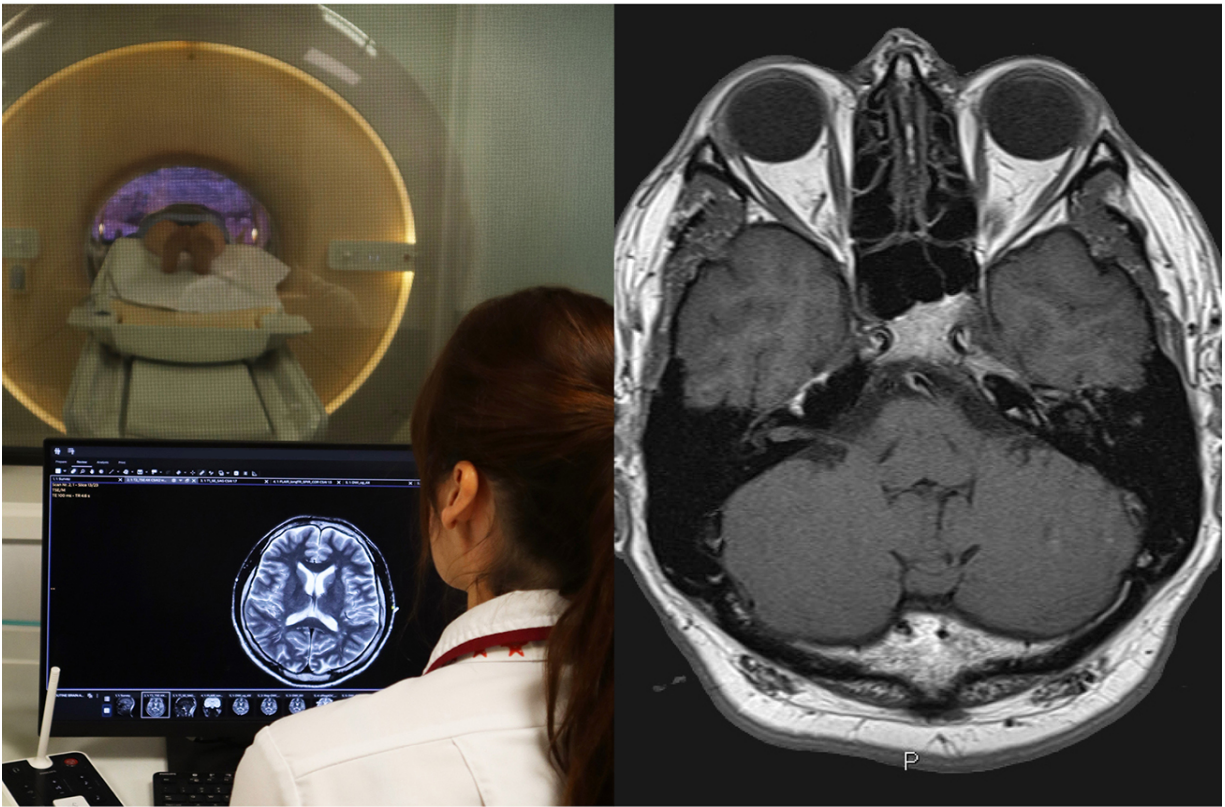
LISA BRINDLE AND CATH MILLS



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CLARK'S

ESSENTIAL GUIDE TO MRI IN CLINICAL PRACTICE



LISA BRINDLE AND CATH MILLS



CRC Press
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CLARK'S Essential Guide to MRI in Clinical Practice

This easy-to-understand guide in the highly respected Clark's stable of diagnostic imaging texts is an essential handbook for daily practice in magnetic resonance imaging, providing clear and practical advice to help both experienced practitioners and those new to the modality at both undergraduate and postgraduate levels. The book provides guidance on general procedures in MRI, summarising current relevant literature and professional body guidelines.

Clark's Essential Guide to MRI in Clinical Practice takes the systematic approach adopted within books in the Clark's family and is designed to be clear and consistent. The book introduces the reader to the technique from first principles, including image generation and capture, physical and psychological preparation of the patient, and safe practice, then moves to MRI by body region. Organised from head to toe, this section includes images that have been carefully selected to demonstrate positioning and, most importantly, adaptive positioning technique, where the reader will learn how to achieve diagnostic images when their patient cannot lie in the desired 'textbook' position. The content concludes with a section devoted to advanced and specialist practice, including cardiac, fetal and breast imaging, and the impact of AI.

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CLARK'S ESSENTIAL GUIDE TO MRI IN CLINICAL PRACTICE

Lisa Brindle

MRI Manager

Blackpool Teaching Hospitals NHS Foundation Trust

Blackpool, UK

Cath Mills

Deputy Clinical Services Manager CT/MRI

Circle Health Group Blackburn, UK

Series Editor for Clark's Companion Essential Guides

A Stewart Whitley

Radiology Advisor, UK Radiology Advisory Services

Preston, Lancashire, UK

Former Director of Professional Practice,

International Society of Radiographers and Radiological
Technologists (ISRRT)



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Dedication

To the memory of Paul Lowe, late partner of our co-author, Cath Mills.

This work is offered in quiet tribute to a life dearly loved and deeply missed.

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FOREWORD

It has been a delight to witness the development and publication of *Clark's Essential Guide to MRI in Clinical Practice*. This latest addition to the *Clark's* series of pocket and desktop books is a testament to the skills, knowledge and dedication of the authors who are key members of the radiography profession and who have at heart the desire to share their knowledge and experience with radiographers and students engaged in this area of expertise. Such radiographer involvement is pivotal in the patient journey where other members of the healthcare team are dependent on their service.

Many of us have witnessed over the years the increased use of MRI, with the corresponding rapid developments in MR scanner design and technology with improved protocols and procedures. The demand for more procedures across the wide spectrum of medical specialties and the request for almost instant scanning puts the practitioner under enormous pressure. This book conveys to its readers an immense amount of important knowledge that is current, relevant and essential in meeting such requests and giving insight on how to adapt techniques relevant to demanding situations.

Miss Kathleen C Clark, I am sure, would welcome this important addition to the *Clark's Companion Essential Guides*, which has its origins in the recently published *Clark's Procedures in Diagnostic Imaging: A System-Based Approach*.

I am confident that the patient and all those involved in this important field of imaging will benefit greatly from this publication.

A Stewart Whitley

Series Editor

Former ISRRT Director of Professional Practice &

Radiology Advisor
UK Radiology Advisory Services
Preston, Lancashire, UK

PREFACE

Work by physicists in the 1930s on nuclear magnetic resonance became the basis of magnetic resonance imaging (MRI). Research into the atomic and molecular properties of solids and liquids in the 1940s, later led to MRI scanners using the body's water content to develop images. By the 1970s, full-body MRI machines had been designed, with the first commercial MRI machine being used in 1980 in the UK. Much has evolved since then in clinical MR to the present day.

This book has been written to offer advice on how to deal with everyday situations where standard textbook positioning techniques cannot be applied due to a patient's physical condition, scanner constrictions, time pressures and safety considerations.

This book has been written by two radiographers who have worked in the specialist area of cross-sectional imaging since 1999. They gained their specialist computed tomography (CT) and MRI knowledge using early generation scanners in busy hospitals with established specialist services in Accident and Emergency, neurosurgery, neurology, musculoskeletal, vascular, oncology, fetal, breast and research scanning, participating for many years in busy emergency on-call service provision. After promotion to senior positions, they worked in supervisory roles where they developed special interests in MR safety, mentoring and training, management and leadership. Since 2013, they have worked as clinical managers overseeing service provision and delivery in crosssectional imaging modalities, management of staff and equipment within the MR unit, developing local policies and procedures to support safe working practices, and are committed to providing high standards of patient care.

Due to the diverse mix of patient types and dealing with patients who are acutely ill or unable to undergo routine MR scans due to physical or

emotional restraints, the authors have used their years of adapting technique to draw from when writing this book. The authors of this book have been supported by colleagues in the UK who have provided input and advice on current practice.

This book is dedicated to explaining diagnostic MRI procedures, using different techniques and contrast media studies that feature in the modern imaging department using a 1.5-tesla (T) scanner. Patients will be mentioned as ‘patients’ in most sections of the book, in keeping with modern parlance. Currently, commercially available clinical systems in the UK range from 0.2T to 3T, with some centres with research scanners operating above 3T. The majority of scanners installed for general diagnostic purposes are 1.5T in strength and are of cylindrical closed bore design.

Professional societies and international organisations (e.g. the Society and College of Radiographers, Medicines and Healthcare products Regulatory Agency, American College of Radiology and Royal College of Radiologists) and subspecialty organisations (e.g. the British Association of MR Radiographers) produce guidance based on evidence-based research, which should be included as part of the continual professional development (CPD) necessary for the area of practice to which you are engaged. These have been utilised in the planning and writing of the content of this book. Readers should always refer to their local protocols and current national and international guidance for the examinations that they perform. The following are examples of guidance, and the list is not exhaustive:

- ***iRefer: Making the Best Use of Radiology*** is a synthesis of evidence-based guidelines from the UK and international sources and provides recommendations for clinical imaging services, helping referrers to determine the most appropriate imaging investigations or interventions

for patients. It provides practical guidance based on the best available evidence.

- **National Institute for Health and Care Excellence (NICE)** guidelines: many of these are imaging pathways related specifically to a disease or medical condition.
- **Medicines and Healthcare products Regulatory Agency (MHRA)** *Safety Guidelines for Magnetic Resonance Imaging Equipment in Clinical Use*: the Fourth Edition of the safety guidelines aims to provide relevant safety information for users of MRI equipment in clinical use.
- **American College of Radiology (ACR)** *Manual on MR Safety* provides guidance as the field of MRI continues to evolve and mature, providing MR services that are not only safe but also valuable from a clinical or research point of view.
- **Society of Radiographers** is the trade union and UK professional body for the diagnostic imaging and radiotherapy workforce.
- **British Association of MR Radiographers**: aims to support and promote the professional development of radiographers and other professionals within the speciality of MRI, through encouraging and developing educational forums and conferences.
- **Public Health England** aims to protect and improve the nation's health and to address inequalities through working with national and local government, the NHS, industry and the voluntary and community sector.*
- **Public Health Scotland** leads and supports work across Scotland to prevent disease, prolong healthy life and promote health and wellbeing.

- **Public Health Wales** is the national public health agency in Wales and exists to protect and improve health and wellbeing and reduce health inequalities.
- **Department of Public Health (Ireland)** works to protect and improve health for the people of Ireland.
- **UK NHS population screening programmes** include details such as programme standards, education and training and quality assurance.

* Since writing PHE has been changed to UK Health Security Agency and Office for Health. [↗](#)

We hope that this book will provide the student and practitioner with a wealth of information and encourage them to look deeper into the subject of MRI.

ACKNOWLEDGEMENTS

The authors are indebted for the help and advice given by many colleagues throughout the diagnostic imaging community, with contributions enthusiastically given by radiographers, consultant radiographers, radiologists, physicists and lecturers from many health institutions, academic departments, the medical imaging industry and professional bodies.

The authors would particularly like to thank the following individuals for their contributions: at Bolton NHS Foundation Trust, Dr Kate Broome (Consultant Radiologist), Dr Rakesh Mehan (Consultant Radiologist) and Dr Rubeena Razzaq (Consultant Radiologist); at University Hospitals of Leicester NHS Trust, Helen Estall (Consultant Radiographer); at Blackpool Teaching Hospital NHS Foundation Trust, Fiona HopwoodCurwen (MRI Clinical Lead), Rebecca Holden (MRI Team Lead) and Neil Woodhouse (Head of Profession); at The Christie NHS Foundation Trust, Michael Hutton (Clinical Scientist); and at The Beardwood Hospital, Blackburn, Hilary Smith (Senior Radiographer).

In addition, the authors are grateful for the provision of images to Trina Herbert at the Royal Marsden NHS Foundation Trust; Dr Sachin Mathur, Consultant Neuro Radiologist at Lancashire Teaching Hospitals NHS Trust; Motion and Graphics Designer Sophie Mills; Paul Morgan and Selene Rowe at Nottingham University Hospitals NHS Trust; John Newton at Blackpool Teaching Hospitals NHS Foundation; and Phil Rowley, University of Nottingham.

The authors would like to extend special thanks to Damien Brindle, Elizabeth Barker and Neil Woodhouse for their unwavering support and encouragement throughout this process.

Finally, thanks are given to the many models who patiently posed for photographs and images. These were mainly radiographers, students and volunteers from a variety of health institutions, including The Beardwood Hospital and Blackpool Teaching Hospital, and include Kristian Akers, Elizabeth Barker, Darren Bullock, Dougal Chisholm, Catherine Haslam, Michelle Keryk, Emma Killingbeck, Joshua Holland, Oliver McMurdo, Shuchika Narang, Matthew Rogers, Jessica Cowgill, Matthew Ainsworth, Hilary Smith and Kirsty Waite.

ABBREVIATIONS

ABMRS

American Board of Magnetic Resonance Safety

ADC

Apparent diffusion coefficient

ANTT

Aseptic non-touch technique

AVM

Arteriovenous malformation

Ax

Axial

C

(when relating to the spine) Cervical

CAIPIRINHA

Controlled aliasing in parallel imaging results in higher acceleration

CISS

Constructive interference in steady state

Cor

Coronal

CoW

Circle of Willis

CMR

Cardiac magnetic resonance

CT

Computerised tomography

CTA

Computed tomography angiography

DESS

Double echo steady state

DLRA

Deep learning reconstruction algorithm

DSA

Digital subtraction angiography

DWI

Diffusion-weighted imaging

F

Flash

FIESTA

Fast imaging employing steady-state acquisition

FISP

Fast imaging with steady-state free precession

FLAIR

Fluid attenuated inversion recovery

FLASH

Fast low-angle shot

FOV

Field of view

FS

Fat saturation

FSE

Fast spin echo

GBCA

Gadolinium-based contrast agent

GRE

Gradient echo

HASTE

Half Fourier single-shot turbo spin echo

HCAI

Healthcare-associated infection

IAM

Internal auditory meatus

ICNIRP

International Commission on Non-Ionizing Radiation Protection

IEC

International Electrotechnical Commission

IPC

Infection prevention methods

L

(when relating to the spine) Lumbar

LT

Left

MEDIC

Multiple echo data image combination

MHRA

Medicines and Healthcare products Regulatory Agency

MPRAGE

Magnetisation-prepared rapid acquisition gradient echo

MR

Magnetic resonance

MRA

Magnetic resonance angiography

MRCP

Magnetic resonance cholangiopancreatography

MRI

Magnetic resonance imaging

MSK

Musculoskeletal

NMR

Nuclear magnetic resonance

NSF

Nephrogenic systemic fibrosis

PACS

Picture archive and communication system

PD

Proton density

PET-CT

Positron emission computerised tomography

PPE

Personal protective equipment

PSA

Prostate-specific antigen

QA

Quality assurance

RF

Radio frequency

RT

Right

Sag

Sagittal

SE

Spin echo

SMRI

Structural magnetic resonance imaging

SNR

Signal-to-noise ratio

SPACE

Sampling perfection with application optimised contrast using different flip angle evolution

SPAIR

Spectral attenuated inversion recovery

SSFP

Steady-state free precession

SSFSE

Single-shot fast spin echo

STIR

Short tau inversion recovery

T

(when relating to MR) Tesla

T

(when relating to the spine) Thoracic

TE

Echo time

TFCC

Triangular fibrocartilage complex

TIRM

Turbo inversion recovery magnitude

ToF

Time of flight

TR

Repetition time

TRUFI

True fast imaging with steady-state precession

TSE

Turbo spin echo

VIBE

Volume interpolated breath-hold examination

SECTION 1

KEY ASPECTS OF MAGNETIC RESONANCE IMAGING

DOI: [10.1201/9781003230229-1](https://doi.org/10.1201/9781003230229-1)

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ANATOMICAL TERMINOLOGY

Standard scanning technique in magnetic resonance imaging (MRI) allows scans to be acquired in the three orthogonal planes of the body: axial, coronal and sagittal ([Figs. 1.1a,b](#); see also schematic diagrams in [Fig. 1.1c-e](#)). This scanning technique gives an advantage over computerised tomography (CT) where images are only ever acquired in the axial plane.

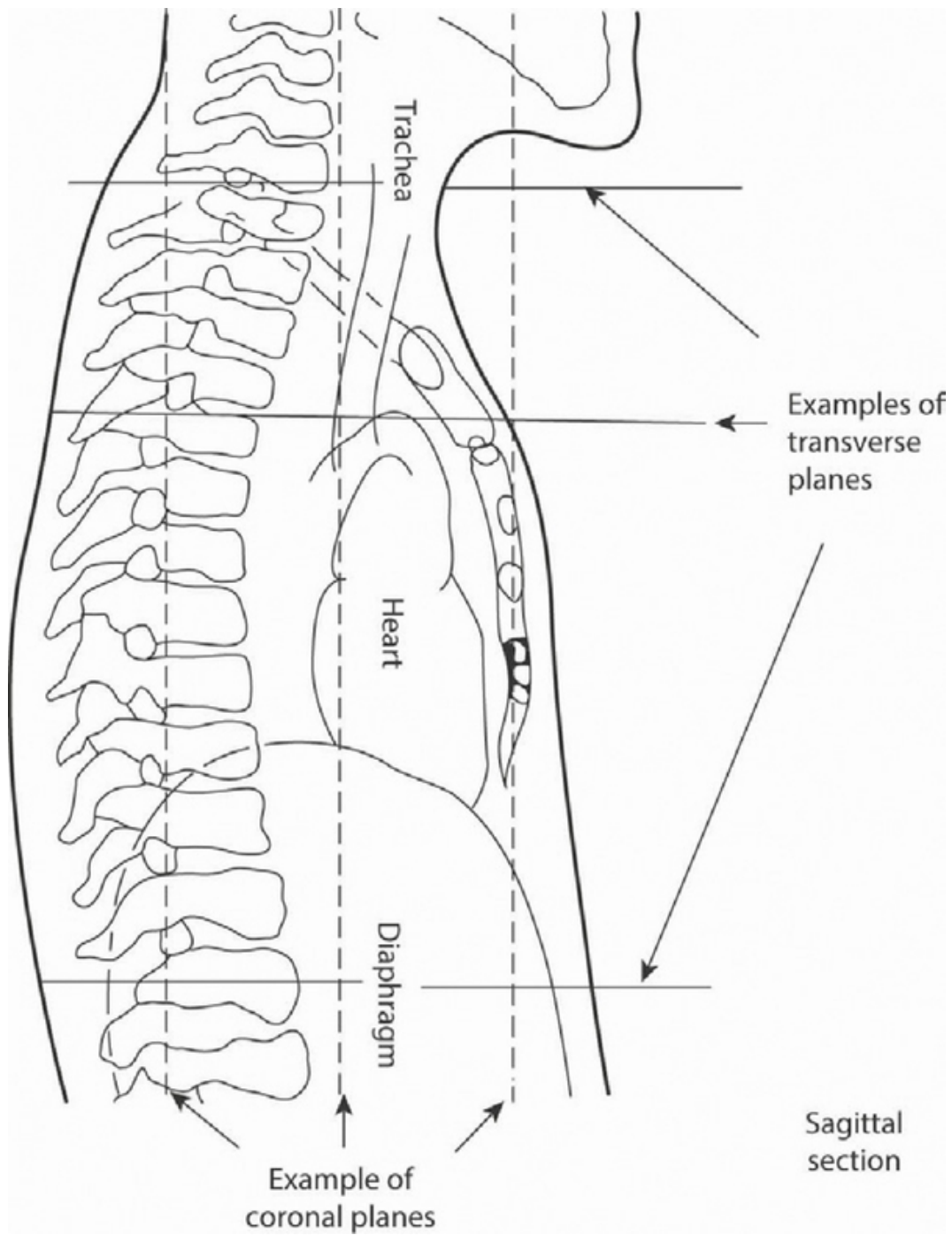
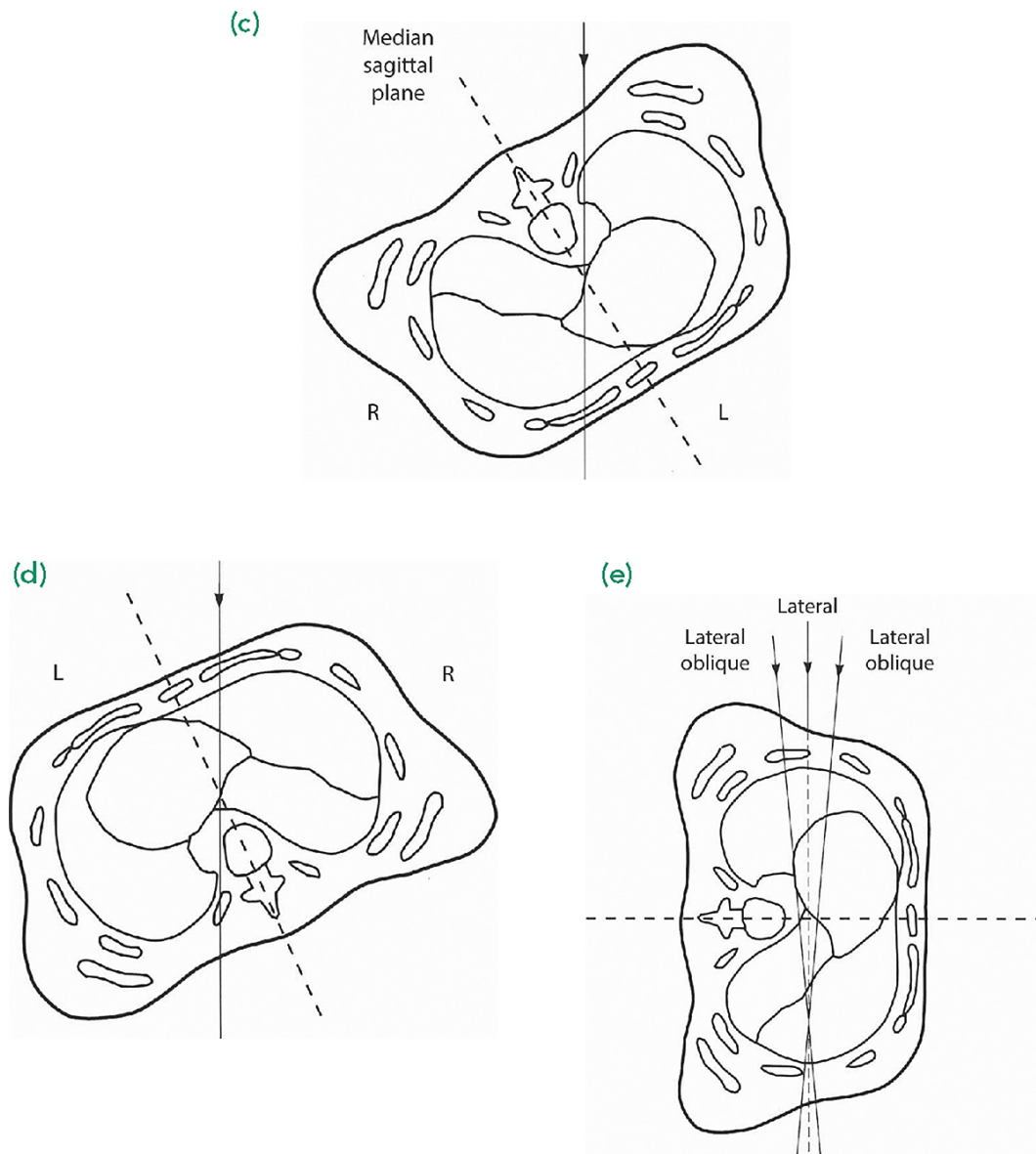


Fig. 1.1a Sagittal section through the thorax. [↗](#)



Figs. 1.1c–e Schematic diagrams showing (c) right anterior oblique; (d) left posterior oblique; (e) lateral obliques. [📄](#)

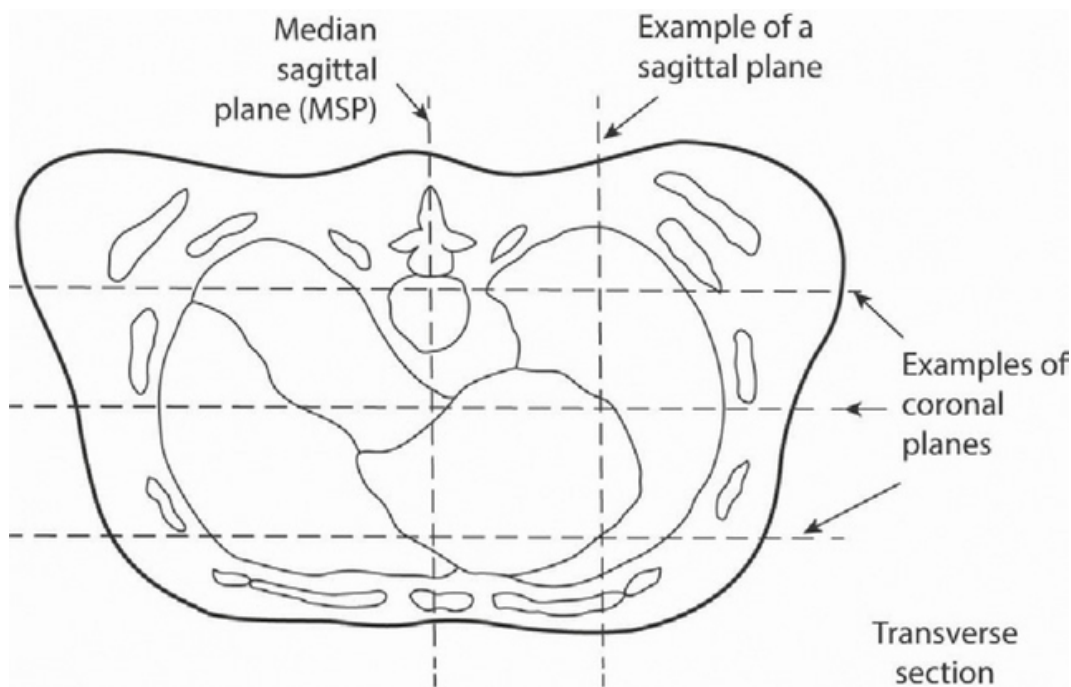


Fig. 1.1b Transverse section through the thorax. [↗](#)

As well as acquiring images in the orthogonal planes ([Fig. 1.2a](#), [Fig. 1.2b](#) and [Fig. 1.2c](#)) MRI allows the operator to plan scans in oblique planes when studying anatomy and organs with an axis of symmetry that is oblique to the magnet coordinate system ([1](#)). An example of this is in the standard shoulder scan, where the coronal images are acquired in an oblique plane when the operator angles the slice block along the supraspinatus tendon ([Figs. 1.2d,e](#)). By acquiring images in a coronal oblique plane this allows more accurate diagnosis of rotator cuff tears and tendinopathies. Rotation of the image plane can also be useful in reducing motion artefacts away from the anatomic region of interest and thus improve magnetic resonance (MR) image quality and the diagnostic value of the patient study.

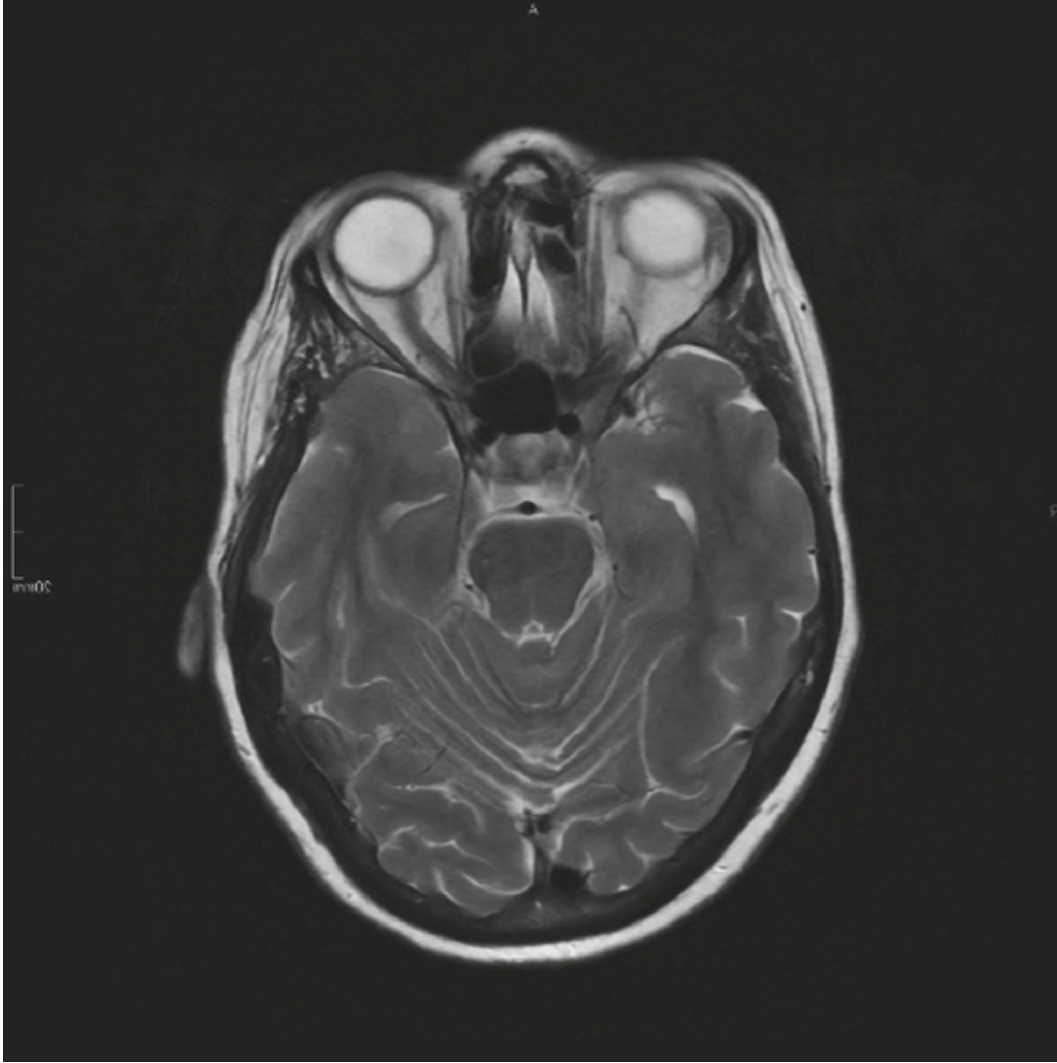


Fig. 1.2a MR scan of the brain demonstrating the axial plane. [↗](#)

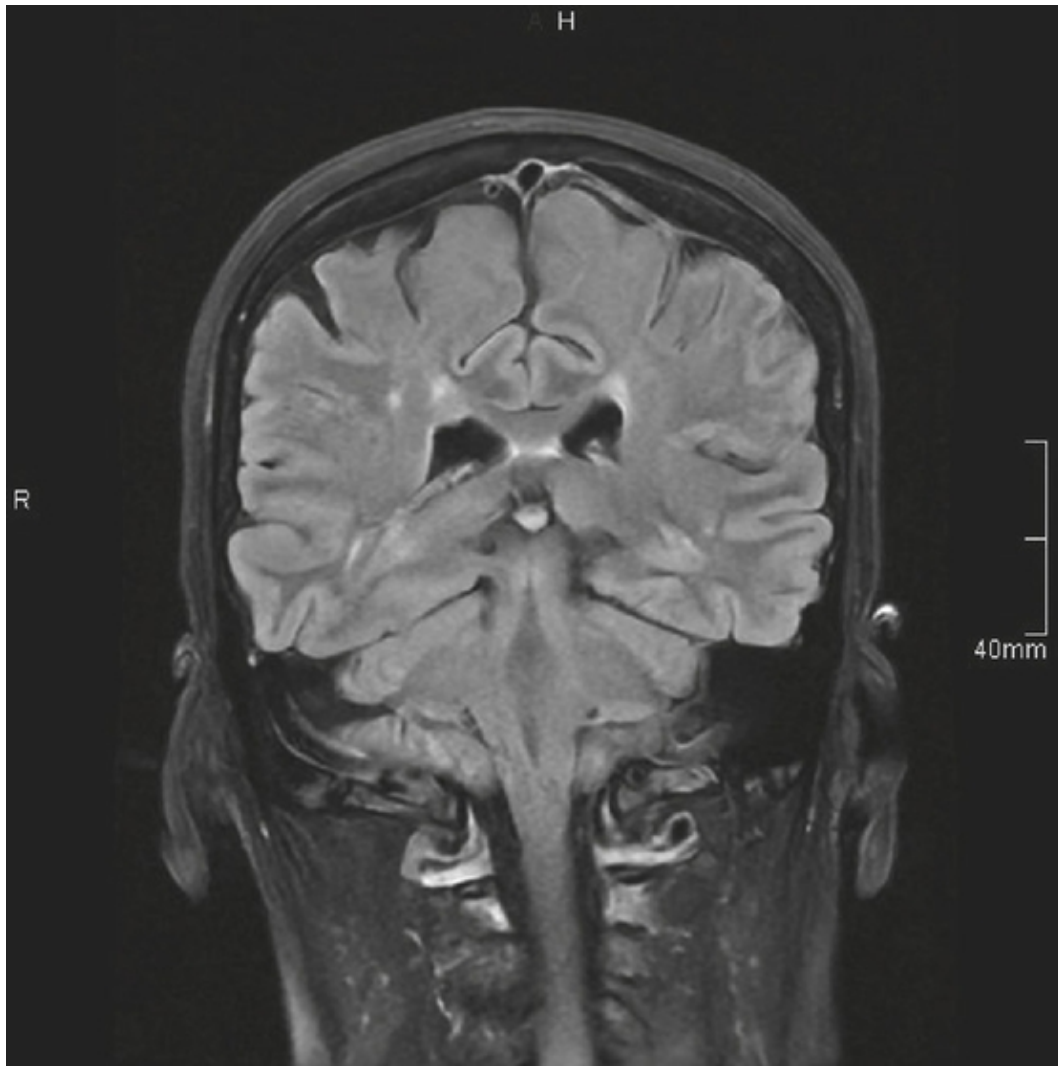


Fig. 1.2b MR scan of the brain demonstrating the coronal plane. [🔗](#)



Fig. 1.2c MR scan of the brain demonstrating the sagittal plane. [↗](#)



Fig. 1.2d Standard coronal shoulder image. [↗](#)

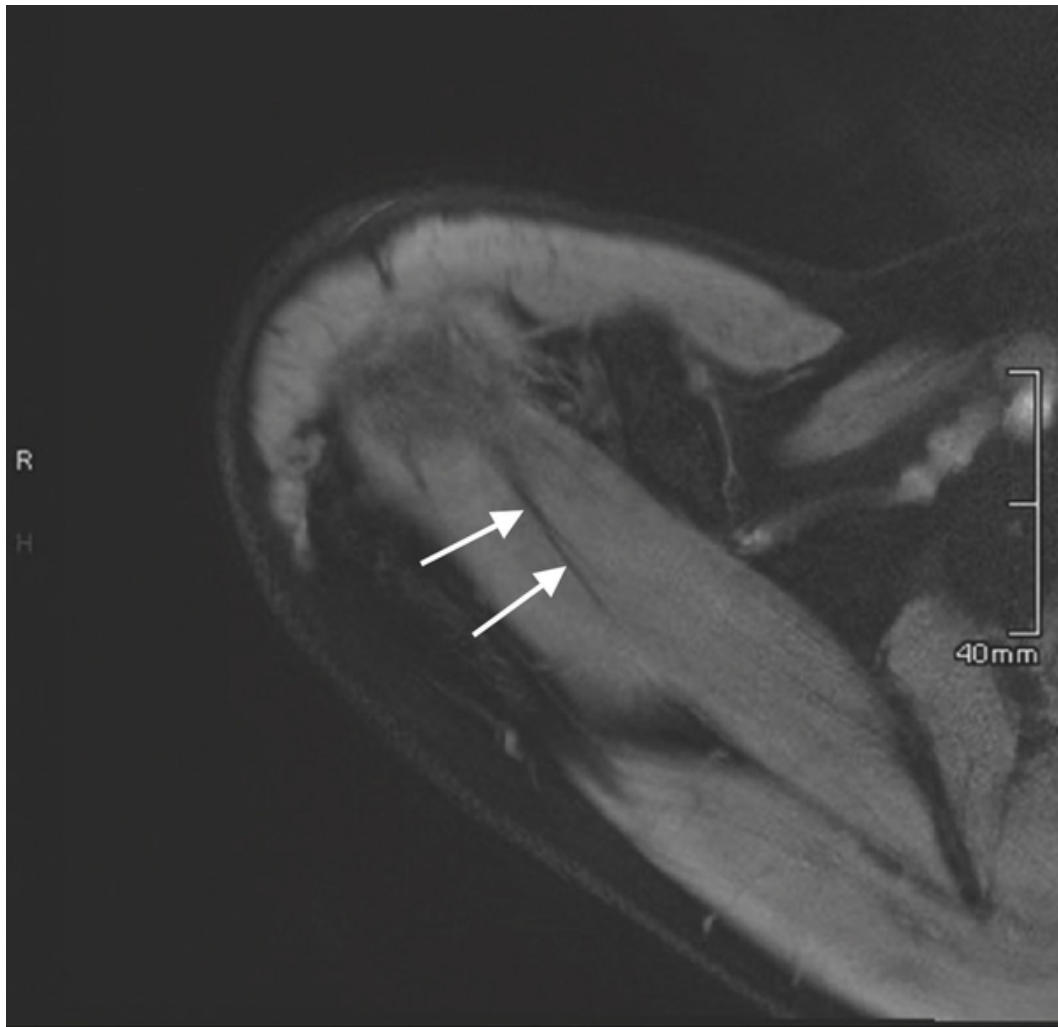


Fig. 1.2e To plan the standard coronal sequence the slice block is angled obliquely to match the angle of the supraspinatus. [📄](#)

BASIC PRINCIPLES OF MAGNETIC RESONANCE IMAGING

The principles of nuclear magnetic resonance (NMR) imaging have been known to scientists since the 1950s, when the technique was used for spectroscopy of small samples of liquid water and solid paraffin wax (2). Using the principles of NMR, techniques had been developed by the late 1970s that enabled anatomical images to be produced. In 1977, the first human MRI examination was performed, and subsequently the technology was developed further to perform whole-body imaging. The equipment

required for MRI and the physical principles underlying the phenomenon are complex. The information in Section 1 of this book is intended only to illustrate the basic principles of this imaging modality, as detailed consideration of both the system components and physics principles are beyond the scope of this book.

One of the early pioneers, Sir Peter Mansfield, worked in the 1970s to develop NMR techniques to create images of the human body's interior ([3](#)). In 2003, he was awarded the *Nobel Prize in Medicine* for his work in the application of MRI ([Fig. 1.3](#)).



Fig. 1.3 Sir Peter Mansfield, Nottingham, UK. Image courtesy of University of Nottingham.[↗](#)

COIL TECHNOLOGY

Radio frequency (RF) coils are components of the scanner hardware and act as ‘antennas’ to aid in broadcasting the RF pulses and then receiving signal from excited spins ([4](#)). They are categorised as either ‘receive’ or ‘transmit receive’ coils.

Coil choice is dependent on the body part being scanned, scan sequence choice and patient position. In MRI the anatomical part and receiving coil are positioned relative to the isocentre of the magnet to acquire localiser scans. Advances in technology have resulted in modern scanners being equipped with a range of wireless, flexible and integrated coils to choose from. They permit imaging with a high signal-to-noise ratio (SNR), image resolution and temporal resolution throughput, which supports accuracy in diagnosis and treatment. They can contribute to increased comfort and ease of the scan providing an overall improvement to the patient experience (5).

IMAGE FORMATION AND REVIEW

In MRI simultaneous image reconstruction and scanning is possible, allowing the operator to view each sequence on its completion. Images are reviewed for patient movement, anatomical coverage, pathology that may require extra sequences or contrast-enhanced sequences, and artefacts; the aim is to ensure a diagnostic scan.

To encourage safe working practice and to minimise risk of incidents, several professional bodies have created a 'Pause and Check' (6) or 'Stop and Check' (7) pathway, to encourage operators to take longer to pause and review the referral and patient identification checks prior to proceeding with the scan, and to pause afterwards to ensure correct image quality and that post-processing checks are carried out.

IMAGE ARTEFACTS

There are several main types of artefacts that could potentially obscure important clinical detail or mimic pathology on the MR image. It is important to be able to recognise them in order to improve the diagnostic properties of the scan.

Physiological Artefact

Such artefacts are caused by unintentional patient movement or movement from physiological factors such as patient breathing, blood flow and heartbeats. This results in ghosting or blurring appearance on images ([Fig. 1.4a](#)). Good patient preparation and immobilisation will help to eliminate unintentional movement, whilst appropriate scan sequence selection can assist in minimising unavoidable physiological movement artefacts ([Fig. 1.4b](#)).

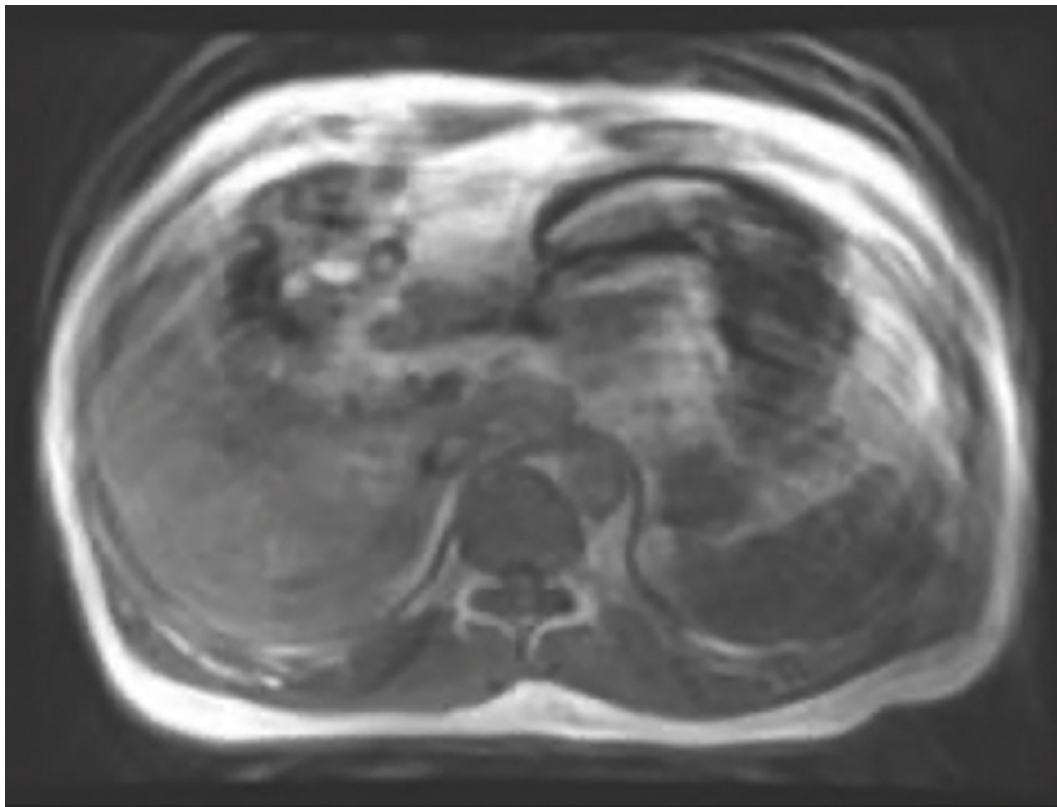


Fig. 1.4a Patient movement: breathing artefact. [↗](#)



Fig. 1.4b Patient movement: physiological. Cerebrospinal fluid flow artefact. [🔗](#)

Metallic Artefact

The inherent physics of MRI can cause a metallic susceptibility artefact which is produced by metallic devices or implants inside or external to the patient and can be reduced by avoiding gradient echo sequences. However, sometimes this effect can be useful in diagnosis because it provides useful information about pathological processes. One example of this is the presence of blood breakdown products in a haematoma that will give susceptibility artefact. Performing a gradient echo sequence can therefore aid in the diagnosis of pathologies such as haemorrhage or aneurysm ([Fig. 1.4c](#)).

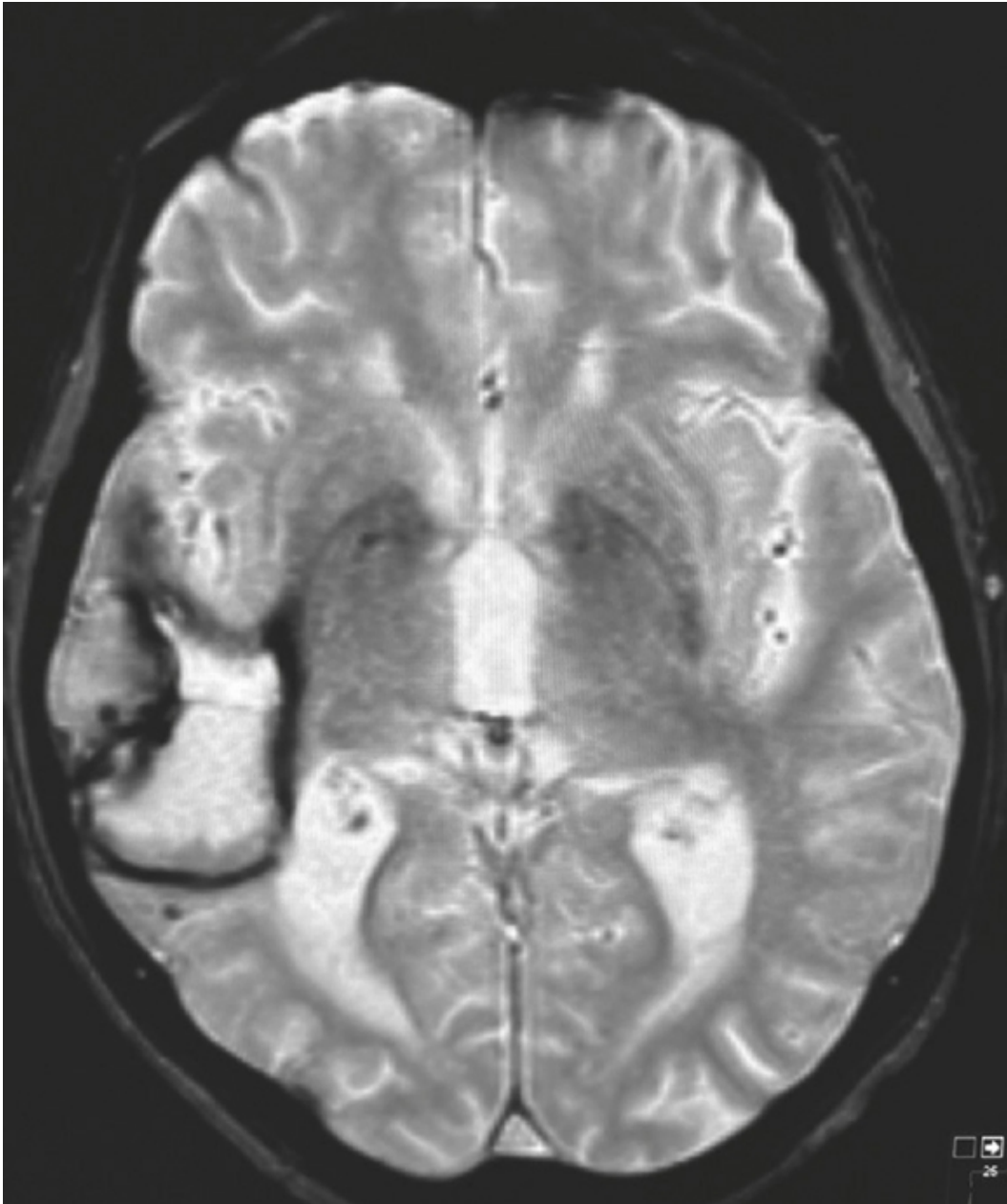


Fig. 1.4c Magnetic susceptibility artefact on a gradient echo image: right temporal lobe haemorrhage. [📄](#)

Chemical Shift Artefact

Chemical shift artefacts occur as a result of spatial mismapping of the MR signal in the frequency encoding direction due to differences in local chemical environment. They are most commonly seen around structures

containing protons in water and in fat as hyperintense and hypointense bands ([Fig. 1.4d](#)).



Fig. 1.4d Chemical shift artefact. [📄](#)

Hardware/Software Artefact

These artefacts are caused during image construction by environmental factors in the MRI room, for example a faulty element in a coil ([Fig. 1.4e](#)), or a signal intensity artefact can be caused by a faulty coil ([Fig. 1.4f](#)).

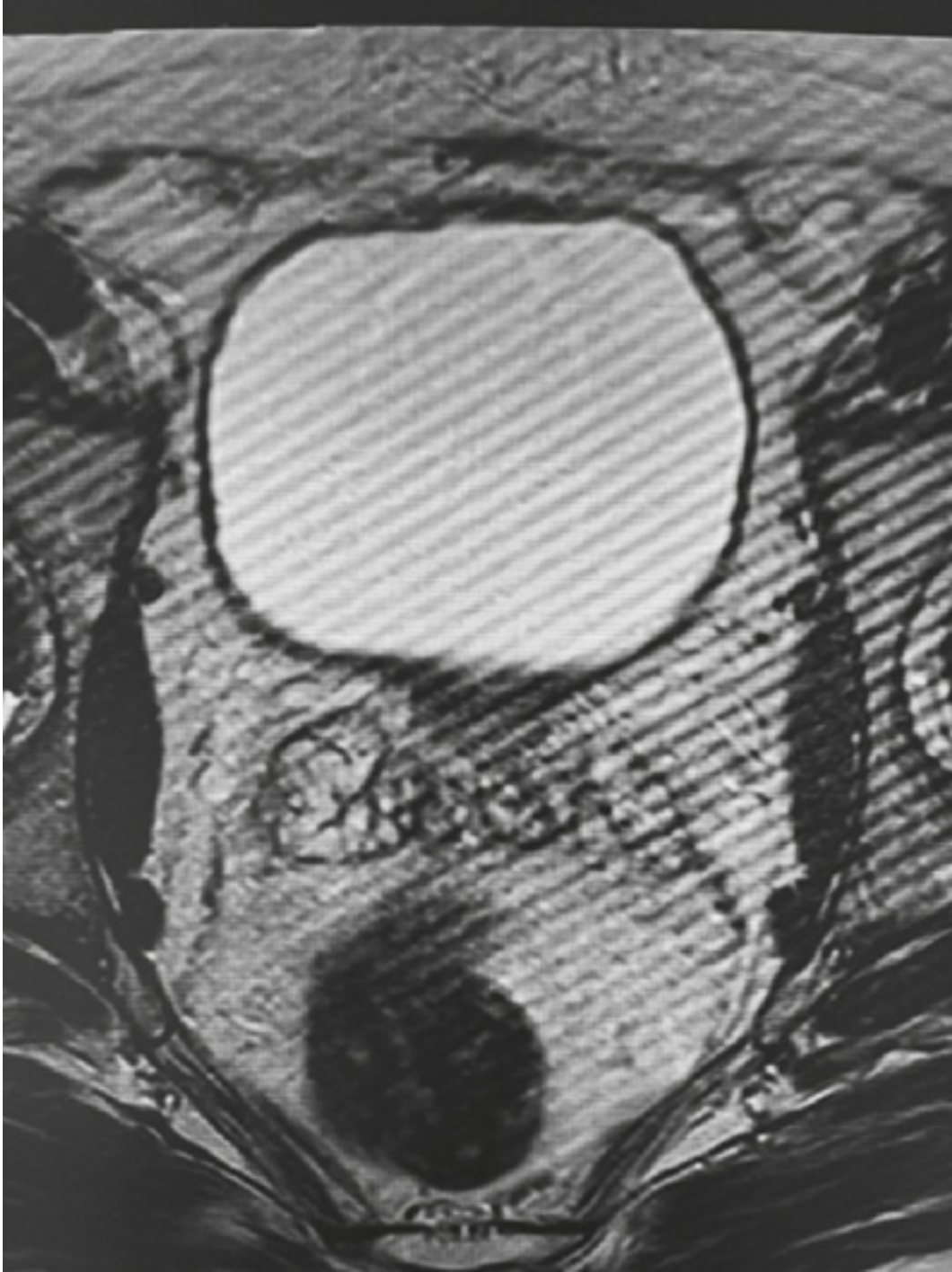


Fig. 1.4e Zipper artefact caused by a faulty element in a coil.[📄](#)

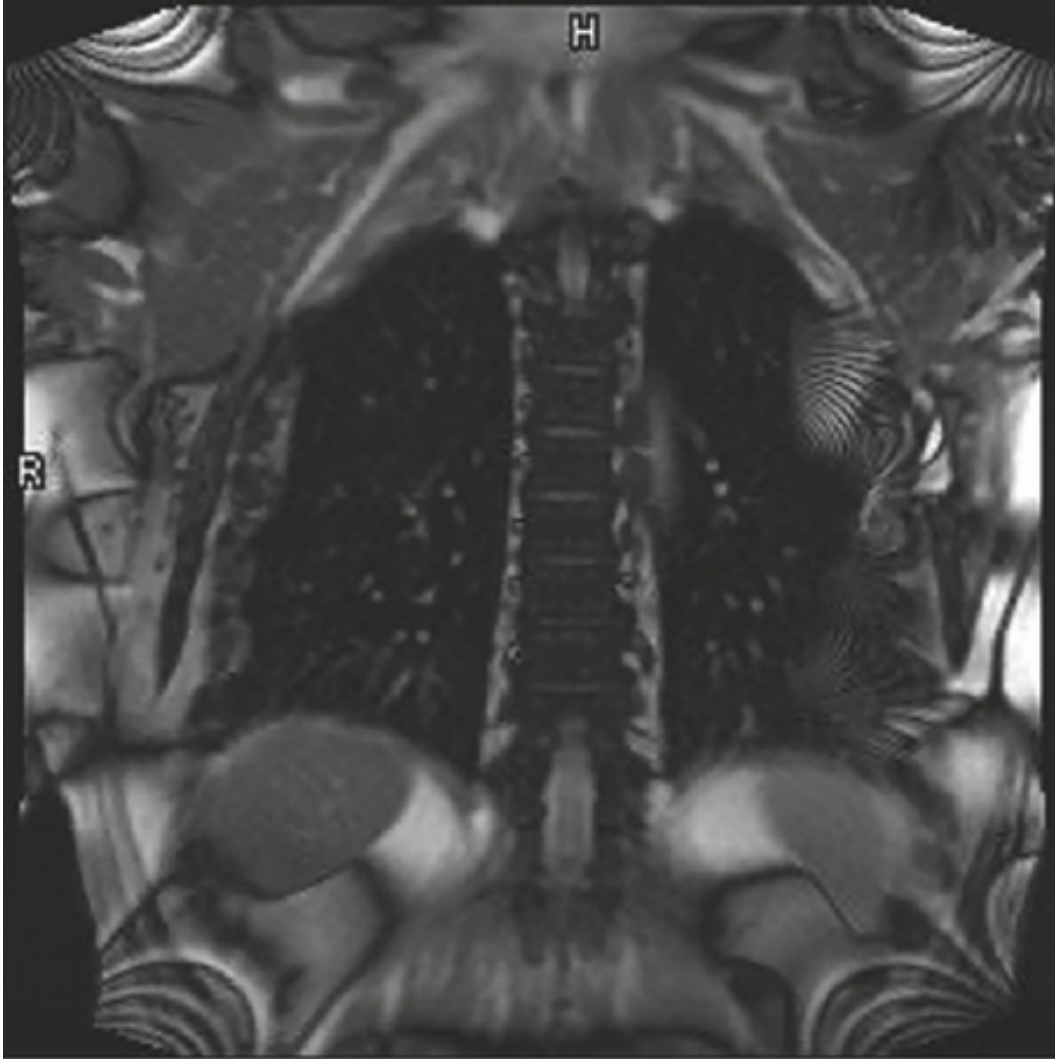


Fig. 1.4f Signal intensity artefact due to non-activation of the coil during sequence setup by the operator. [🔗](#)

QUALITY ASSURANCE

Equipment quality control tests are mandatory for all clinical scanners to ensure optimal image quality is achieved for patient care and accurate diagnosis. Regular quality assurance (QA) testing is important in assessing whether there are changes to image quality over time. Regular QA testing ensures that the scanner is operating in a standardised way ([8](#)). Any aspects of the MR system (strong magnet, magnetic field gradients, RF coils, analogue to digital converters, image reconstruction computers) have the

potential to affect image quality, so QA imaging protocols are designed to be sensitive to degradation in any of these components.

Test objects called phantoms are provided by the scanner manufacturer and allow QA testing to be carried out on the MRI system. These devices have been specifically designed to be imaged in the MRI field to evaluate and analyse the performance of the scanner (9) ([Fig. 1.5](#)).



Fig. 1.5 Phantom placement during routine head coil QA. [📄](#)

QA is carried out using standardised imaging protocols, and many MR systems are set up with automated QA protocols that will typically assess SNR on a given phantom and an RF coil. SNR is the most widely used QA

measurement since it provides a general but non-specific assessment of system performance ([Fig. 1.6a](#), [Fig.7](#) and [Figure d](#)). Other tests that are typically carried out annually by a medical physicist or the manufacturer include image uniformity, geometric accuracy, ghosting, slice positioning and slice thickness accuracy. In other clinical applications other measurements are required; for instance, in MRI screening for breast cancer fat suppression is critical to the detection of breast tumours and so an assessment of the quality of fat suppression is a requirement for inclusion in the routine QA programme ([10](#)).



Fig. 1.6a Typical setup of a body array coil phantom QA test. [🔗](#)

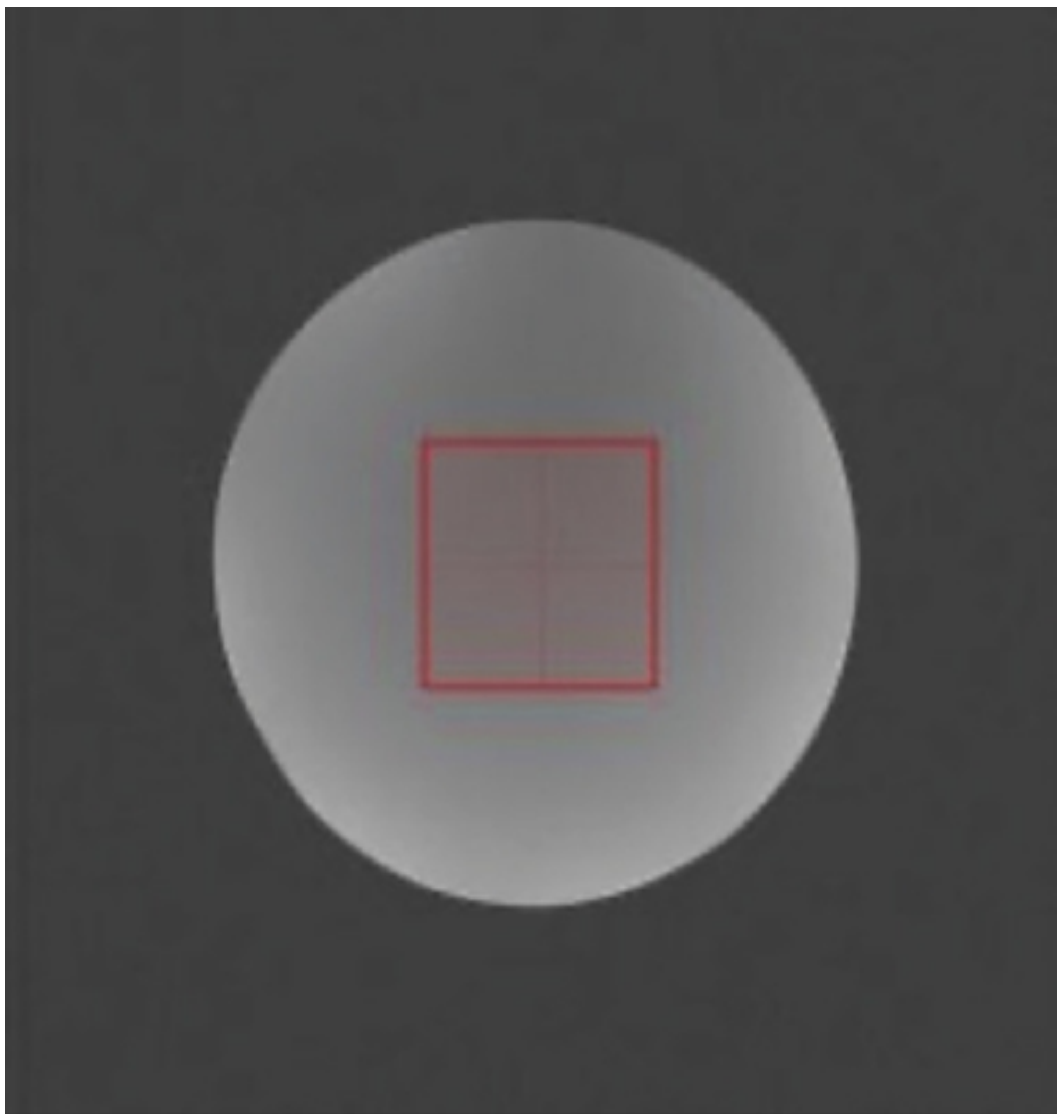
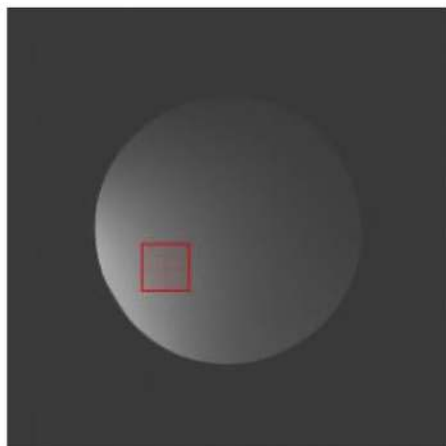
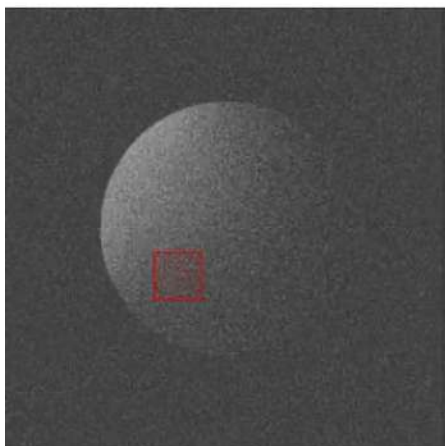


Fig. 1.6b Phantom QA image showing normal SNR results from the body array coil. [↗](#)



Figs. 1.6c and 1.6d Two phantom QA images that demonstrate low SNR. Conclusion: two coil elements are not working in the body array coil.[↗](#)

The frequency of quality testing is determined by the scanner manufacturer recommendation and locally implemented practices. Typically, radiographers carry out QA scans with basic phantoms on a daily or weekly basis, with more comprehensive QA scans carried out by engineers during routine scheduled scanner services throughout the year. Each QA phantom is customised to be used with a specific scanner system and to measure outputs for that system. The tests that are performed evaluate accuracy and precision of measurement in MRI studies (8). The complexity of the variables that MRI measures means that the phantoms used must provide standards for the calibration of these measurements in a repeatable and traceable way. This allows the MR operators to know that the scanner is working at normal standards, and ultimately that patients' receive an accurate diagnosis ([11](#)).

MRI SAFETY

Patient safety is of paramount importance in MRI. There are many safety considerations in MRI and by addressing them it ensures that high standards of patient care are maintained. There are several risks associated with the electromagnetic fields and the environment used in MRI that apply to patients, staff and visitors.

The Hazards in MRI

The main hazards associated with MRI are well documented in all international MRI safety guidance documents.

Static magnetic field, time-varying magnetic field gradients and RF fields

There are three types of electromagnetic fields used in MRI: the static magnetic field, time-varying magnetic field gradients and RF fields.

Biological effects, projectile hazards, compatibility of medical equipment and interaction with implanted medical devices are all risks associated with the **static magnetic field**.

Peripheral nerve and muscle stimulation, biological effects and acoustic noise are all risks associated with the **time-varying magnetic fields**, primarily due to the rapidly switched gradients that are part of the image formation process in MRI. The main safety issues relating to **RF fields** are thermal heating

The main safety issues relating to **RF fields** are thermal heating which can cause contact burns or induced current burns by the heating effect on implants such as orthopaedic joint replacements or external monitoring equipment.

Thorough safety screening and visual safety checks and good patient positioning will significantly reduce risks caused by the magnetic fields used in MRI.

Acoustic noise

Acoustic noise is produced by the switching of gradient magnetic fields during scan sequences and if it reaches levels that are recognised as unacceptable by the International Electrotechnical Commission (IEC) there is a risk of temporary or permanent shift in hearing threshold ([12](#)).

To minimise this risk, hearing protection is always given to the patient and this should comply with scanner manufacturer noise specifications in order to reduce the sound produced to a level that is deemed as acceptable.

Scanner manufacturers provide headphones with the scanner, the main function of which is to allow effective communication with the patient; however, some do not provide suitable noise attenuation. For this reason, earplugs should be given as a minimum standard in order to ensure noise levels are reduced to an acceptable level for the patient.

Many studies have been carried out into the effect of MRI acoustic noise in unborn babies and there is currently no evidence that the noise in MRI poses a risk to the fetus. However, special consideration is given to this group of patients to ensure that MRI is only performed when clinically required and that exposure to the magnetic fields and acoustic noise is kept to a minimum.

Cryogens and phantom fluids

Cryogens (helium) are used in superconducting MR systems and this poses an additional significant risk if there is exposure to the helium. As there is a potential to cause asphyxiation, cold burns or hypothermia, there are therefore early warning systems in place for monitoring the oxygen levels within the MR Environment to alert operators to a potential cryogen leak.

In the event of a leak of cryogen gases, MR systems have a quench pipe installed to allow the helium to escape to the outside environment ([Fig. 1.7a](#)).



Fig. 1.7a External quench pipe. [📄](#)

Phantoms may also pose a risk in MRI as they can contain chemicals that may be hazardous if they come into contact with skin, are inhaled or are exposed to fire. Contact with the liquid after a leak must be controlled and

requires careful handling and special attention. Each department should have control of substances hazardous to health (COSHH) risk assessments, spill kits and policies in place to ensure risks are kept to a minimum and that staff know how to deal with spills.

Department Layout

Every MRI department consists of different zones. The first zone is the reception/waiting area, and this is accessible by the general public. The second zone is a **Controlled Access Area** that is accessed via a restricted access door. Authorised staff who have completed safety screening and specific MR safety training have free access to this area, whilst all patients, visitors and other hospital staff are required to complete safety screening prior to entering this zone.

The Controlled Access Area will typically contain the scan control room, changing cubicles, a preparation area, the equipment room and the MR Environment. The MR Environment is the room that contains the MR scanner, the 5-gauss line and the projectile zone ([Fig. 1.7b](#)).

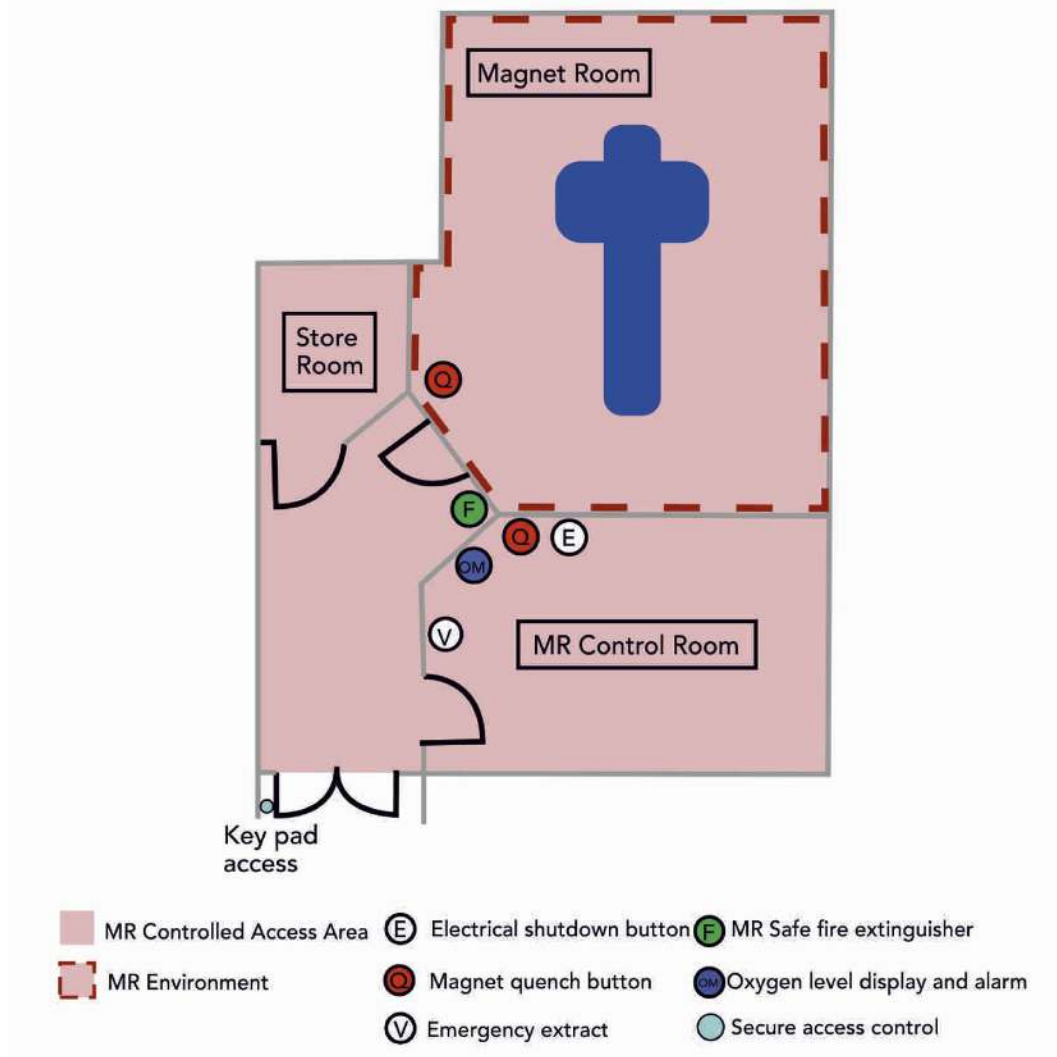


Fig. 1.7b Typical MRI department layout to include Controlled Access Area and MR Environment. [📄](#)

Safety Screening

A safety screening checklist must be completed and checked by everyone before entry to the Controlled Access Area can be permitted ([Fig. 1.8](#)). The safety checklist contains key questions that aim to identify whether there are any internal implants or foreign bodies that may be affected by the magnetic fields used in MRI. It also identifies any external metallic objects that need to be removed prior to entry to the MR Environment. For some patients that have a history of a penetrating eye injury, an orbit radiograph

may be required in order to ascertain the presence of an intraocular metallic foreign body prior to their scan.



Fig. 1.8 Safety screening is an important part of ensuring patient safety. Good safety checks help to reduce the risk of incidents in MRI. [🔗](#)

Local safety policies are referred to when a patient has declared that they have an implant so that relevant safety guidance can be followed. Each department will have its own policies, processes and procedures that are followed, which can be supported by a relevant risk assessment and medical physicist support. Guidance will vary depending on the type of implant, whether it is passive or active, and further safety checks will be carried out if necessary to determine whether it is safe to proceed with the MRI scan. Where local policy dictates, for some ‘MR Conditional’ implants it is necessary to consult specific manufacturer information before deciding

whether it is safe to proceed with the scan. In some cases, it may be necessary for the MR safety expert, the referrer, the radiologist and the radiographer to carry out a risk assessment for some implants that cannot be deemed safe or conditional after safety screening, or where conditions cannot be met – for example, a hybrid pacemaker system that has components from two different manufacturers or a foreign body such as a pellet where no MR safety guidance is available. In these cases, the patient must also be made aware of the risks and benefits. Such risk assessments are termed ‘off label’ and will determine the risk involved, which must be balanced with the clinical indications for the scan.

There are instances where MRI is contraindicated and it is not possible for the patient to be scanned. In these instances, thorough safety checks will have been completed and an investigation carried out. The decision that it is unsafe to proceed with MRI will be based on findings of the investigation information, for example for a patient who had a cerebral aneurysm clip fitted in the 1980s and the operation notes have been destroyed; in this instance there is a possibility that the aneurysm clip is ferromagnetic and without manufacturer information it would not be safe to proceed with MRI.

Anxiety and Claustrophobia

There is a lot of general anxiety about MRI that healthcare professionals are trained and equipped to deal with by offering reassurance during the patient preparation and positioning stages. For patients with severe anxiety and claustrophobia, departments often have local pathways in place to support the patient, which can include telephone coaching or an opportunity to visit the scanner prior to their appointment. In some instances, the referrer or GP will prescribe an oral sedative which may be sufficient for the patient to then undergo the scan. The radiographer needs to be aware of ways to adapt

the scan for these patients. For those patients who are unable to tolerate their scan, the referring clinician may consider whether an alternative diagnostic test is available, or if MRI is essential to aid diagnosis, then they may choose to refer them to a centre that has a sedation/general anaesthetic scan service.

Management of the MRI Unit

Every department should have an established MR safety framework that addresses all aspects of MR safety in order to provide the highest standards of care to patients, staff and visitors.

International and national guidelines (such as the Medicines and Healthcare products Regulatory Agency [MHRA] in the UK, the American Board of Magnetic Resonance Safety [ABMRS] in the US and the International Commission on Non-Ionizing Radiation Protection [ICNIRP]) enable the creation of local guidelines and the implementation of local policies and practices. Duties and responsibilities are defined for named individuals who carry out the specific roles such as MR safety expert, MR manager, MR responsible person, MR safety officer or a clinical person with a lead role relating to MR safety and other MR authorised personnel. Policies and practices are regularly reviewed, and annual training for the named individuals is carried out to ensure that competency and knowledge for MR safety is maintained.

Managers and the MR responsible person are responsible for ensuring that safe staffing levels are in place; arranging adequate resuscitation equipment and emergency situation training, such as fire, anaphylaxis and cardiac arrest; organising regular education about MR safety issues to improve safety standards; and supporting individuals with continued professional development. Continuity plans should be in place to deal with interruptions to scanning services due to disasters. Special consideration

should be given to the unique requirements during fire and resuscitation emergencies within the MRI unit.

Considerations during site planning and installation of a new MRI unit will include the cryogen vent system, the location of the 5-gauss line in relation to neighbouring rooms and departments, patient access pathways, emergency escape routes, access control and access requirements for the magnet to be transported during installation.

Equipment

American Society for Testing and Materials (ASTM) International standard F2503, 'Standard practice for marking medical devices and other items for safety in the magnetic resonance environment', should be used in all MRI departments to ensure that all equipment is identified as MR Unsafe ([Fig. 1.9a](#)), MR Safe ([Fig. 1.9b](#)) or MR Conditional ([Figs. 1.9c,d](#)) in order to minimise the risks of projectile incident and electronic monitoring equipment malfunction due to exposure to electromagnetic fields. The IEC has a standard that also supports this practice (IEC 62570, 2014).



Fig. 1.9a MR Unsafe label on a noncompatible resus citation trolley. [↗](#)



Fig. 1.9b MR Safe label affixed to an MR-compatible wheelchair. [↗](#)



Fig. 1.9c MR Conditional label affixed to an MR-compatible trolley. [↗](#)



Fig. 1.9d MR Conditional label affixed to emergency equipment.

IMAGING SEQUENCES

All the imaging parameters and sequences in this section are based on a 1.5-tesla closed bore MR system. The sequences can be modified for higher or

lower field strength systems, but this is outside the scope of this book. Specific protocols will be carried out dependent on the area selected and the clinical history. For anatomical areas a multiplanar localiser is carried out initially in up to three orthogonal planes to allow for planning of the more detailed sequences to ensure accurate angulation and correct anatomical coverage. For the majority of the scans selected a combination of T1- and T2-weighted pulse sequences are performed in at least two planes. In a T1-weighted scan the repetition time (TR) and echo time (TE) are short, and contrast on images is predominantly determined by the T1 properties of tissue. In a T2-weighted scan longer TE and TR are used, and the contrast on resulting images is predominantly determined by the T2 properties of tissue ([Fig. 1.10a](#)). In a T1-weighted image fluid appears dark and fat appears bright ([Fig. 1.10b](#)) and in a T2-weighted image both fluid and fat appear bright ([Fig. 1.10c](#)).

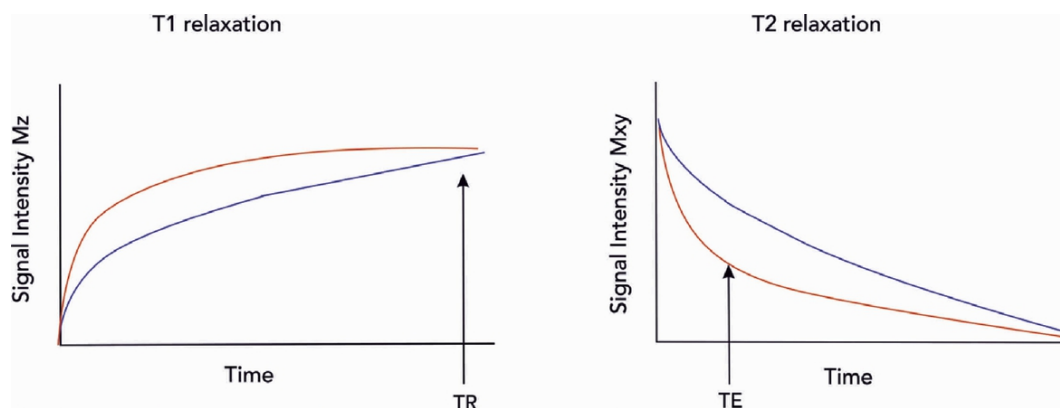


Fig. 1.10a T1 and T2 relaxation. [↗](#)



Fig. 1.10b T1 image: fluid appears [bright](#)



Fig. 1.10c T2 image: fluid dark, fat bright. appears bright, fat bright. [🔗](#)

There are many sequence parameters that the operator may choose from but for a standard protocol most of the changes are related to anatomical coverage, number of slices, slice thickness and field of view.

These changes in turn can influence the SNR of the image, the spatial resolution, the scan acquisition time and the image contrast. There are multiple different sequences in each scanner library and each department

should have specific sequences set up for different anatomical areas, such as the brain and spine.

Spin echo (SE), turbo spin echo (TSE) and (single-shot) fast spin echo ([SS]FSE) sequences and half Fourier fast spin echo can be used for breath-hold or respiratory-triggered imaging for the abdomen and cardiac scans.

In inversion recovery sequences the inversion time (TI) is adjusted to null the signal from fluids. Sequences such as short tau inversion recovery (STIR) are used predominantly for pathology such as soft tissue tumours, and fluid attenuated inversion recovery (FLAIR) imaging is often used predominantly in brain imaging to provide images in which high signal abnormalities are not obscured by adjacent fluid in the sulci and the ventricles.

T1 inversion recovery is useful for increasing contrast between the grey to white matter areas in the brain but has a disadvantage of having a longer scan time than a standard T1-weighted image ([Fig. 1.11a](#)).

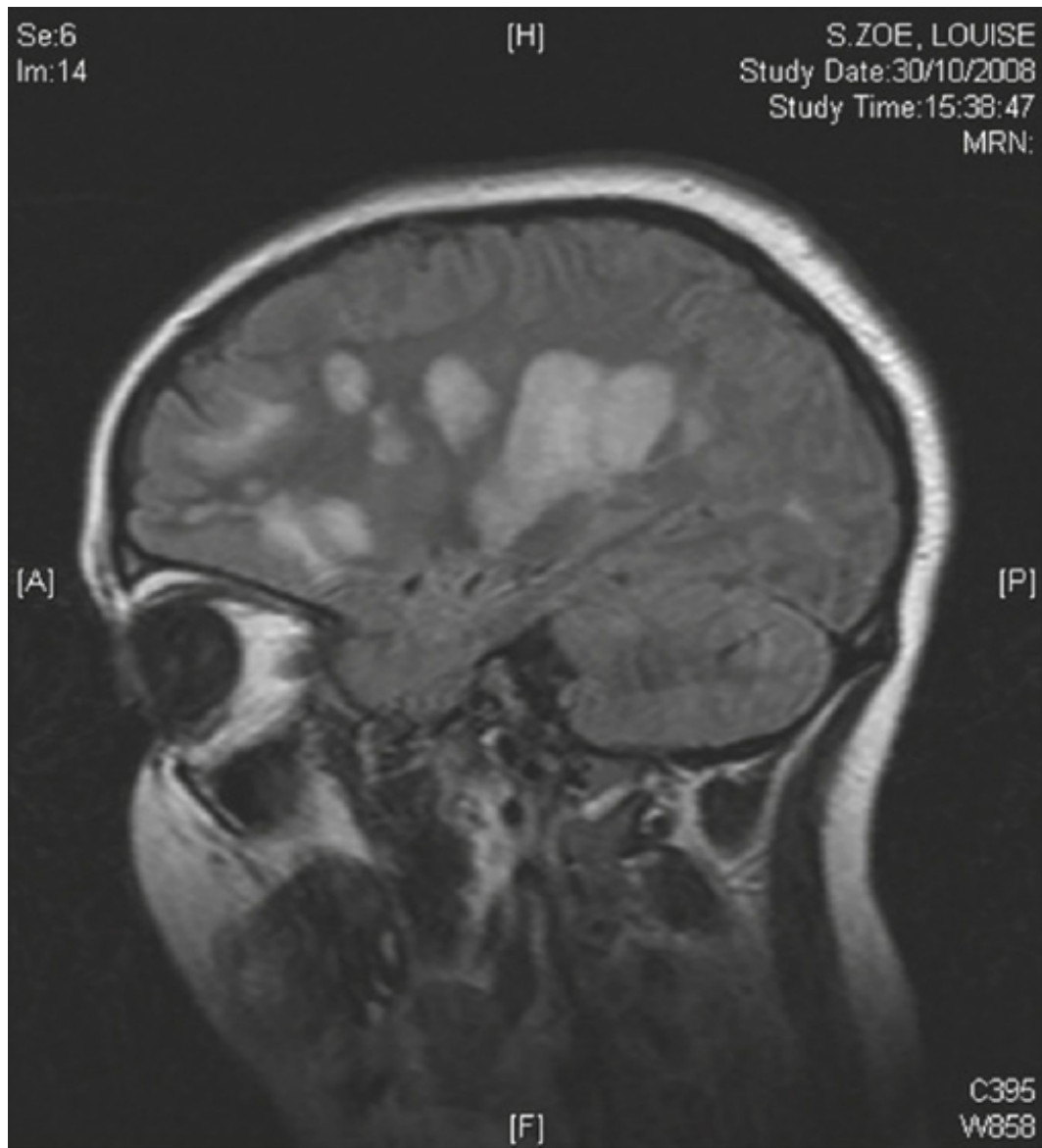


Fig. 1.11a FLAIR image. [📄](#)

Gradient echo imaging utilises an RF refocusing pulse to compensate for magnetic field inhomogeneities and can be categorised as coherent or spoiled. Coherent gradient echo imaging can be used for non-contrast time-of-flight MR angiography (MRA) and 3D imaging of the joints and the inner ear such as steady-state sequences ([Fig. 1.11b](#)). Spoiled gradient echo is widely used for MRA and in and out of phase gradient echo imaging for adrenals and liver. Gradient echo planar imaging is typically used for

diffusion-weighted imaging (DWI) and functional brain imaging ([Fig. 1.11c](#)), is often based on gradient echo imaging and allows the acquisition of a single slice in as little as 10 ms.

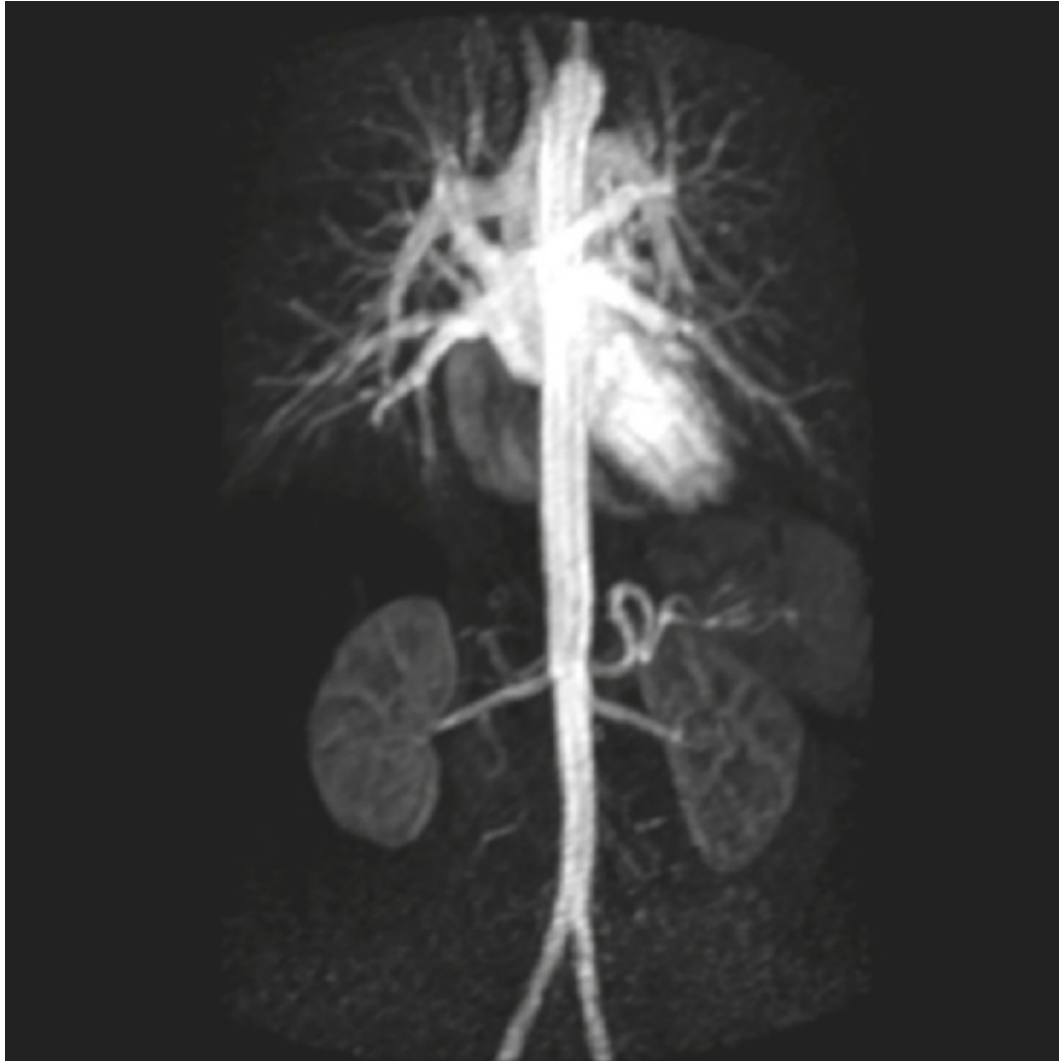


Fig. 1.11b Aorta and renal arteries MRA image. [↗](#)

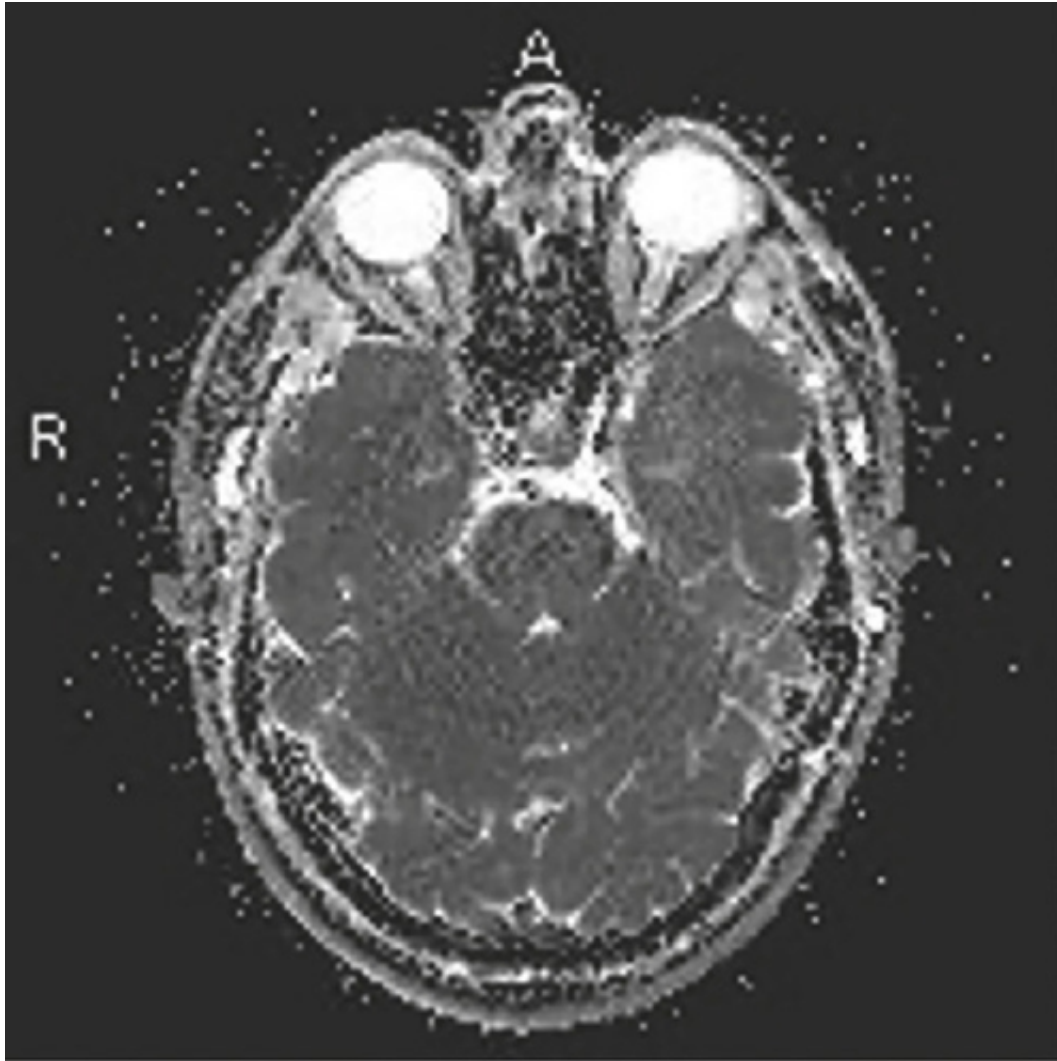


Fig. 1.11c Diffusion-weighted [🔗](#)

Fat- and/or water-suppressed images include Dixon sequences. Frequency selective fat suppression involves the application of a frequency selective saturation pulse to null the signal from spins contained within fat which may increase the minimum TR values compared with non-fat-suppressed sequences ([Fig. 1.11d](#)). The Dixon method of fat suppression is less susceptible to magnetic field inhomogeneity than the aforementioned frequency selective method.



Fig. 1.11d Fat-saturation image. [🔗](#)

PATIENT CARE

Patient Preparation (Physical)

Patient screening is a vital part of the MRI journey to ensure that the patients and staff are kept as safe as practicably possible. The safety screening form is completed prior to entry into the Controlled Access Area

by a suitable member of the MR team. This process identifies any contraindications and/or conditions to scanning such as implants that require additional considerations or other external devices that are MR Unsafe. It allows for the MR team to review and obtain all necessary information required to safely scan the patient.

Physically the patient must remove all metallic material that they have about their person so that it cannot cause harm or damage in the scan room by means of the projectile effect. This will also minimise any heating effects and reduce the risk of susceptibility artefact on the resulting images. The safest way to ensure safety in the scan room from external metal is to ask the patients to change into a gown or scrubs. This prevents the risk of heating in clothing that may contain metal fibres, e.g. sports clothing, and the patient's clothing from being too restrictive which may cause discomfort and increase the chance of movement on resulting images.

This also prevents patients' clothing from being too restrictive which may cause discomfort and increase the chance of movement on resulting images.

To acquire optimal imaging in MRI it is important that the patient is as comfortable as they can be prior to the scan and during the scanning process once positioned on the scanner. There are a number of aids such as under-knee rests and pads that can be used to help the patient be as comfortable as possible and therefore less prone to movement during their scan. It is also important to ensure when positioning the patient that skin-to-skin contact is avoided including the crossing of legs and holding of hands as this can create a conductive loop within the patient which has the potential for additional tissue heating that in rare cases may cause burns. Ear protection is provided in the form of headphones and/or earplugs. As previously mentioned, ear protection must meet the scanner manufacturer requirement

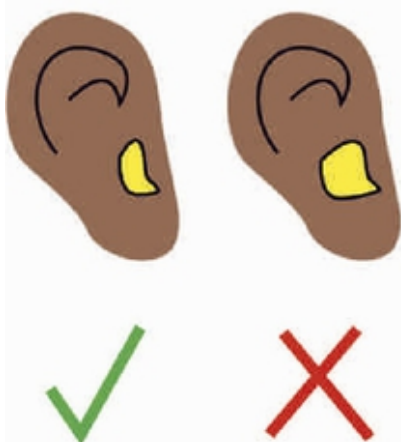
for noise reduction, and in order to reduce acoustic noise effects earplugs must be fitted correctly ([Fig. 1.12a](#)) and headphones should be secured correctly ([Fig. 1.12b](#)).



ROLL earplug
until fully compressed



OPEN ear canal



PUSH earplug into
canal and hold until
fully expanded

Fig. 1.12a Recommended earplug technique.[↗](#)



Fig. 1.12b Headphone placement allows reduction in acoustic noise and effective communication between operator and patient during scan.[↗](#)

The area to be scanned is ideally placed within the isocentre of the scanner with any necessary receive or transmit/receive coils placed over this area.

It is important to ensure that there are no coils touching skin surfaces (pads may be used) and that all cables are straightened.

During imaging, communication is available between the patient and the operator by means of a two-way intercom, which is used before, during and after the scan whilst the patient is alone in the scanner. The patient is also given an emergency buzzer to alert the staff if they have any issues during scanning. Instructions on breath holds for examinations can be given via the headphones and the intercom system.

Patient Preparation (Emotional)

There are many emotions and anxieties that the patient may experience when they are having an MR scan. Understanding these anxieties is important to help achieve the best diagnostic images. Claustrophobia is one of the main reasons that patients cannot attempt or complete their scans. Strategies to prevent claustrophobia include reassurance from the MR staff ([Fig. 1.13a](#)) and a clear explanation of the procedure, an explanation on how use to the patient buzzer, and angled mirrors and prism glasses to allow the patient to see beyond the aperture of the magnet and out into the room. There are also relaxation techniques that can be used, as well as eye masks. A visit to the department prior to the scan may also be helpful. More advanced techniques include hypnosis, virtual in-bore experience prior to visiting the department and acupuncture. If the patient is still unable to tolerate the scan, then a mild form of oral sedation may be prescribed.



Fig. 1.13a Time taken during patient positioning offers reassurance and eases anxiety (13).[↗](#)

Open scanners may also provide an alternative for those patients who are claustrophobic or patients who cannot tolerate a cylindrical MR scanner.

Young children that require MR may achieve this successfully by use of play therapists, or, for babies, a ‘feed and wrap’ technique may be successful ([Fig. 1.13b](#)). However, there are some patients who may require general anaesthetic in order to acquire diagnostic images. Equipment to support this such as MR conditional monitoring and ventilators are available for use within the scanner room.



Fig. 1.13b Feed and wrap technique using manufacturer immobilisation device.[🔗](#)

INFECTION CONTROL

For all equipment in the MRI department the importance of a clean, safe environment for all aspects of healthcare should not be underestimated. Good standards of basic hygiene, cleaning and regular planned maintenance will assist in preventing healthcare-associated infection (HCAI). For HCAIs to be reduced, it is imperative that infection prevention control (IPC) measures are adhered to. That being said, the MR machine bore is the most common source of infection, mainly because it is difficult to access and MR safe equipment is required to ensure that the bore is cleaned appropriately. Most MRI departments utilise authorised staff members for the routine

cleaning of the scanners due to the safety issues surrounding MR scanners and the training required to enter the rooms. It is essential that all equipment is appropriately cleaned after every patient. All departments should have local policies and procedures in place for the cleaning of the scan room and equipment.

To support infection prevention in staff, all departments should have policies and procedures in place for the effective use of personal protective equipment (PPE) ([Figs. 1.14a, b](#)), aseptic non-touch technique (ANTT) and hand hygiene.



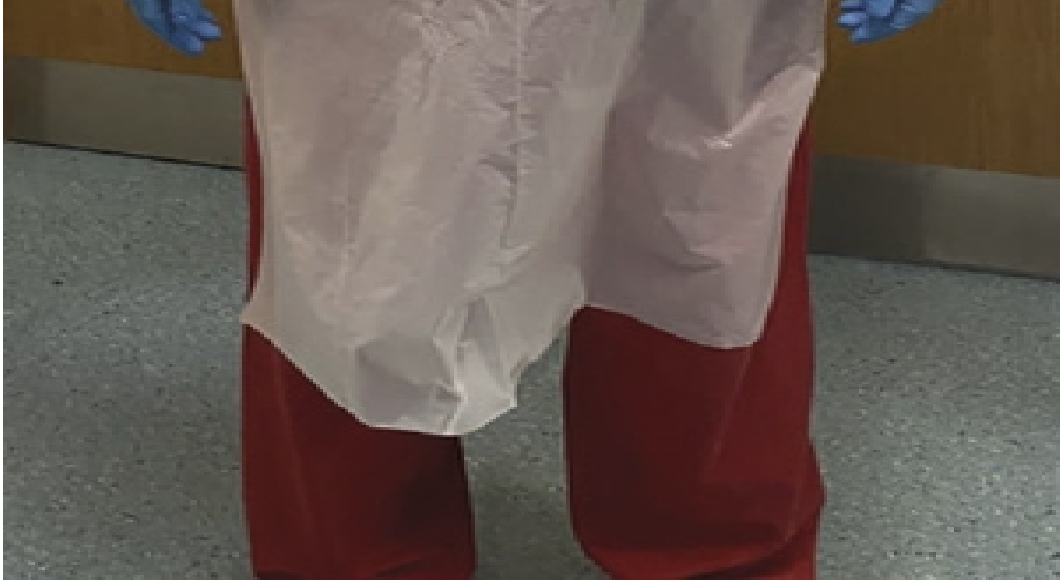


Fig. 1.14a Staff member wearing PPE. [📄](#)



Fig. 1.14b Typical PPE worn during an intravenous cannulation. [↗](#)

CONTRAST ENHANCEMENT AGENTS

Contrast enhancement agents increase specificity, sensitivity and accuracy of MRI. The role of the pharmaceutical in these agents is to change the relaxation times of the tissues to be depicted in the image. MR contrast agents work by altering the magnetic environment (magnet susceptibility) of the local tissue and are not directly visualised. This is unlike iodinated contrast agents that function by their ability to directly alter the image, being additive to the normal tissue attenuation. Providing a full description

of the physics and chemistry of contrast agents is beyond the scope of this book. Gadolinium-based contrast agents (GBCAs) ([Fig. 1.15a](#)) are the most common type of contrast agents used in MRI and examples given in this book will therefore be associated with this type ([13](#)).

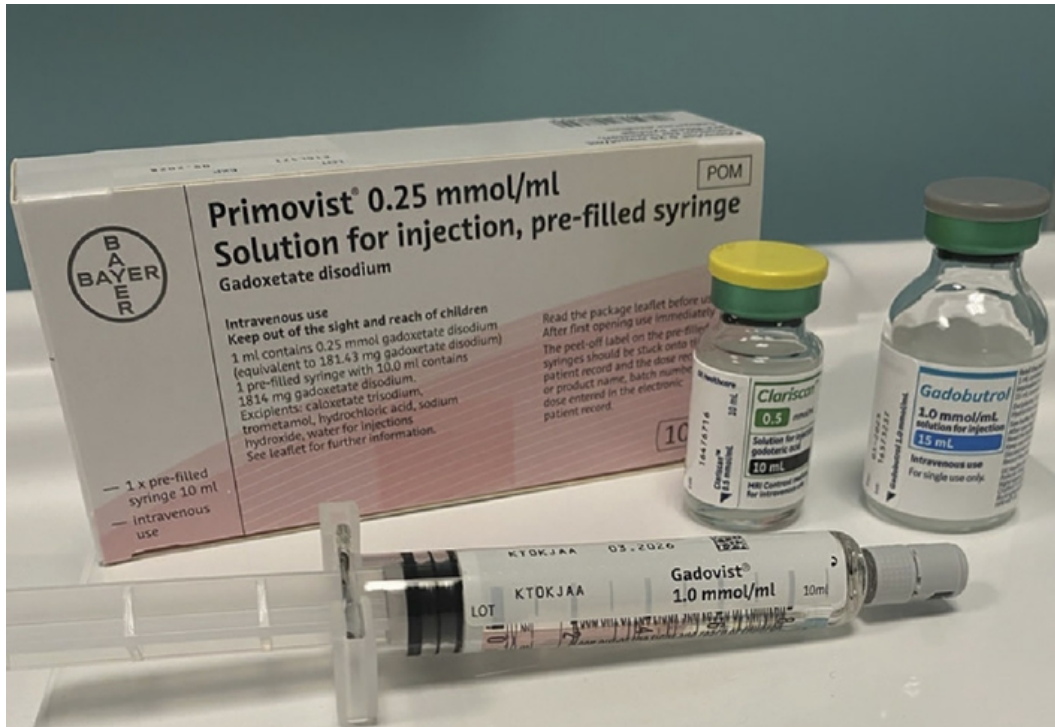


Fig. 1.15a Examples of MRI contrast enhancement agents.[🔗](#)

Contrast-enhanced examinations in MRI are either performed by hand injection using a prefilled syringe or delivered dynamically via a pump injector, intravenously directly into the bloodstream ([Fig. 1.15b](#)). Once injected the contrast travels to the right side of the heart before entering the arterial system to allow for rapid imaging of the arteries without venous contamination. Venous imaging may also be acquired; however, the contrast volume becomes very dilute and can be obscured by the remaining contrast in the arteries. T1 sequences are used post-contrast due to the effect of the gadolinium on the surrounding tissue which shortens T1 relaxation. The

gadolinium shortens the T1 relaxation times of tissues or increases the T1 relaxation state and that has an effect on T1-weighted images producing a hyperintense signal in regions with high gadolinium uptake. The TR is short so that the T1 recovery is restricted in most tissues and therefore the background tissue is suppressed. An additional gradient spoiling sequence is applied to eliminate any residual transverse magnetisation influencing image contrast and the TE is as short as possible to limit the influence of T2 and T2* relaxation.



Fig. 1.15b Typical MR contrast injector. [🔗](#)

The minimum TE and TR that is achievable is system dependent. High signal on a T1-weighted image exists where the contrast medium is present in sufficiently high concentrations. The rate of the injection will also

determine the concentration of contrast medium. Injections which are delivered at a higher rate will increase the signal intensity. However, with injections which are delivered at the higher rate the duration of the bolus passing through the vessels is shorter, thus making the time window for acquisition shorter, and this requires greater accuracy. Contrast is administered dependent on the patient weight up to a maximum volume dependent on contrast type and departmental policy, which differs from department to department. There have recently been an increasing number of dynamic MR examinations including vascular imaging and breast, abdomen and pelvis scanning where the contrast is injected over a specific time period using an MR contrast pump injector, various models of which are available on the market.

CONTRAST ENHANCEMENT AGENT SAFETY

Several safety issues need to be considered when using MRI contrast agents, namely potential allergic reactions, nephrotoxicity, the development of a rare condition called nephrogenic systemic fibrosis (NSF) and the potential impact of long-term gadolinium retention in the brain.

NSF is a rare condition that involves fibrosis of the skin and connective tissues, which can lead to contractures and joint immobility. The Committee for Medicinal Products for Human Use issued a letter in 2007 identifying an association between NSF and some MR gadolinium intravenous contrast agents in patients with severe renal impairment.

Based on evidence that signal hyperintensity was noted on unenhanced T1-weighted brain scans in patients who had received multiple doses of gadolinium, extensive research has been carried out into long-term gadolinium retention in the brain. Due to these risks MRI contrast agents have been categorised as low, medium and high risk, and recommendations

and guidance for healthcare professionals and patients have been issued by the European Medicines Agency (14).

All departments work under local guidance and procedures for the safe use of GBCA. Patients are asked to complete safety screening checks in order to identify risk factors such as previous allergic reactions and renal impairment.

The use of MRI contrast agents in pregnancy is not currently advised unless the clinical condition of the patient makes their use absolutely necessary for diagnosis (15). Local procedures should be in place for how to deal with emergencies, emergency equipment should be available and staff should be appropriately trained in how to deliver immediate life support.

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SECTION 2

MRI PROCEDURES AND ADAPTIVE TECHNIQUE

DOI: [10.1201/9781003230229-2](https://doi.org/10.1201/9781003230229-2)

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[Pelvis Groin](#)

[Rectum](#)

[Perineum](#)

[Prostate](#)

[Penis/Testes](#)

[Bladder](#)

[Gynaecological Pelvis](#)

[Femur/Thigh](#)

[Knee](#)

[Lower Leg: Tibia and Fibula](#)

[Ankle](#)

[Foot, Forefoot and Toes](#)

Advice notes for this section: all positioning and sequences used within this section are subjective to the authors and in different clinical practices may vary from scanner to scanner and in line with locally agreed policies. Manufacturers use acronyms to represent specific pulse sequences, refer to the [appendix](#) for major scanner manufacturer sequence acronyms. For standard physical patient preparation please refer to [Section 1](#). Indications lists are not exhaustive.

HEAD

MRI is the gold standard for investigation of most diseases of the central nervous system and as such MRI in the acute setting is often done following CT scan. CT is still the preferred primary investigation for brain imaging, as it is faster and more easily accessible and allows decisions to be made regarding interventions ([1](#)). This is especially applicable in the acute setting when it is not possible to ascertain MR safety due to the patient being unconscious or uncooperative due to injury. MRI allows multiplanar assessment of the brain without the use of ionising radiation. It achieves higher levels of resolution of neurological structures than CT, allowing significantly better clinical visualisation and accurate assessment of the

cranial nerves, brainstem structures and abnormalities of the posterior fossa ([2](#)).

Indications

Indications of the central nervous system are wide, including stroke, temporal lobe epilepsy, tumour, infection, inflammation, multiple sclerosis, dementia, metabolic disorders, congenital malformations and nerve palsies.

- Acute presentations following trauma and stroke
- Pituitary pathology
- Vascular diseases
- Acoustic neuroma
- Chronic headache
- Dementia and Alzheimer's diagnosis
- Sialogram for salivary gland assessment
- Cholesteotoma

Imaging Procedure ([Fig. 2.1](#))



Fig. 2.1 Standard positioning. [↗](#)

- Position the patient headfirst supine.
- Position the head securely in the head coil.
- Use cushions and pads as appropriate to ensure patient stays immobilised and straight throughout the scan.
- Centre for the localiser with the laser light over the centre of the head.

Sequence Planning Brain ([Fig. 2.2a](#), [Fig.2b](#), [Fig.2c](#) and [Fig. 2d](#))

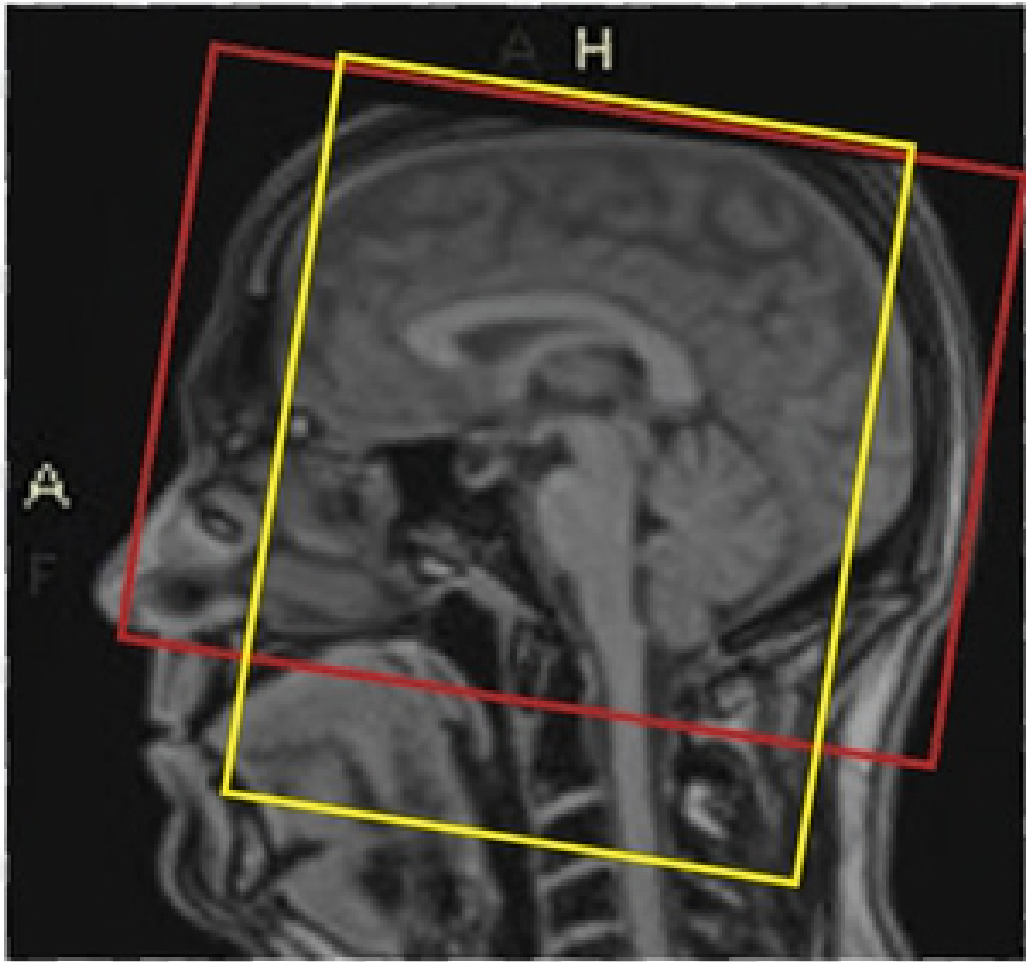


Fig. 2.2a [↗](#)

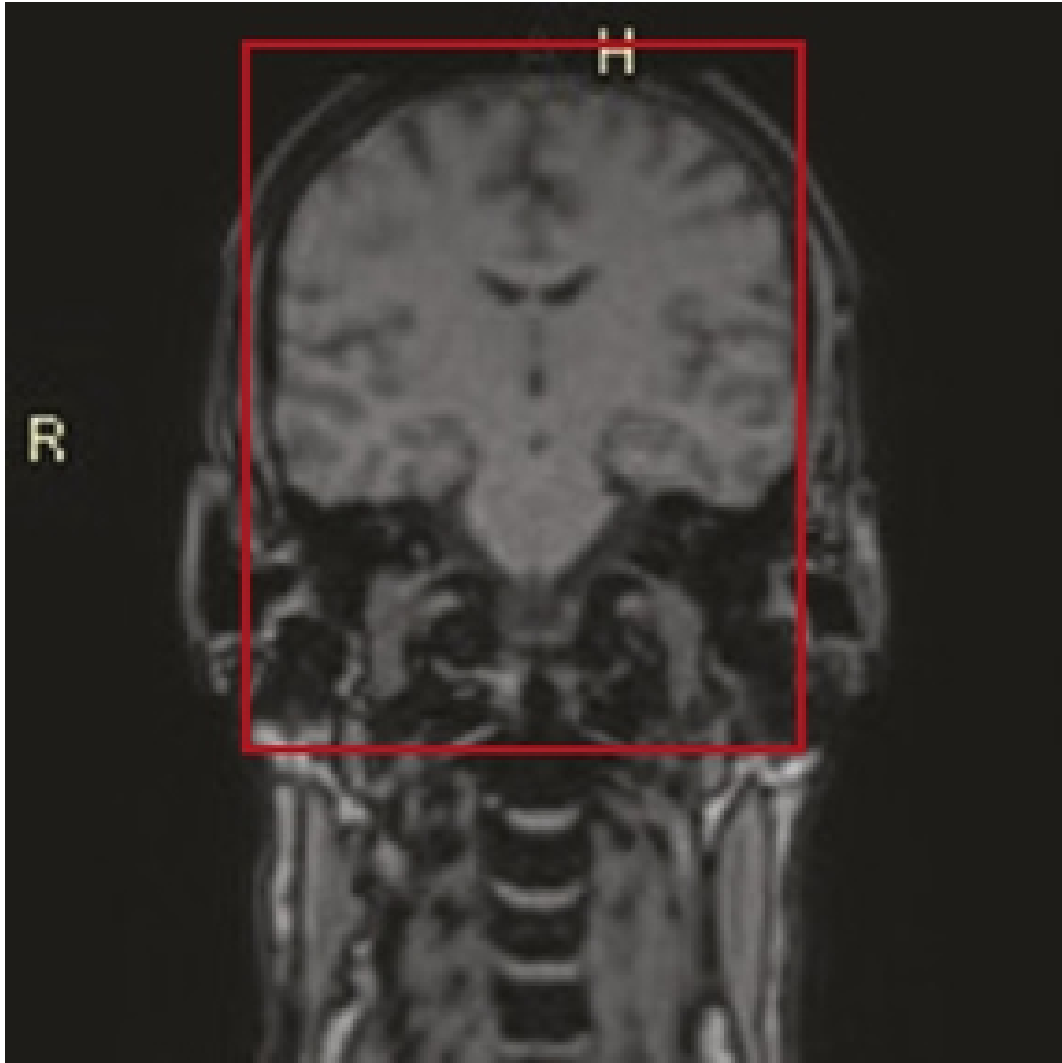


Fig. 2.2b [↗](#)

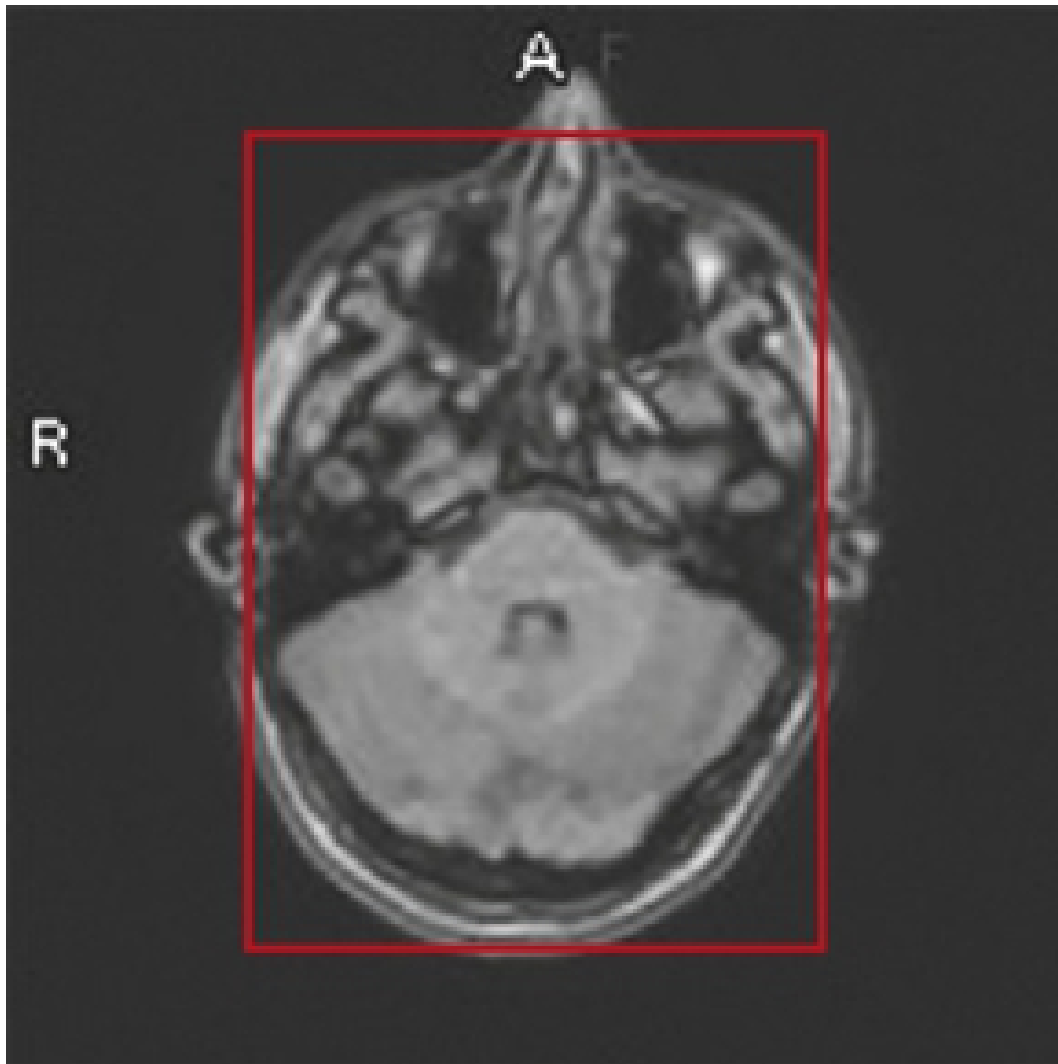


Fig. 2.2c [↗](#)

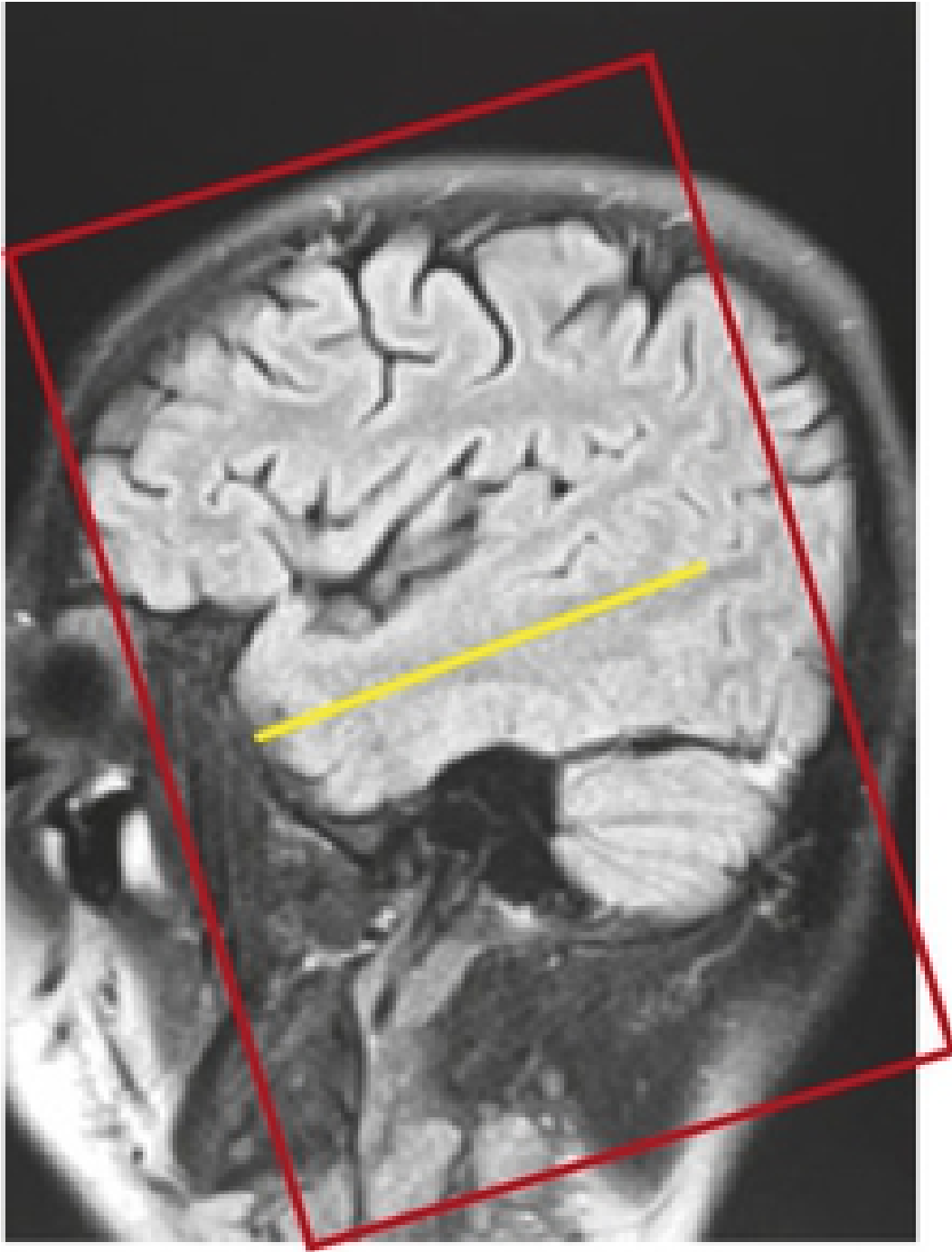


Fig. 2.2d [↗](#)

Planning axial sequence: on a central sagittal plane, angle slices along the anterior and posterior margin of corpus callosum, covering from cerebellum to vertex (demonstrated with the red box in [Fig. 2.2a](#)).

Planning coronal sequence: plan orthogonal to the axial slices, perpendicular to the corpus callosum (demonstrated with the yellow box in [Fig. 2.2a](#)). Check central in the coronal plane ([Fig. 2.2b](#)).

Planning sagittal sequence: angle slices parallel to the midline of the brain on an axial image. Ensure slices cover entire brain ([Fig. 2.2c](#)).

Planning coronal oblique sequence: for epilepsy and dementia protocols, angle perpendicular to the temporal lobes (yellow line in [Fig. 2.2a](#)). Use an acquired sagittal T1 to plan ([Fig. 2.2d](#)).

Example sequences: brain					
Routine sequences	3 plane localiser	Ax T2	Sag T1	Cor/Sag FLAIR/STIR	Ax DWI
Additional for epilepsy	Cor T2 3 mm	Cor T1 volume	MPRAGE		
Additional for multiple sclerosis	Sag FLAIR brain	Ax T1			

Ax, axial; Cor, coronal; MPRAGE, magnetisation-prepared rapid acquisition gradient echo; Sag, sagittal.

Internal Auditory Meatus ([Fig. 2.3a](#), [Fig. 2.3b](#) and [Fig. 2.3c](#))

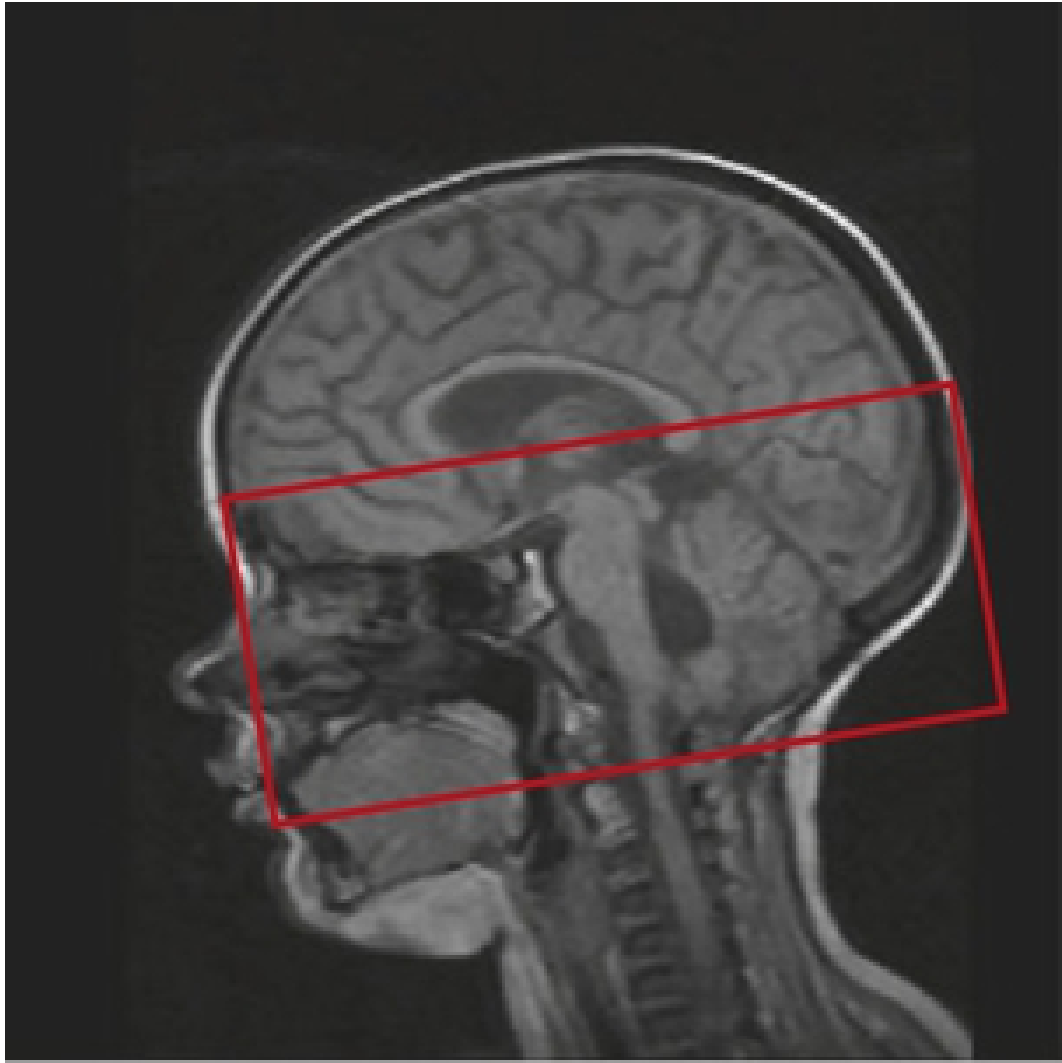


Fig. 2.3a [🔗](#)

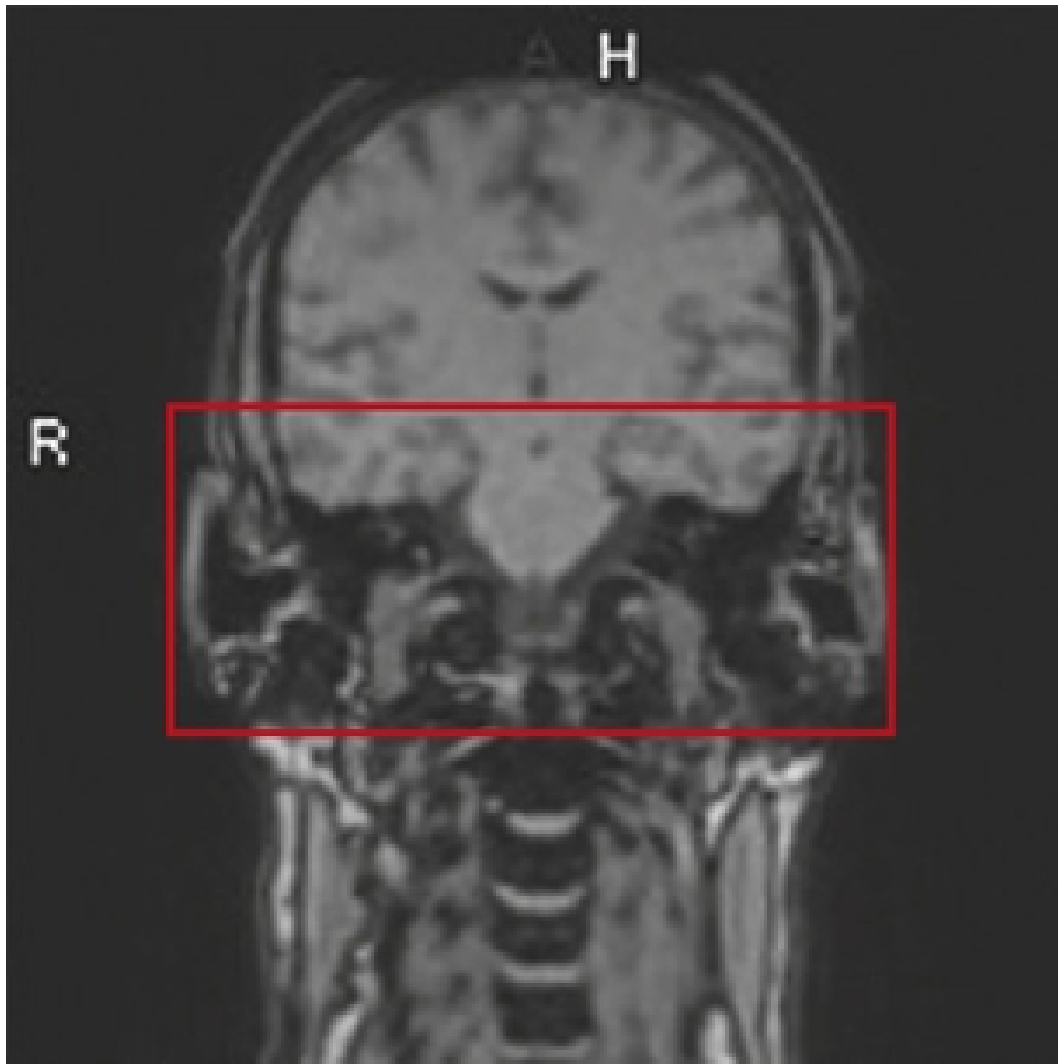


Fig. 2.3b [🔗](#)

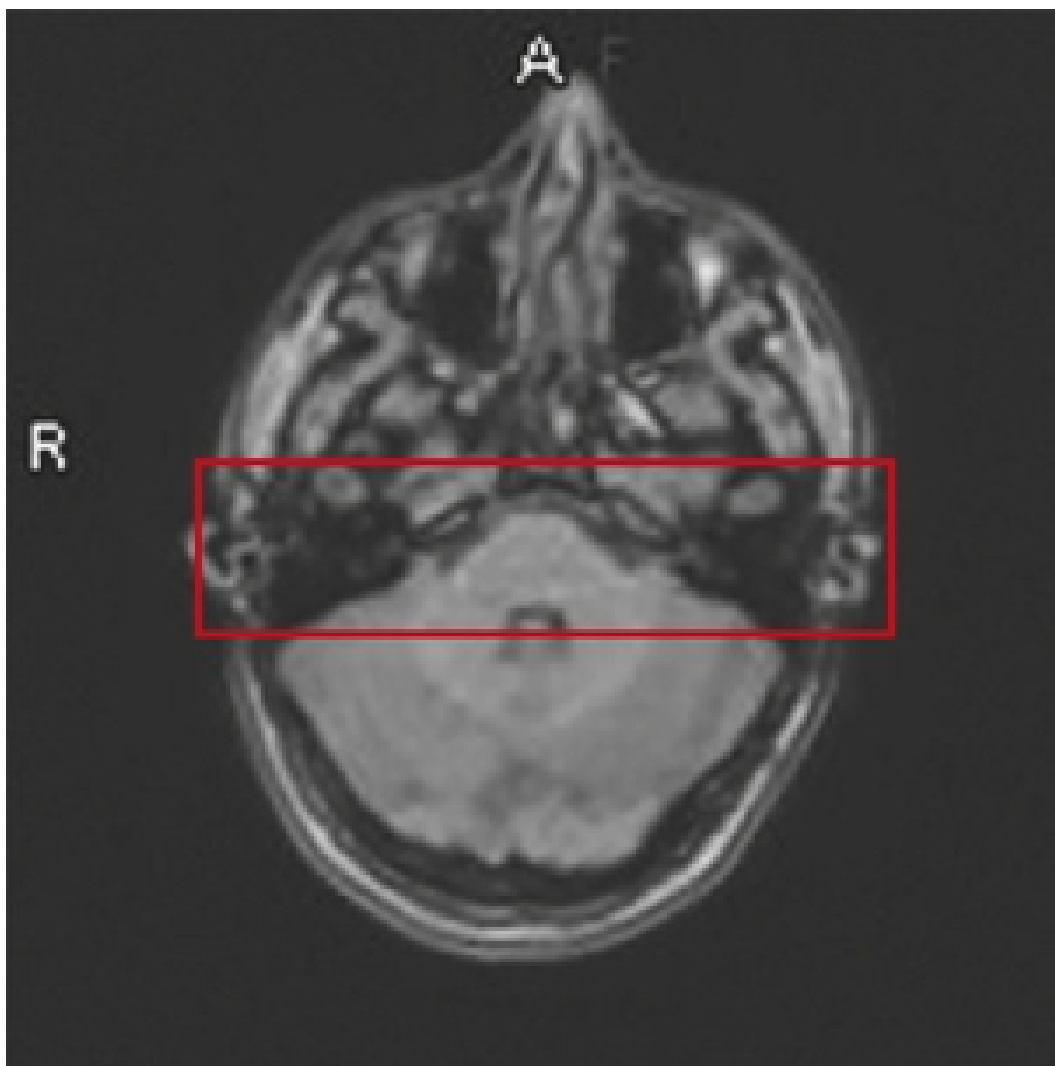


Fig. 2.3c [🔗](#)

Planning axial 3D sequence: Position both lines parallel to the internal auditory meatus (IAM) on a coronal image ([Fig. 2.3b](#)) perpendicular to the brainstem on a sagittal image ([Fig. 2.3a](#)) covering the whole of the IAM, from the hippocampus to the C1 vertebral body ([Fig. 2.3a](#)). Angle the block, if necessary, on a coronal image through the right and left IAMs ([Fig. 2.3b](#)).

Example sequences: IAMs
--

Example sequences:**IAMs**

Routine	3 plane localiser	Ax T2	Ax 3D CISS/SPACE/FIESTA
sequences		brain	centred over IAM

CISS, constructive interference in steady state; FIESTA, fast imaging employing steady-state acquisition; SPACE, sampling perfection with application optimised contrast using different flip angle evolution.

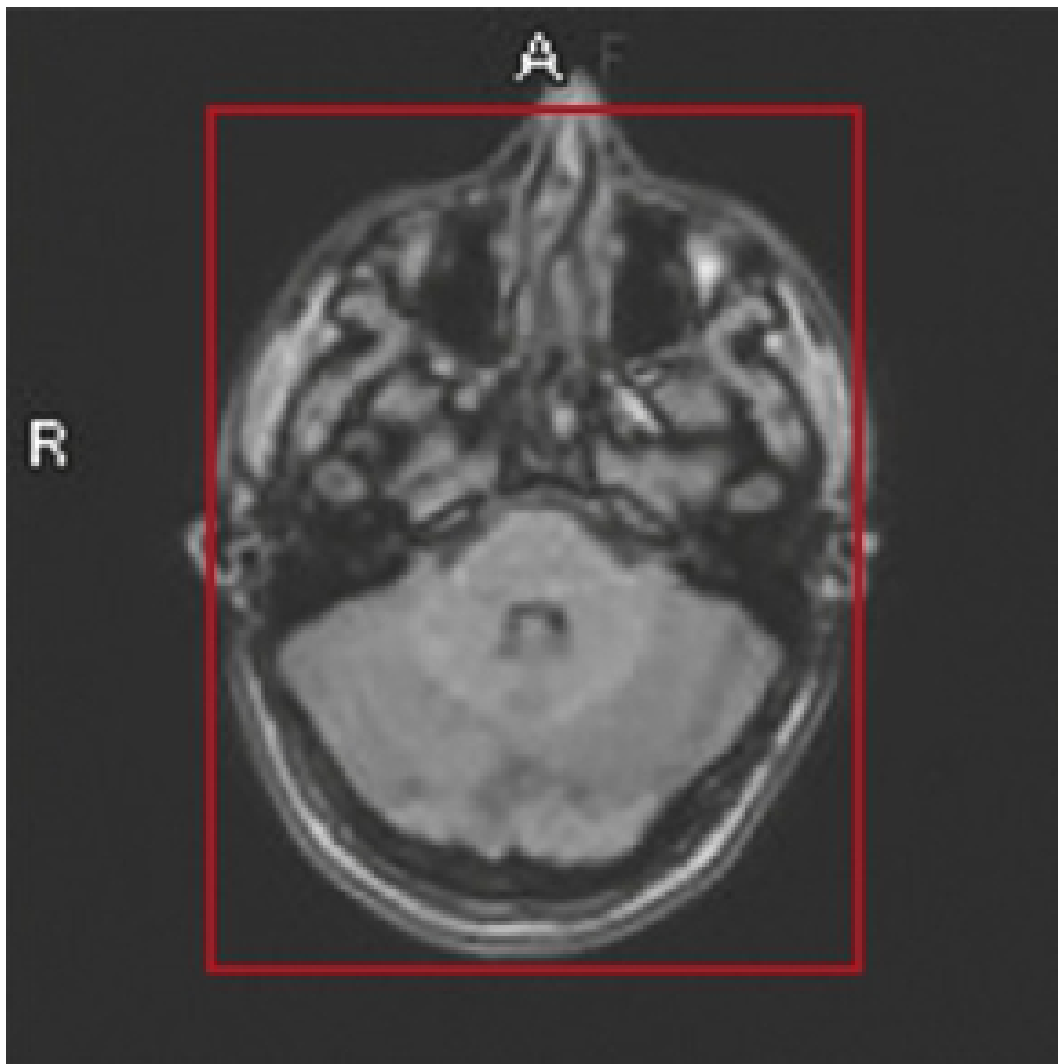
Circle of Willis 3D Time of Flight ([Fig. 2.4a](#), [Fig. 2.4b](#) and [Fig. 2.4c](#))

Fig. 2.4a [📄](#)

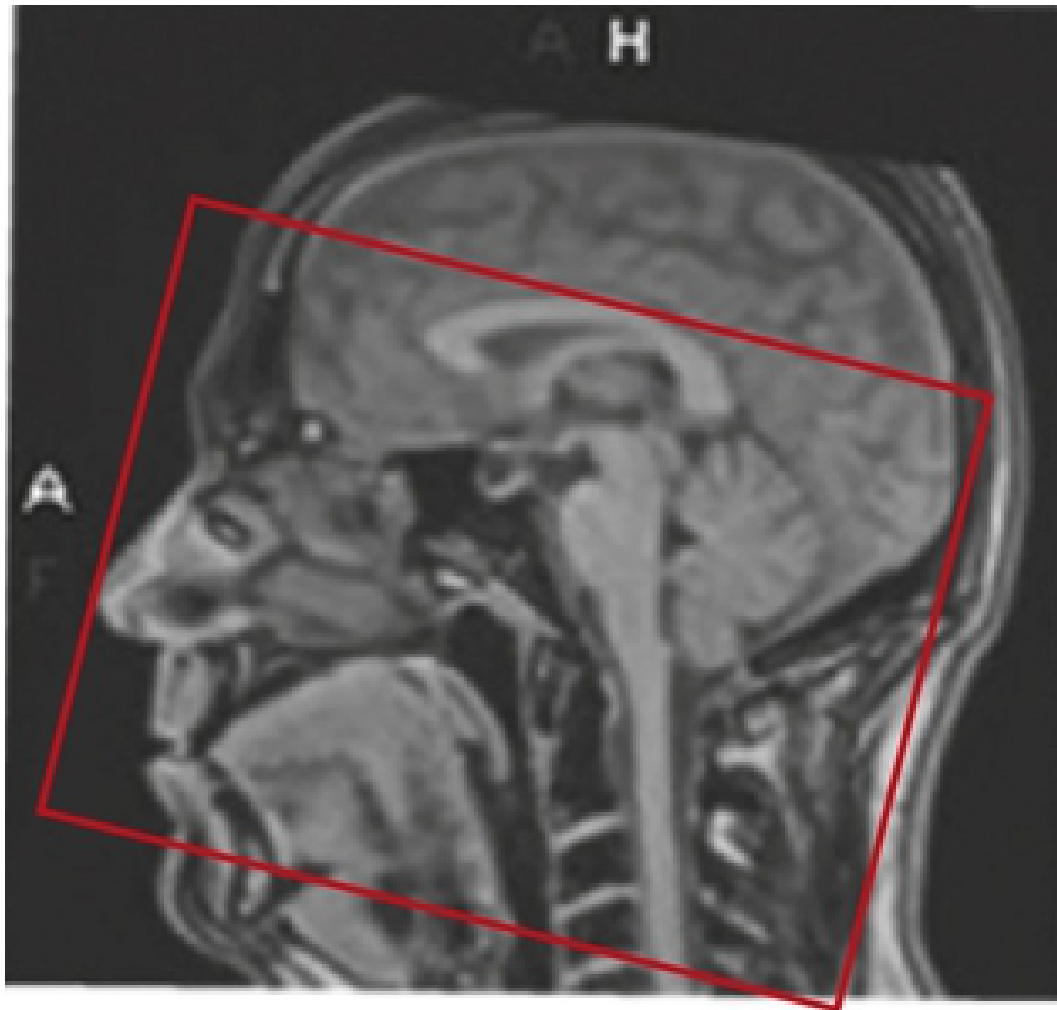


Fig. 2.4b [↗](#)

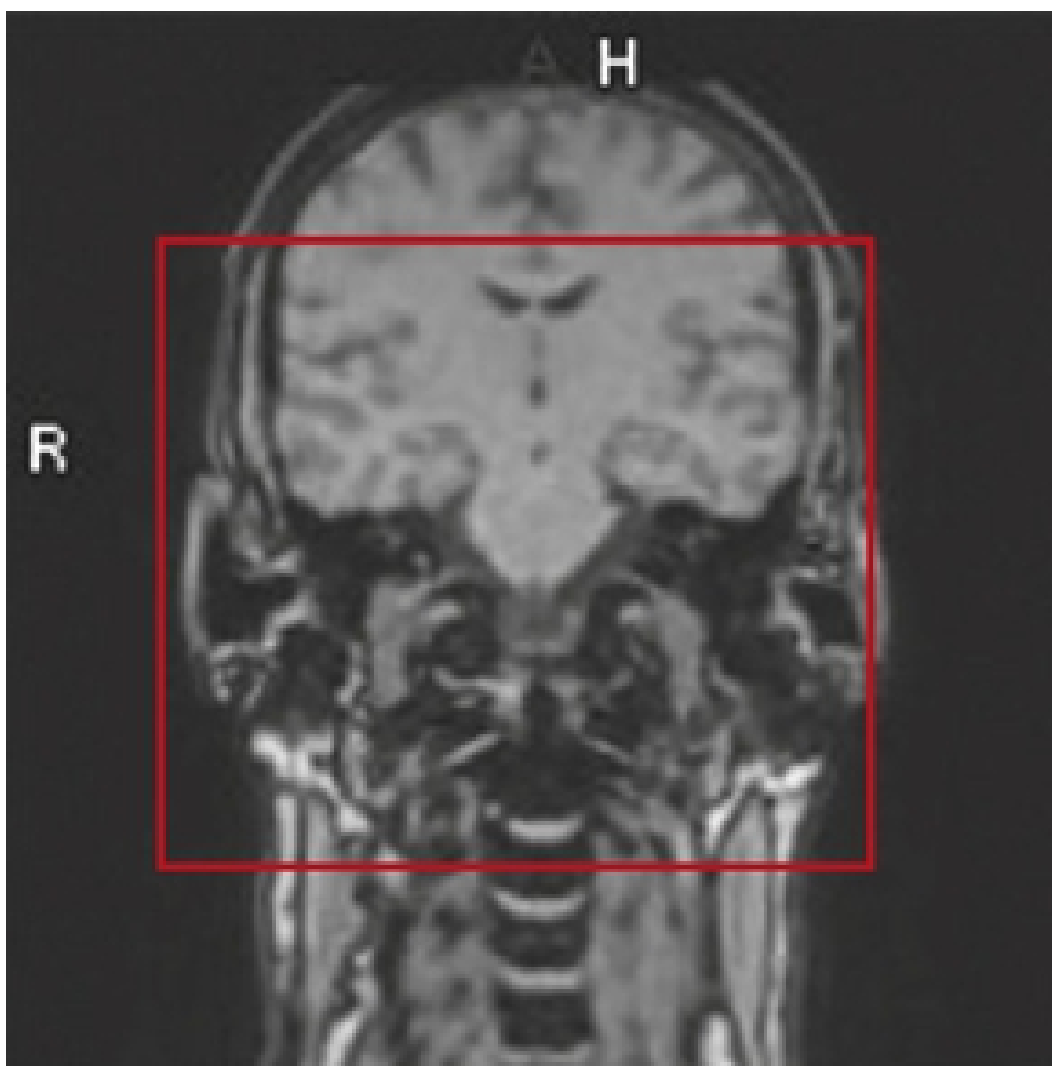


Fig. 2.4c [↗](#)

Planning circle of Willis images: angle the block along the corpus callosum, covering from the top of the corpus callosum to the level of C2 ([Fig. 2.4a](#), [Fig. 2.4b](#) and [Fig. 2.4c](#)). Where arteriovenous malformation (AVM) is considered, the block should be extended up to the vertex to include the whole head.

Example sequences: circle of Willis			
Routine	3 plane localiser	Routine brain sequences	ToF MRA CoW
Additional	Ax T2 GRE		

Example Sequences Brain ([Fig. 2.5a](#), [Fig. 2.5b](#) and [Fig. 2.5c](#))

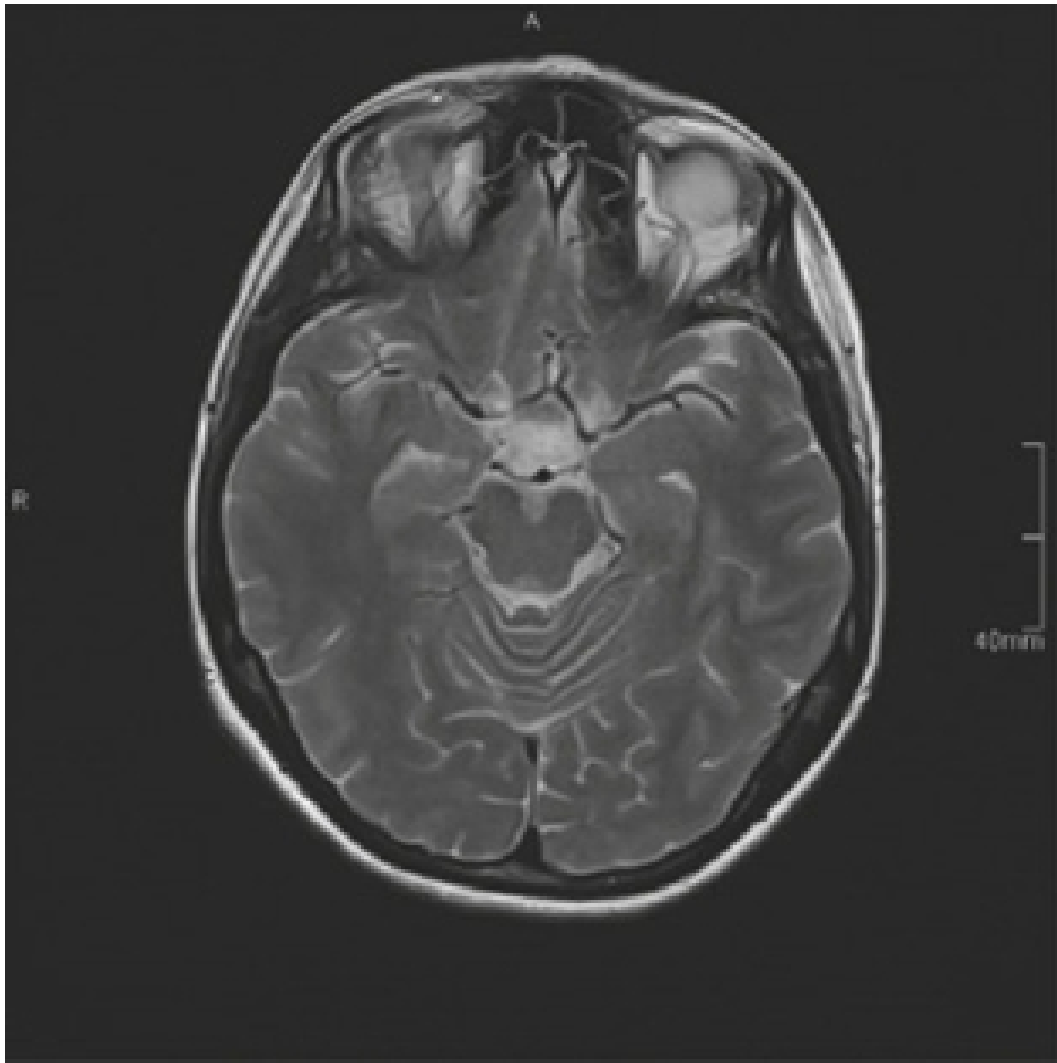


Fig. 2.5a Example of an axial T2 brain image. [↗](#)



Fig. 2.5b Example of a T2 SPACE 3D sequence for an IAM image. [📄](#)



Fig. 2.5c Example of a circle of Willis maximumintensity projection. [📄](#)

Example Sequences Pituitary ([Fig. 2.6a](#), [Fig. 2.6b](#) and [Fig. 2.6c](#))

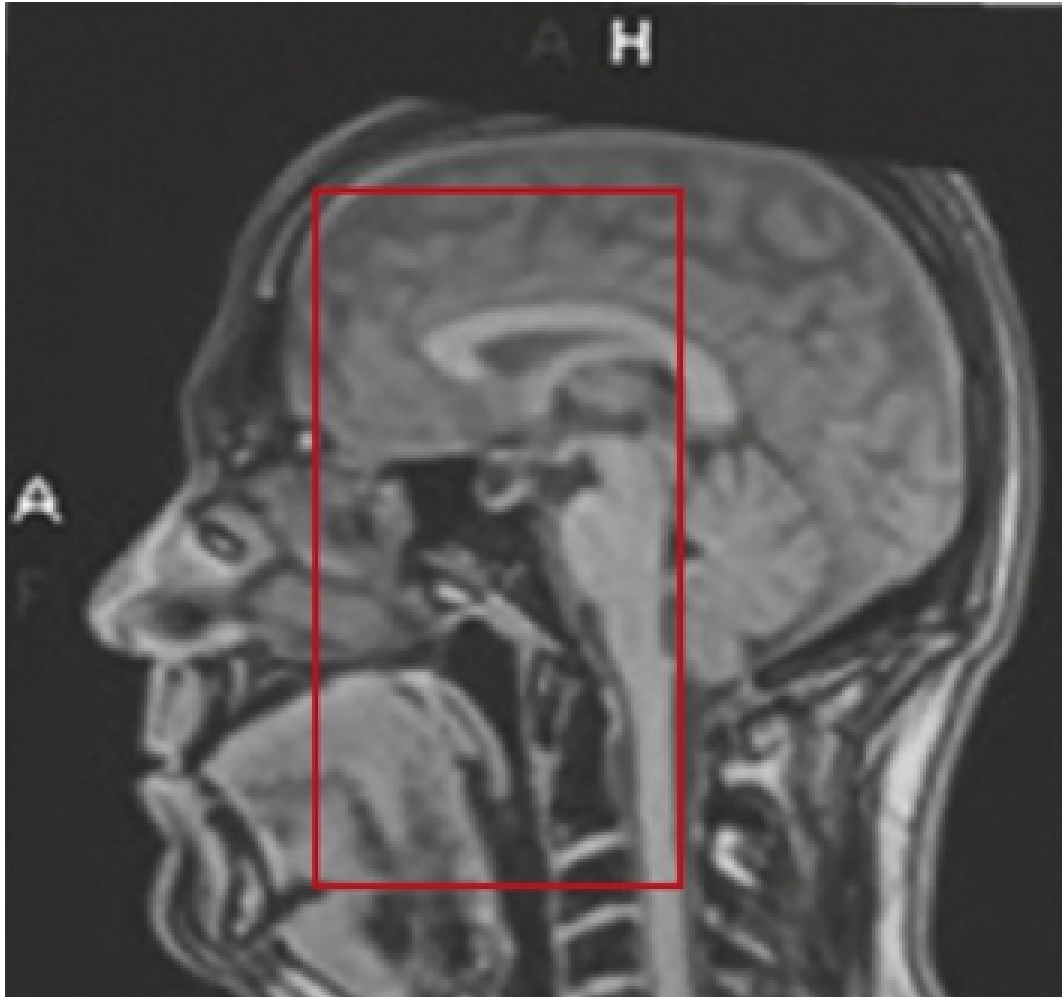


Fig. 2.6a [↗](#)

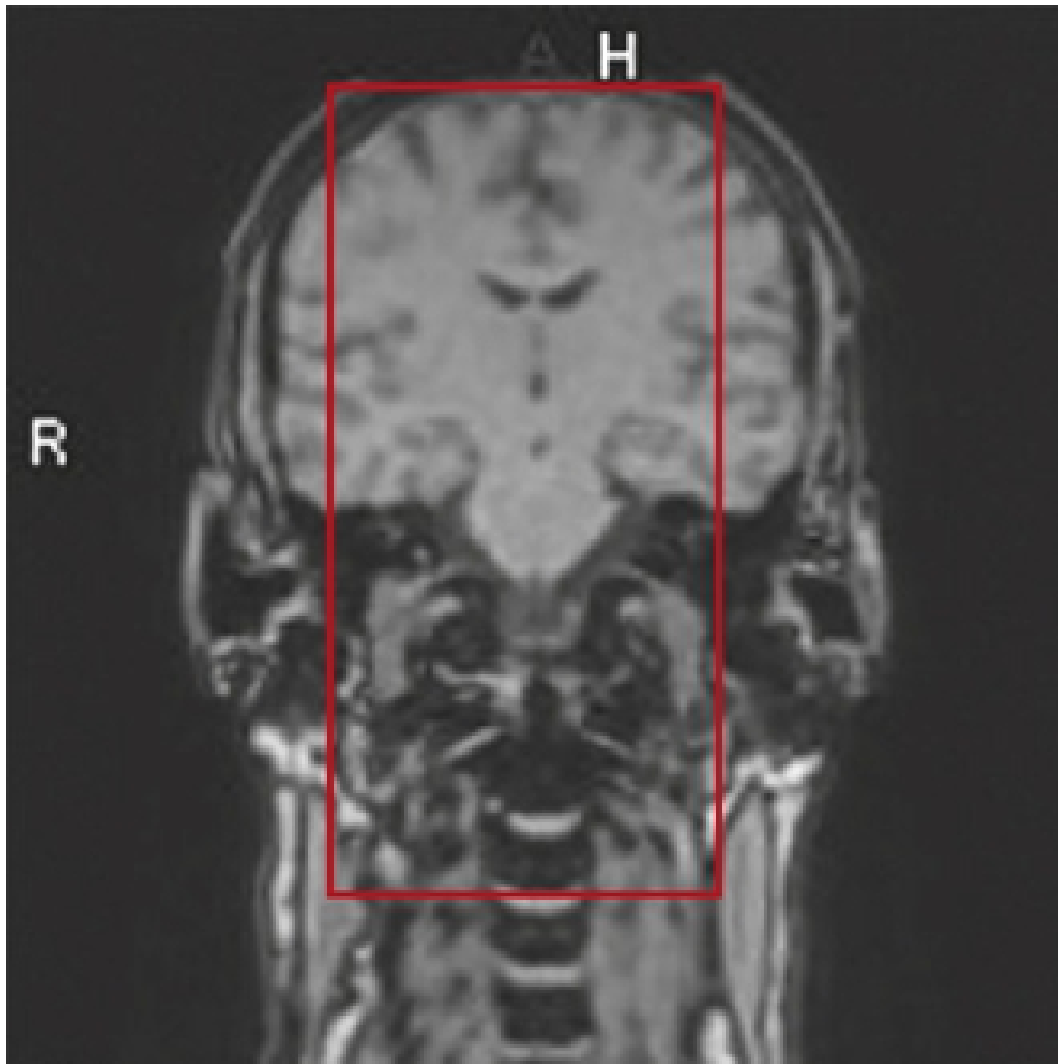


Fig. 2.6b [↗](#)

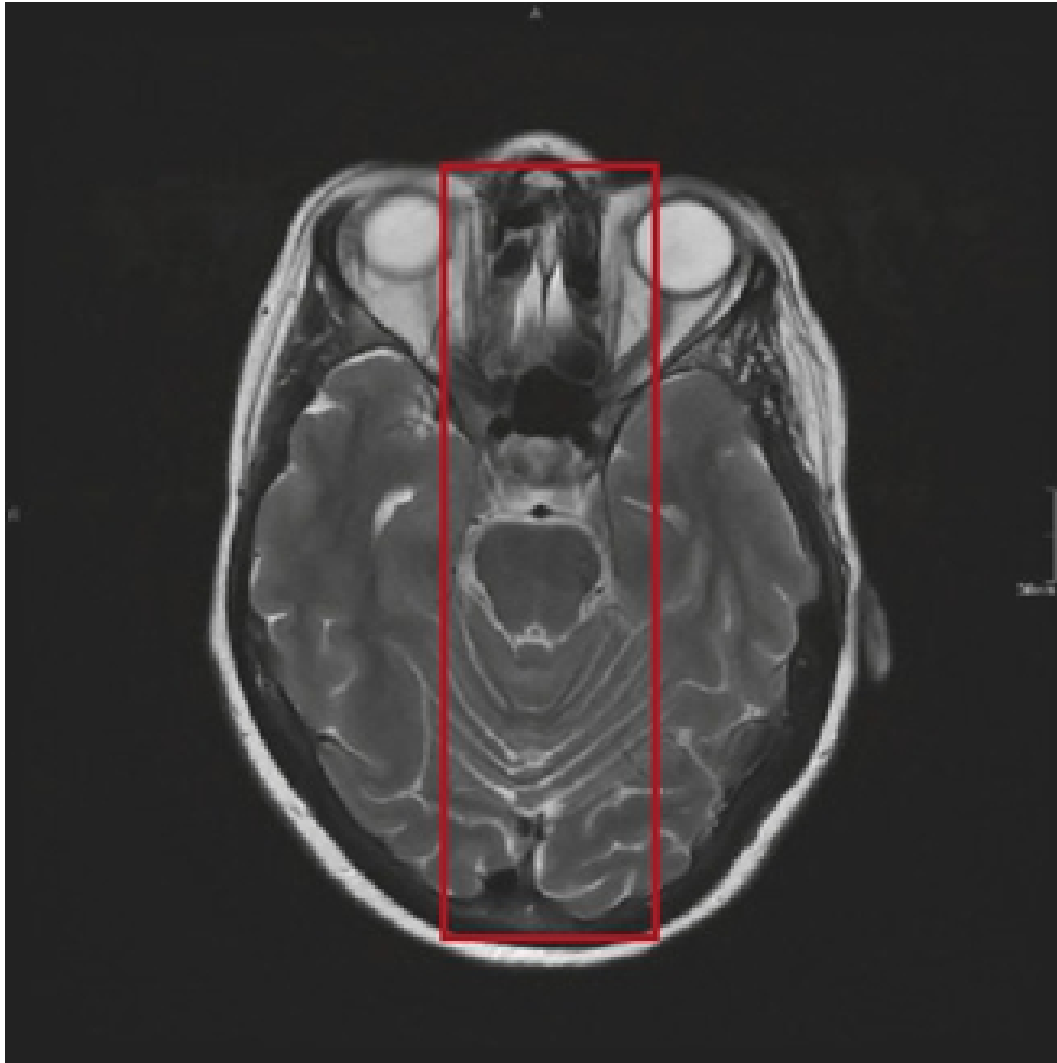


Fig. 2.6c [↗](#)

Planning coronal sequence: angle slices perpendicular to the sella turcica, covering from the anterior border of the sphenoid sinus to the anterior border of the pons ([Fig. 2.6a](#)). Check appropriate angle in the coronal plane ([Fig. 2.6b](#)).

Planning sagittal sequence: angle slices parallel to the sella turcica, covering the whole of the pituitary gland ([Fig. 2.6c](#)).

Example sequences: pituitary				
Routine	3 plane localiser	Ax T2 brain	Sag T1 2 mm	Cor T1 2 mm
Pre- and post-contrast		Sag T1 2 mm	Cor T1 2 mm	

Acquired Images: Examples ([Figs. 2.7a, b](#))

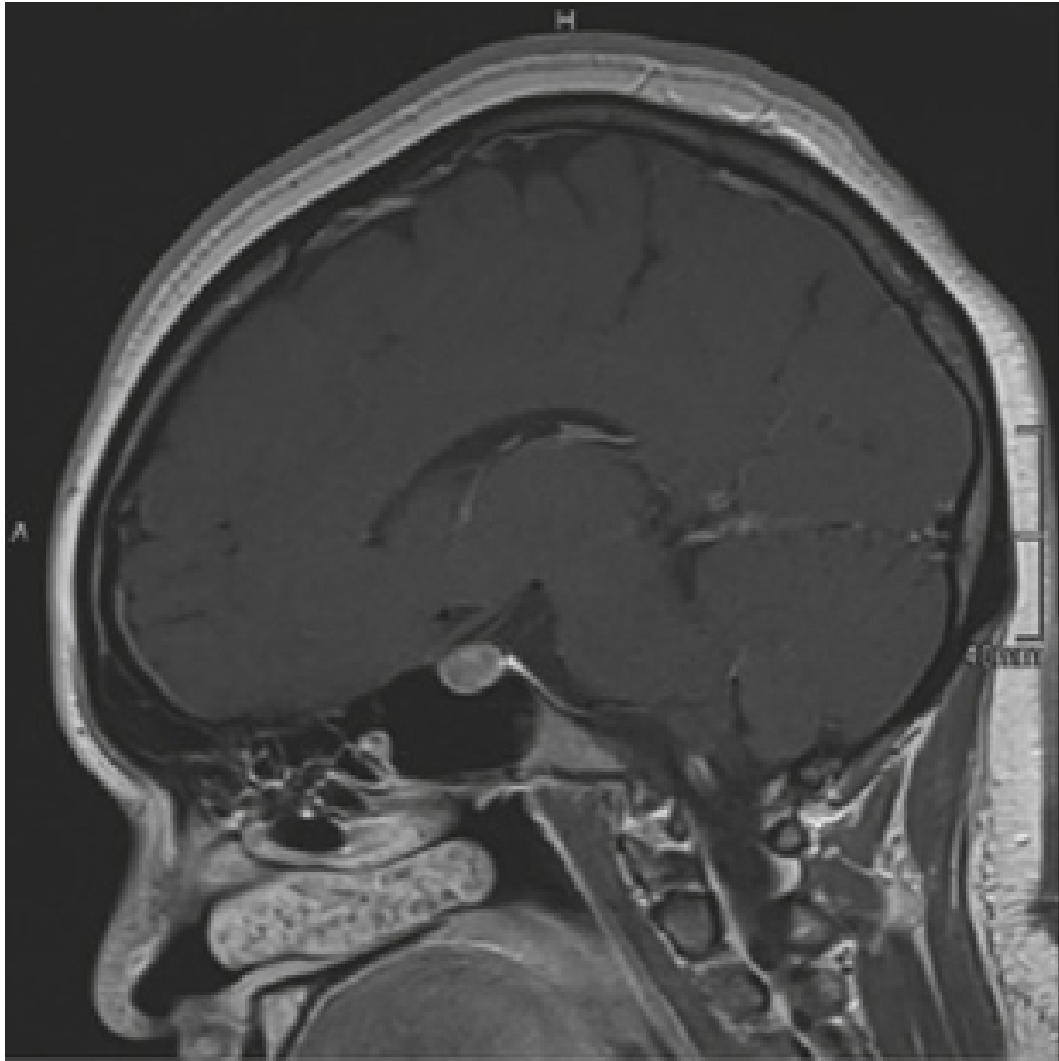


Fig. 2.7a Example of a T1 post-contrast pituitary sagittal image. [📄](#)

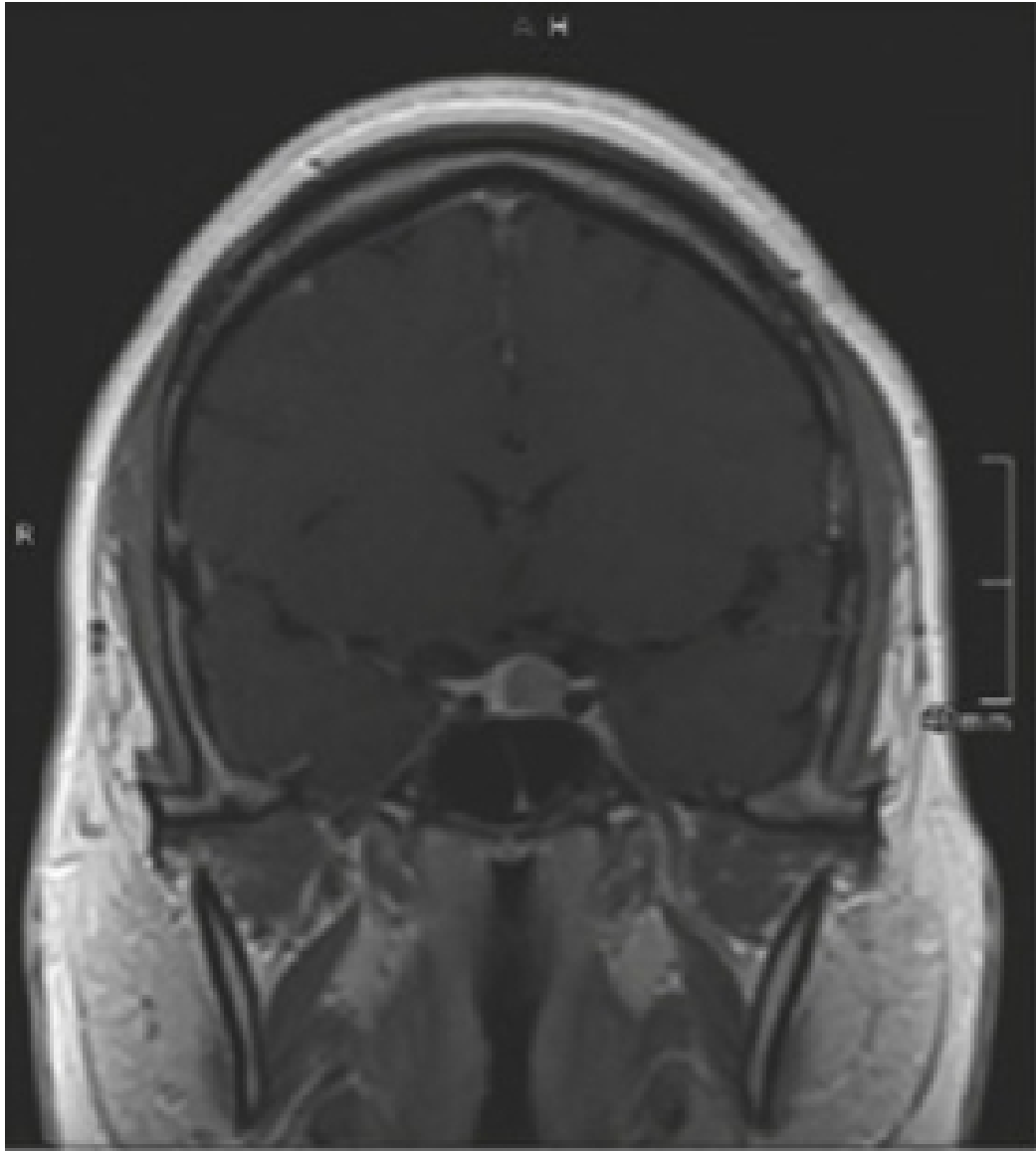


Fig. 2.7b Example of a T1 post-contrast coronal pituitary image.[↗](#)

Orbits Planning Images ([Fig. 2.8a](#), [Fig. 2.8b](#) and [Fig. 2.8c](#))

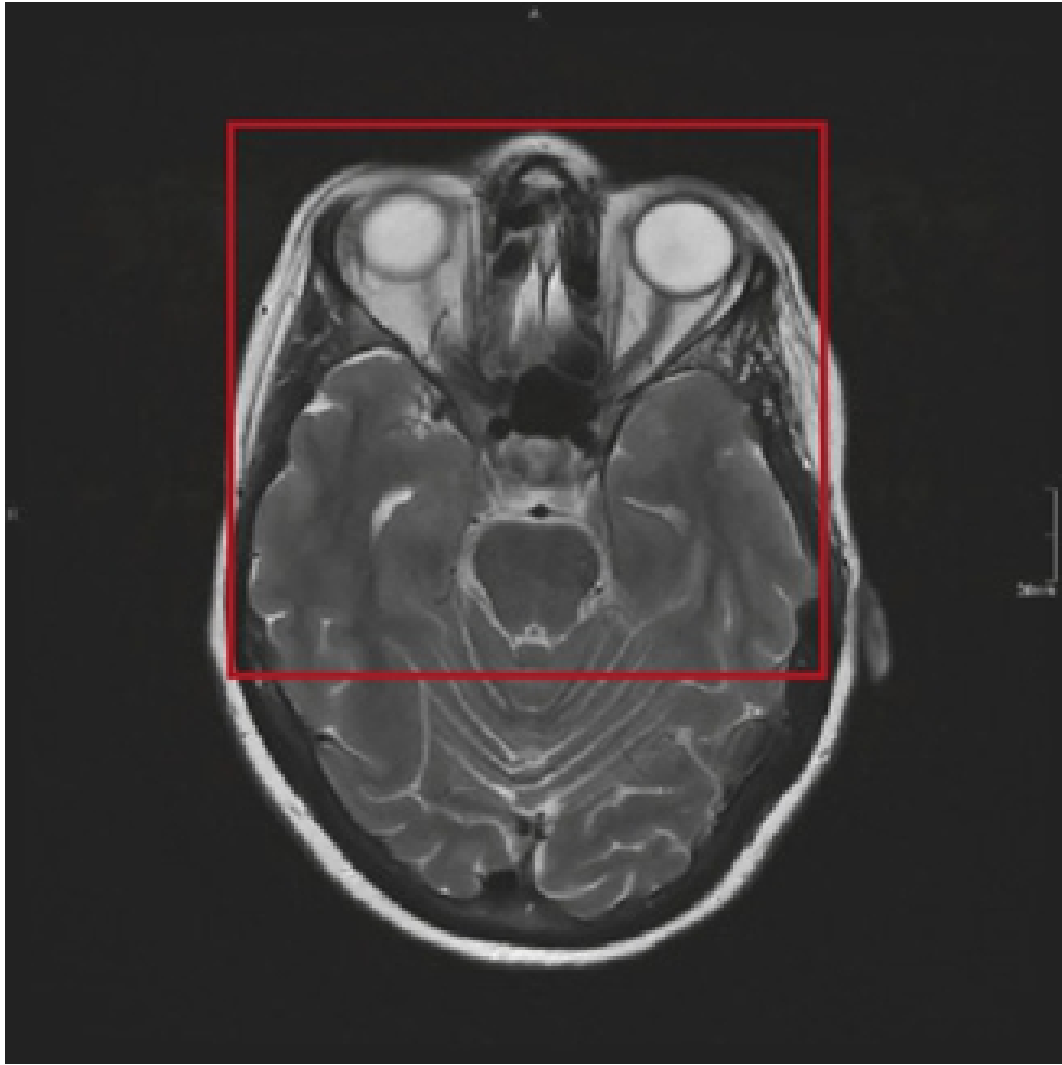


Fig. 2.8a [📄](#)

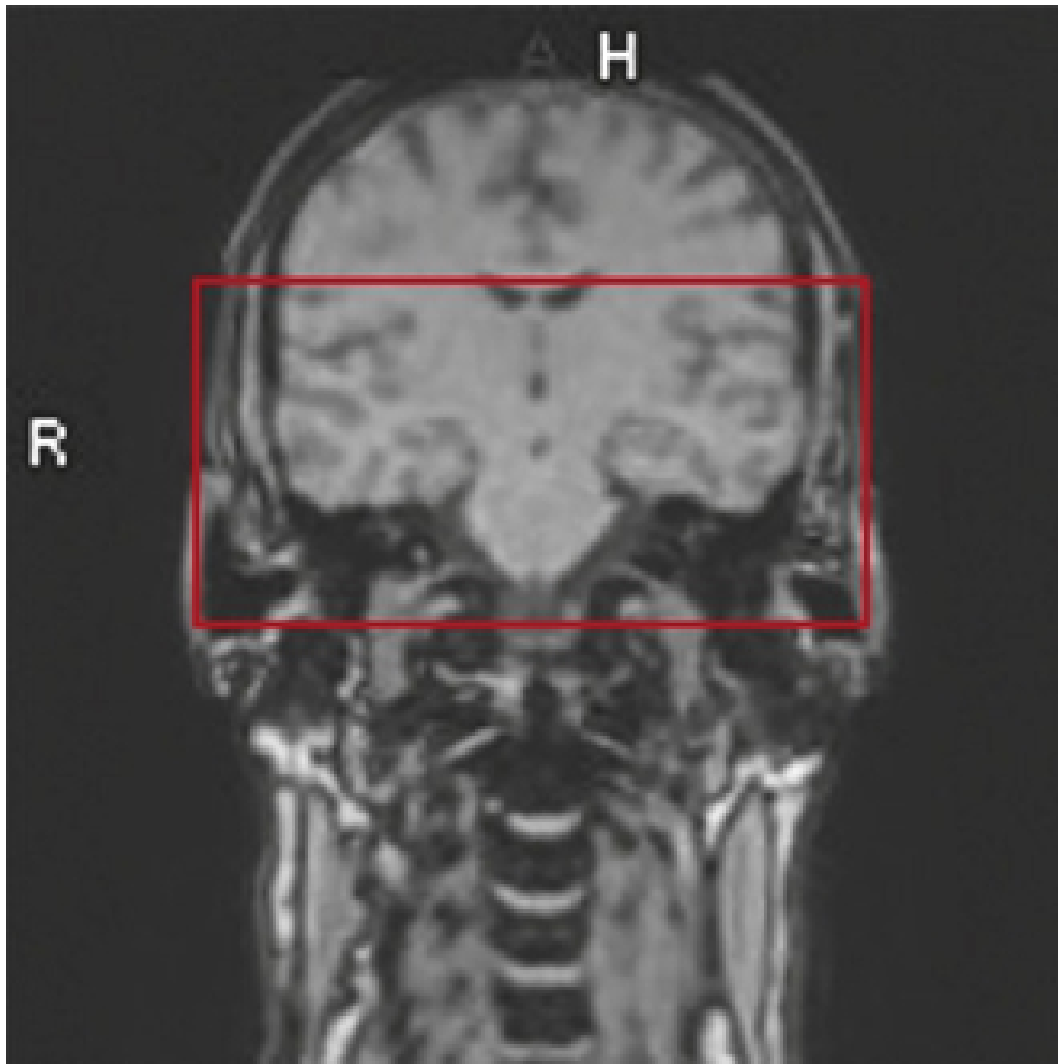


Fig. 2.8b [↗](#)

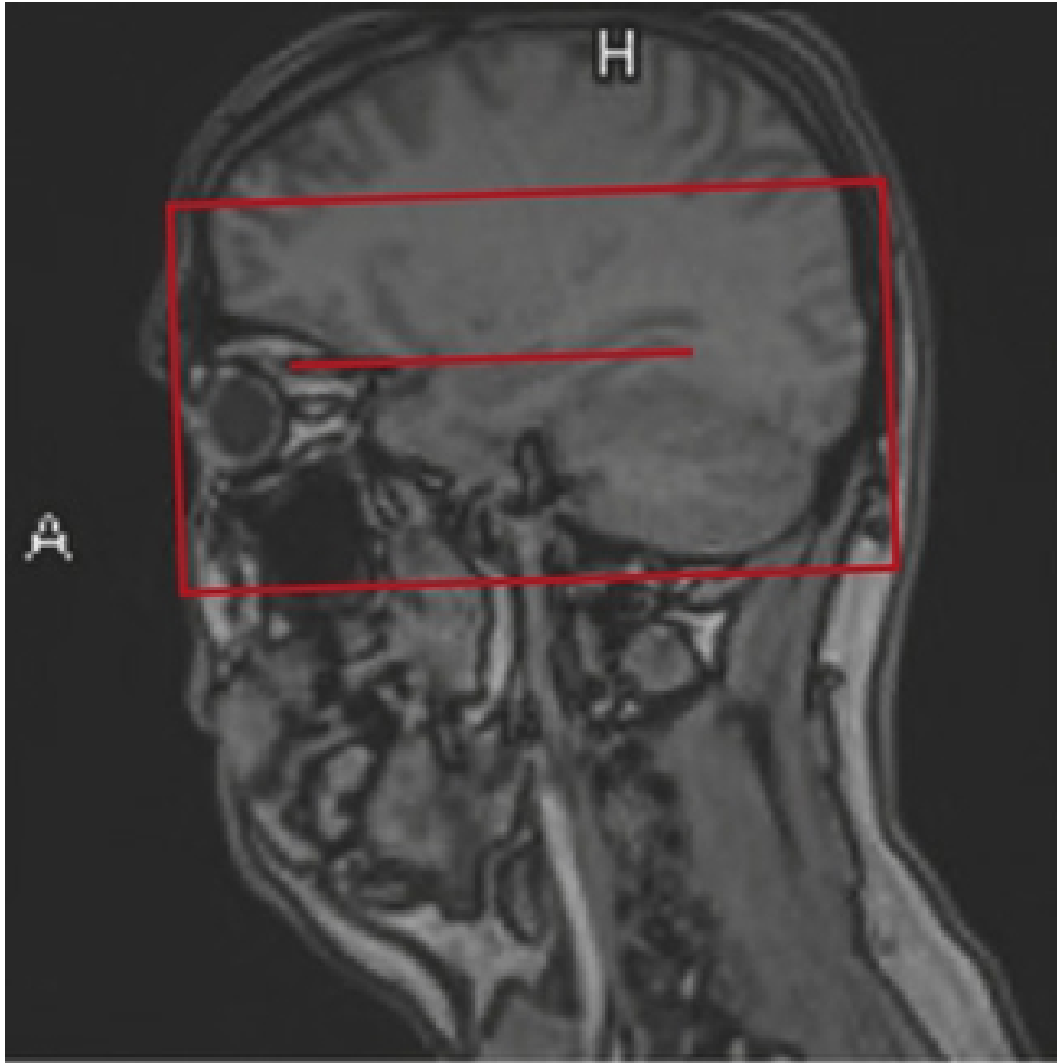


Fig. 2.8c [🔗](#)

Planning coronal sequence: angle slices parallel to lenses of the eyes, covering from the front of the orbit to include the optic chiasma and anterior part of the brainstem on an axial image ([Fig. 2.8a](#)). Check appropriate angle and coverage in the coronal plane ([Fig. 2.6b](#)).

Planning individual sagittal sequences: angle the block parallel to the optic nerve (as demonstrated with the red line in [Fig. 2.8c](#)).

Planning axial sequence: angle slices parallel to the optic nerve, cover from superior border to inferior border of the orbits ([Fig. 2.8c](#)).

Example sequences orbits						
Routine	3 plane localiser	Ax T2 brain 3 mm	Cor T2 STIR 3 mm	Cor T1 3 mm	Ax T1 3 mm	Ax CISS/SPACE/FIESTA FAT SAT
Additional		Ax T1 + Cor T1 3 mm pre- and post- contrast		Cor T2 Dixon/FAT SAT post-contrast		

Acquired Images: Examples ([Fig. 2.9a](#), [Fig. 2.9b](#) and [Fig. 2.9c](#))

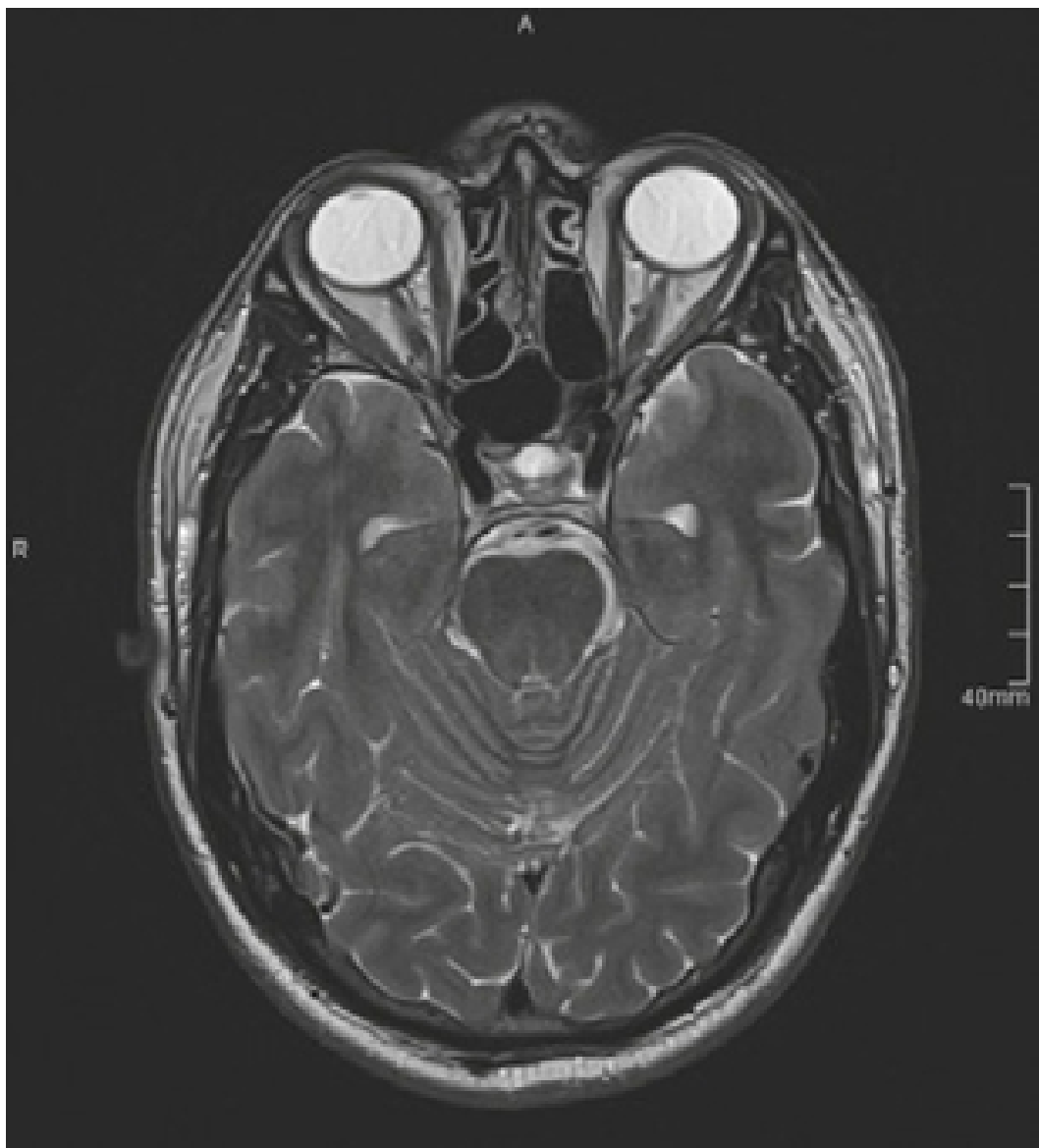


Fig. 2.9a Example of T2 orbit image. [📄](#)

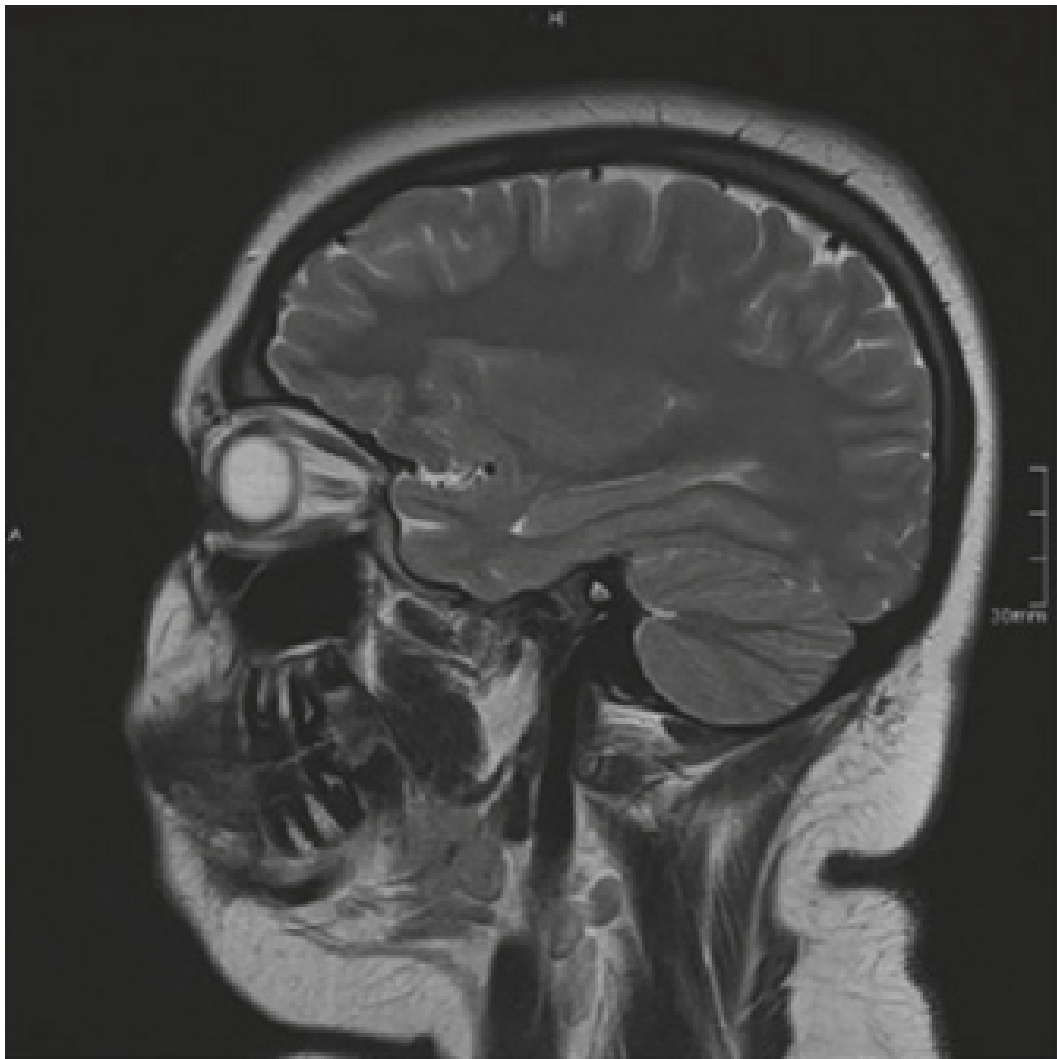


Fig. 2.9b Example of T2 sagittal orbit image. [📄](#)

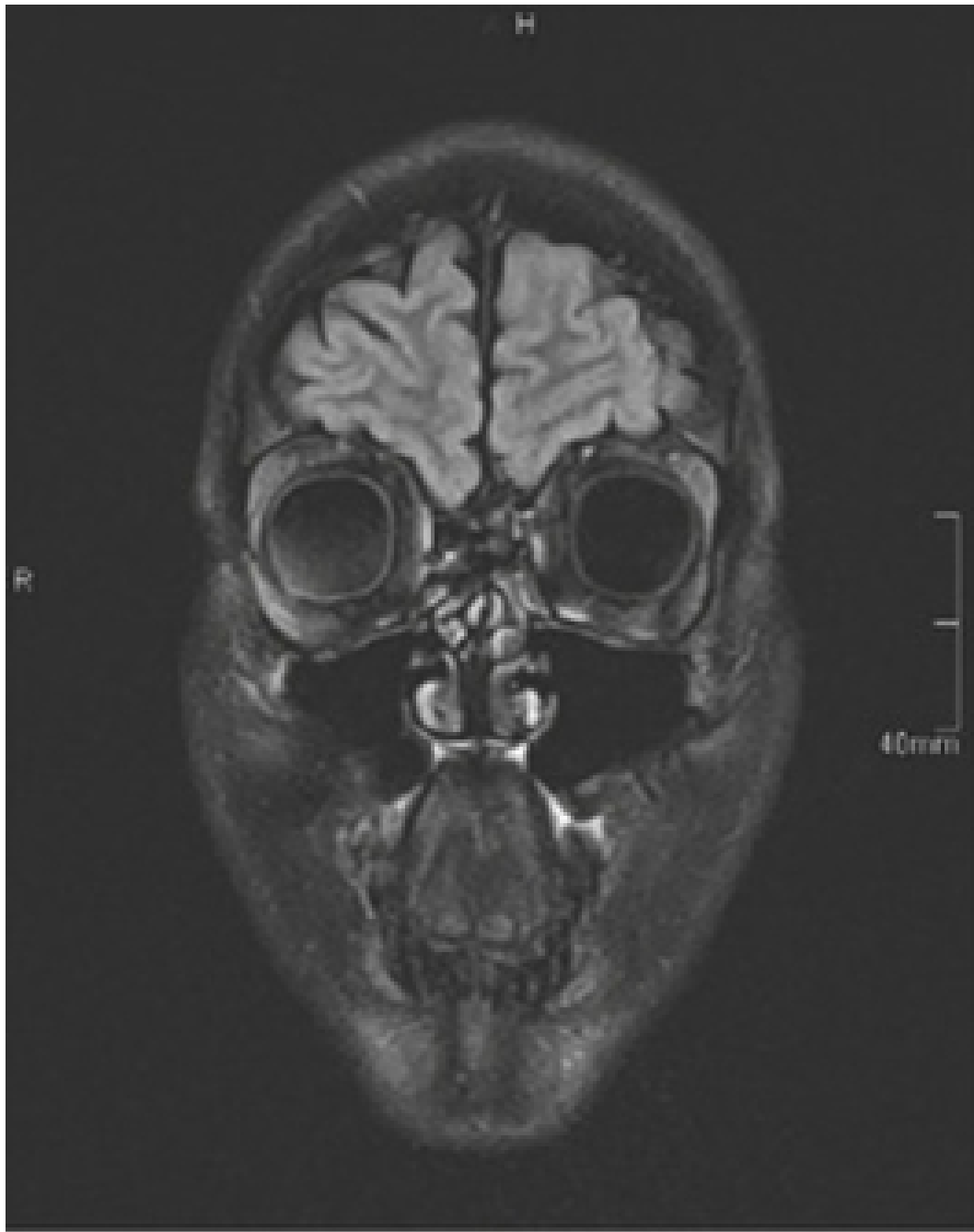


Fig. 2.9c Example of T1 coronal orbit image. [📄](#)

Temporomandibular Joints ([Fig. 2.10a](#), [Fig. 2.10b](#) and [Fig. 2.10c](#))

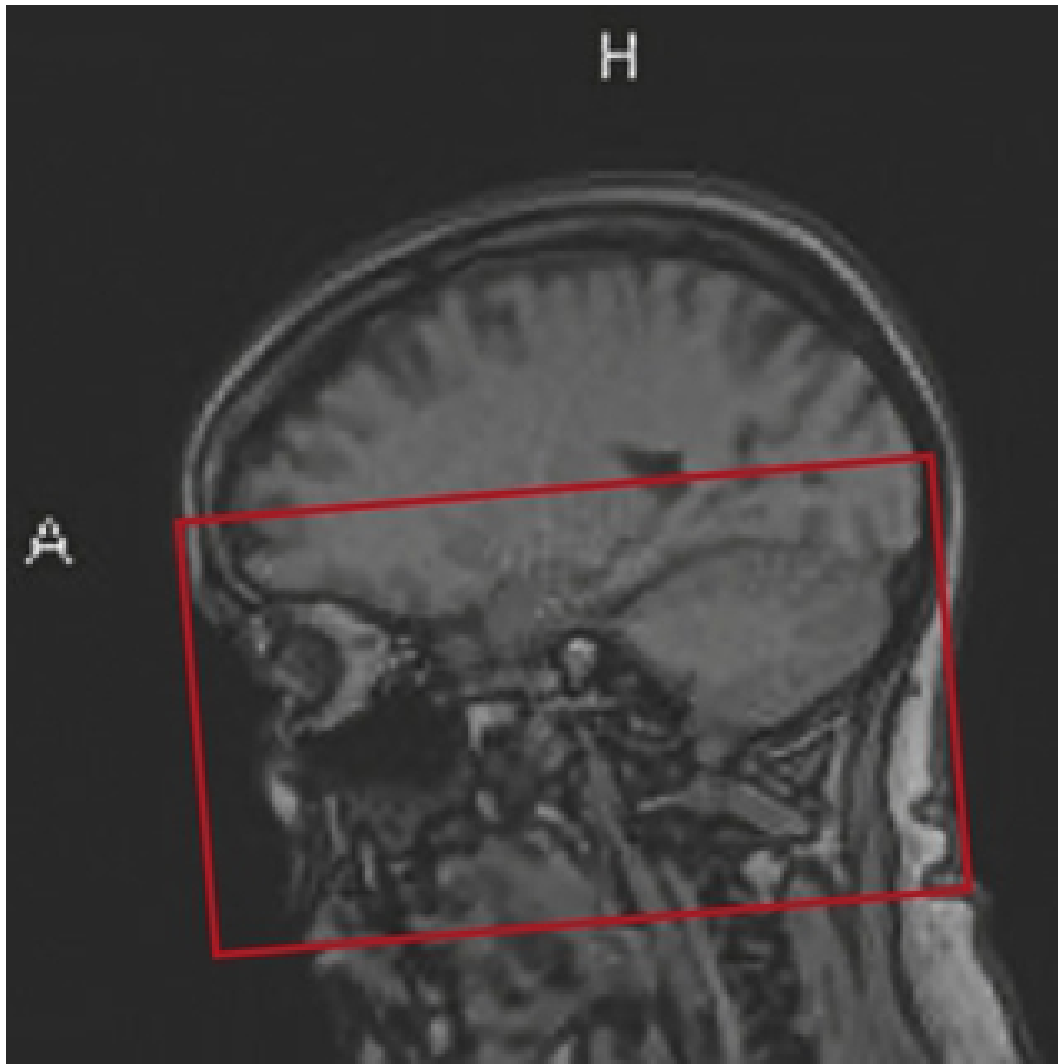


Fig. 2.10a [📄](#)

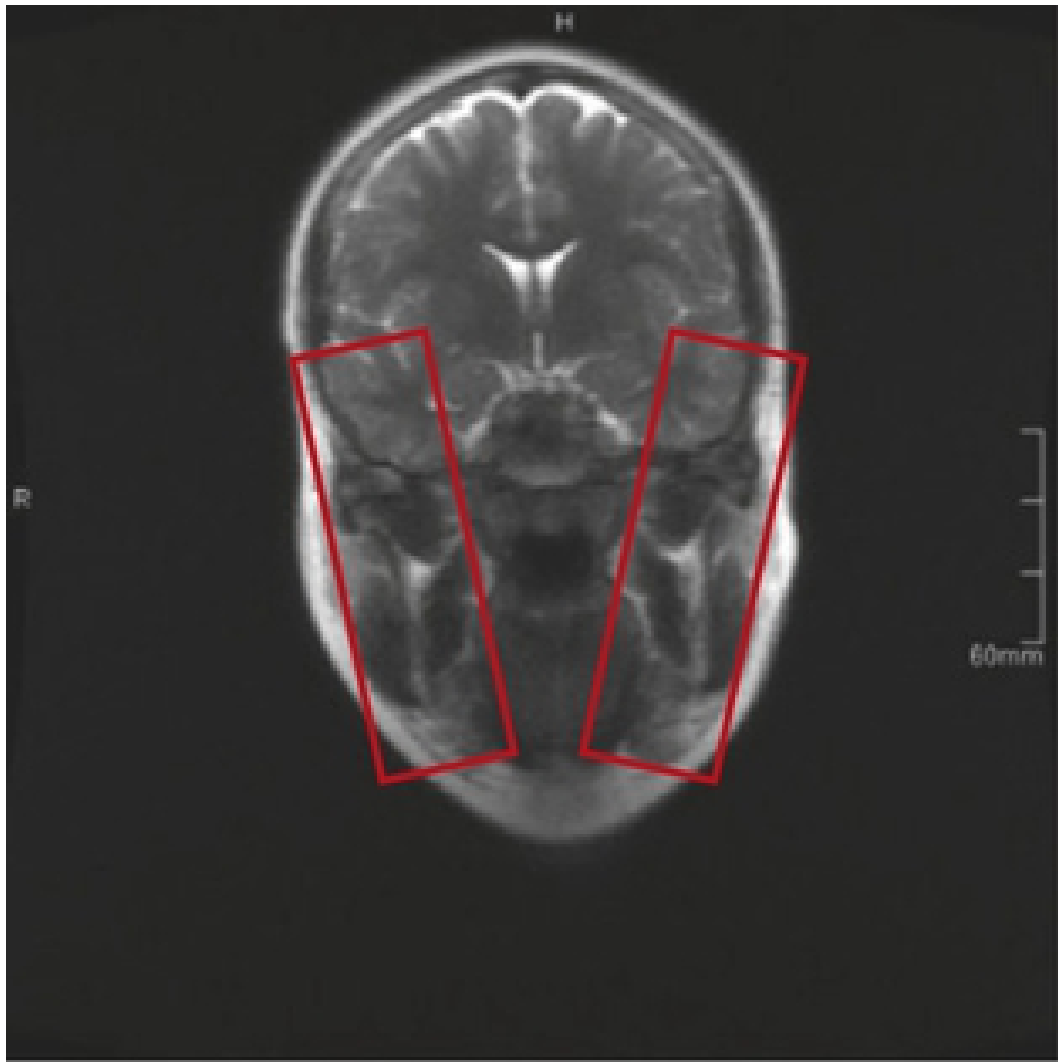


Fig. 2.10b [🔗](#)



Fig. 2.10c [📄](#)

Planning axial sequence: angle slices parallel to the hard palette, covering from the corpus callosum to the angle of the mandible ([Fig. 2.10a](#)).

Planning individual coronals: angle the block parallel to the condyles of mandible ([Fig. 2.10b](#)).

Planning individual sagittal sequences: angle the block perpendicular to the condyles of mandible in the open and closed mouth position ([Figs. 2.10b, c](#)).

Example sequences (typical): temporomandibular joints (TMJs)	
Routine	3 plane localiser Ax T2 HASTE Cor T2 FS or STIR LT and RT Sag T1 relaxed LT and RT Sag T2 relaxed LT and RT Cor T2 FS relaxed LT and RT Sag T2* jaw clenched LT and RT Sag T2* mouth wide open LT and RT Sag T2 mouth open (Tip: use a 50 mL syringe placed in the patient's mouth to ensure the mouth is open consistently)
Additional	Sag T1 FLASH 2D dynamic

FLASH, fast low-angle shot; HASTE, half Fourier single-shot turbo spin echo; LT, left; RT, right.

Acquired Images: Examples ([Figs. 2.11a, b](#))

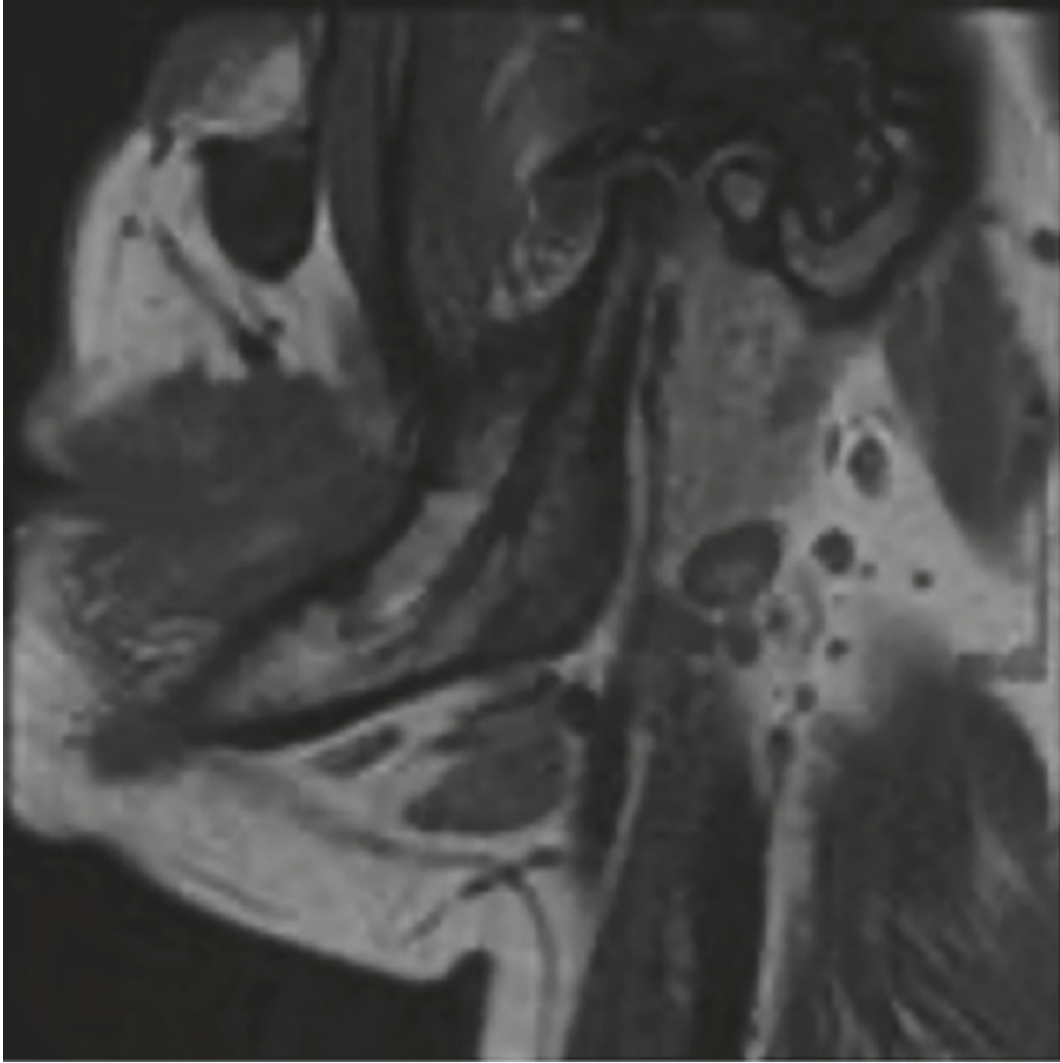


Fig. 2.11a Example of a sagittal oblique image through the TMJ. [📄](#)

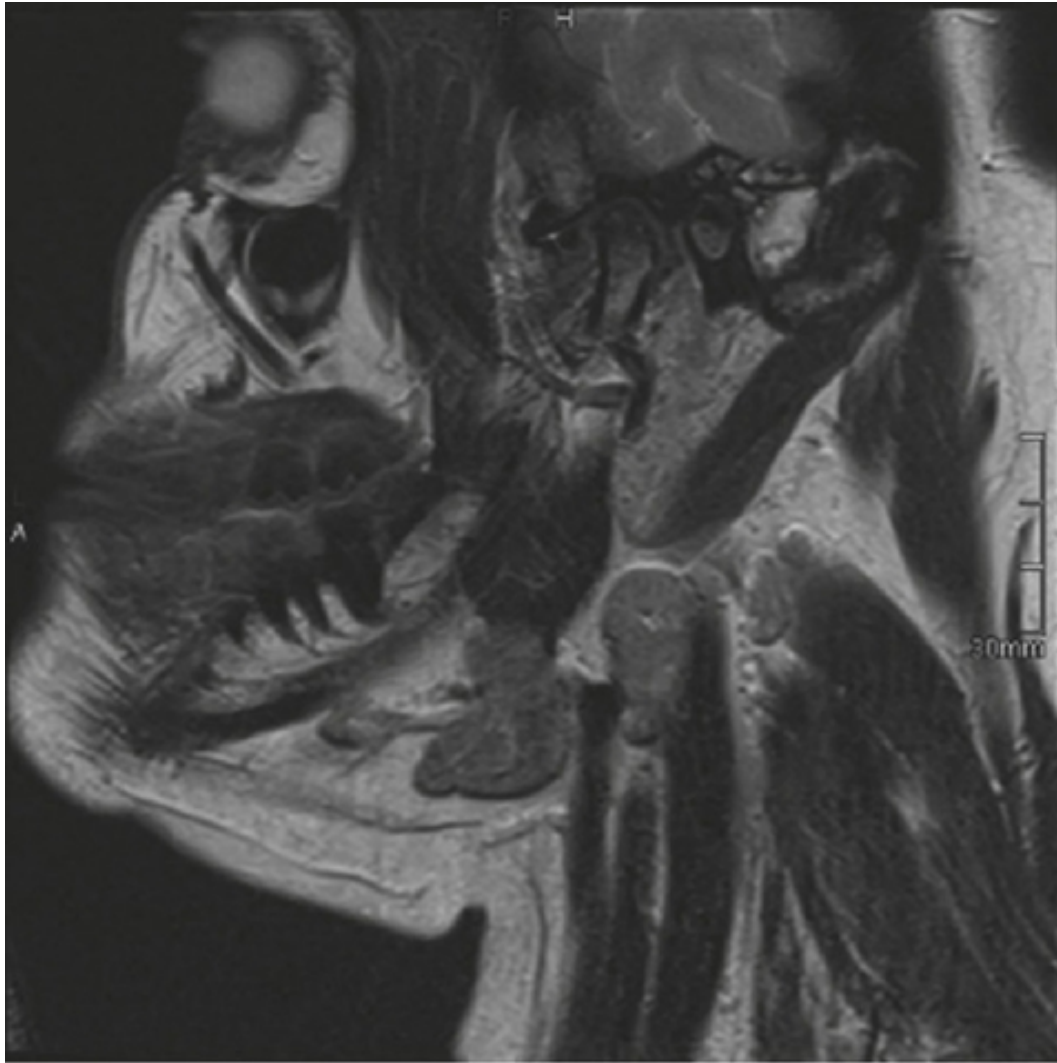


Fig. 2.11b Another example of a sagittal oblique image through the TMJ. [📄](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard brain imaging is adequate. For circle of Willis imaging, a dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.12a](#), [Fig. 2.12b](#), [Fig.12.c](#) and [Fig. 12.d](#))



Fig. 2.12a The anterior coil has been left off for a patient with severe claustrophobia. Images will have signal loss in the anterior part of the brain. [📄](#)

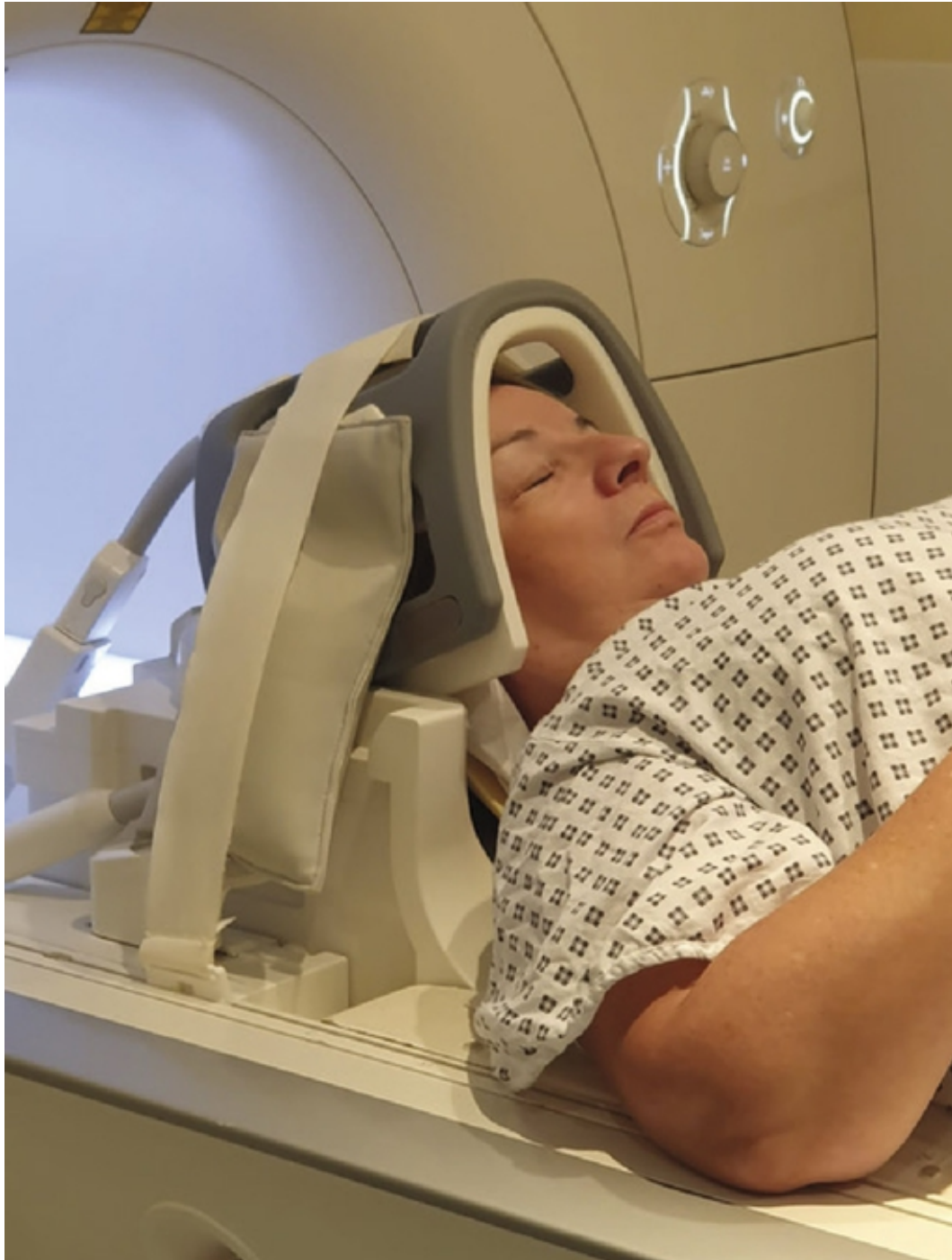


Fig. 2.12b Use of a flexible coil on a kyphotic patient where it is not possible to place the anterior coil. [📄](#)



Fig. 2.12c Patient unable to lie flat due to kyphosis/pain. Scanned lying in a lateral right decubitus position with the dedicated head coil. Extra padding has been placed inside the coil to aid comfort. [↗](#)



Fig. 2.12d Use of a tilted head coil in a patient with kyphosis (available on some newer MRI systems).[📄](#)

When it is not possible to position in the standard position for the imaging of the brain then we can position the patient as below.

CHEST AND CHEST WALL

MRI is the most sensitive imaging modality used for looking at the anatomy of the chest and chest wall. There will be separate comments made on cardiac imaging in [Section 3](#). This chapter is specifically focused on looking at the chest and any swelling/lumps/masses that require imaging. Other modalities may fail to pinpoint the exact cause for a swelling/mass/lump on the chest or chest wall, but the high spatial resolution of MR can demonstrate the cause and extent of any lesions and can define the precise outline of any abnormality.

Indications

- Assessment of abnormal growths, including cancer of the lungs, e.g. mediastinal nodes
- Assessment of chest wall tumours, e.g. sarcoma, osteochondroma, haemangioma and metastatic tumours of the bone
- Assessment of lymph nodes and blood vessels, including vascular and lymphatic malformations of the chest
- Assessment of disorders of the bone marrow, e.g. anaemia and avascular necrosis of the bone
- Assessment of chest wall or diaphragmatic extension of intrathoracic masses
- Assessment of chest and chest wall infections
- Suspected superior sulcus tumour following a chest X-ray
- Lung cancer staging
- Chest trauma.

Imaging Procedure ([Fig. 2.13](#))



Fig. 2.13 Standard positioning. [📄](#)

- Position the patient head-first prone.
- Place the body coil over the upper back to cover the entire upper chest.
- Centre to the middle of the body array coil.

- Securely tighten the body array with straps to limit the amount of breathing artefacts.
- Use cushions and pads as appropriate to ensure that the chest wall stays immobilised and straight throughout the scan.

Sequence Planning ([Fig. 2.14a](#), [Fig. 2.14b](#) and [Fig. 2.14c](#))



Fig. 2.14a [🔗](#)

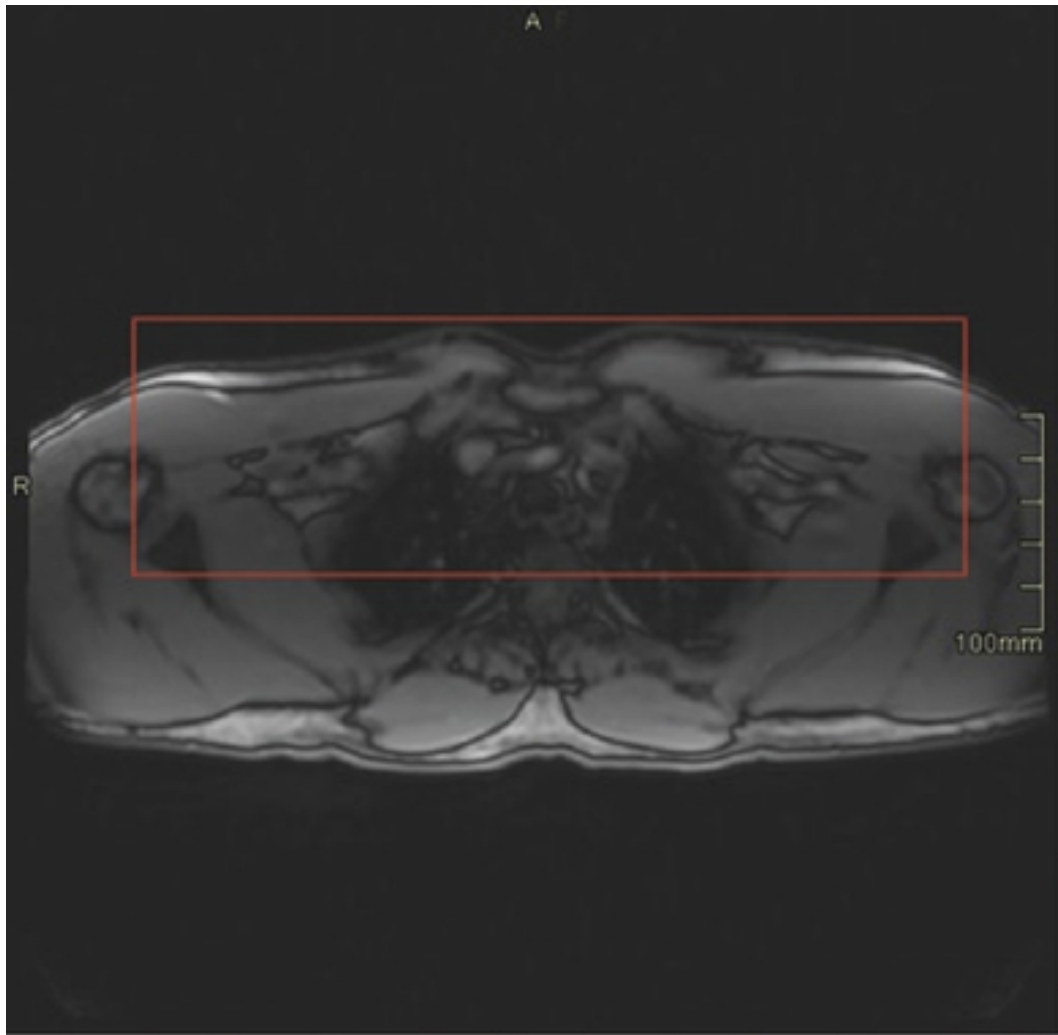


Fig. 2.14b [↗](#)



Fig. 2.14 [↗](#)

The types of sequences that can be acquired are heavily reliant on the pathology under question. For standard sequences, planning should be carried out as follows.

Planning coronal sequence: plan the coronal slices on the axial localiser and position the block horizontally across the chest ([Fig. 2.14b](#)). Establish an appropriate angle in the sagittal plane by aligning it vertically across the chest ([Fig. 2.14a](#)).

Planning axial sequence: align the slices vertically on a coronal image ([Fig. 2.14c](#)).

Planning sagittal sequence: position the block vertically across the chest on a coronal image. Establish an appropriate angle in the axial plane by aligning it horizontally across the chest.

Saturation bands and breath-hold techniques can be used to limit the amount of movement artefact. For anterior chest wall pathologies, positioning the patient prone will minimise movement artefacts.

Example sequences: chest							
Routine	3 plane localiser	Ax T2 HASTE	Cor T2 HASTE	Ax T2 STIR	Cor T2 STIR	Ax T1	Cor T1
Additional for sternum	Sag T1	Sag T2					

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard chest wall imaging is adequate. If a contrast injector pump is used, a flow rate of 1–2 mL/sec is recommended.
- If the patient has a symptomatic side, it is advisable to place the cannula in the opposite arm. This will minimise artefacts from the contrast in the injector tubing and ensure that the area being scanned does not move position during the examination.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Acquired Images: Examples ([Figs. 2.15a, b](#))

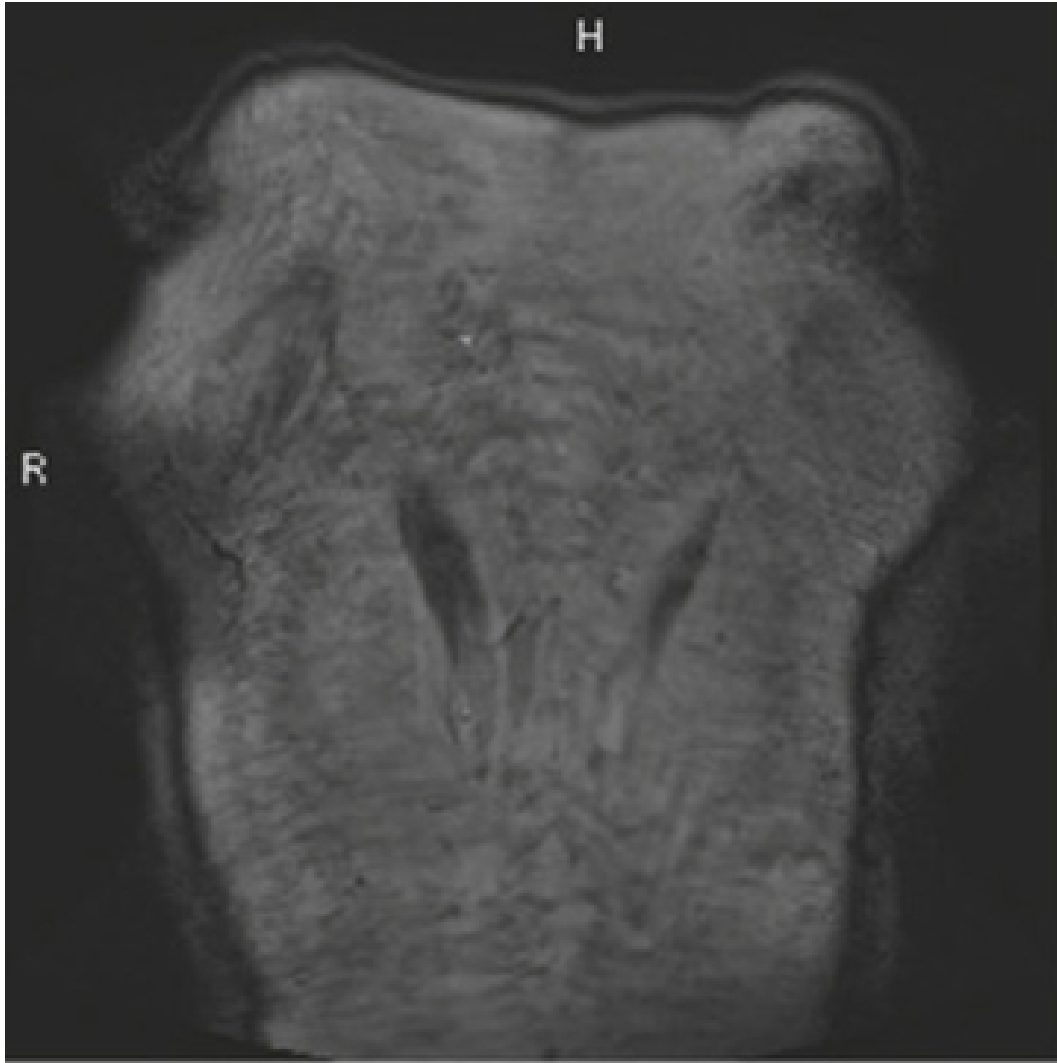


Fig. 2.15a Example coronal chest wall image. [📄](#)

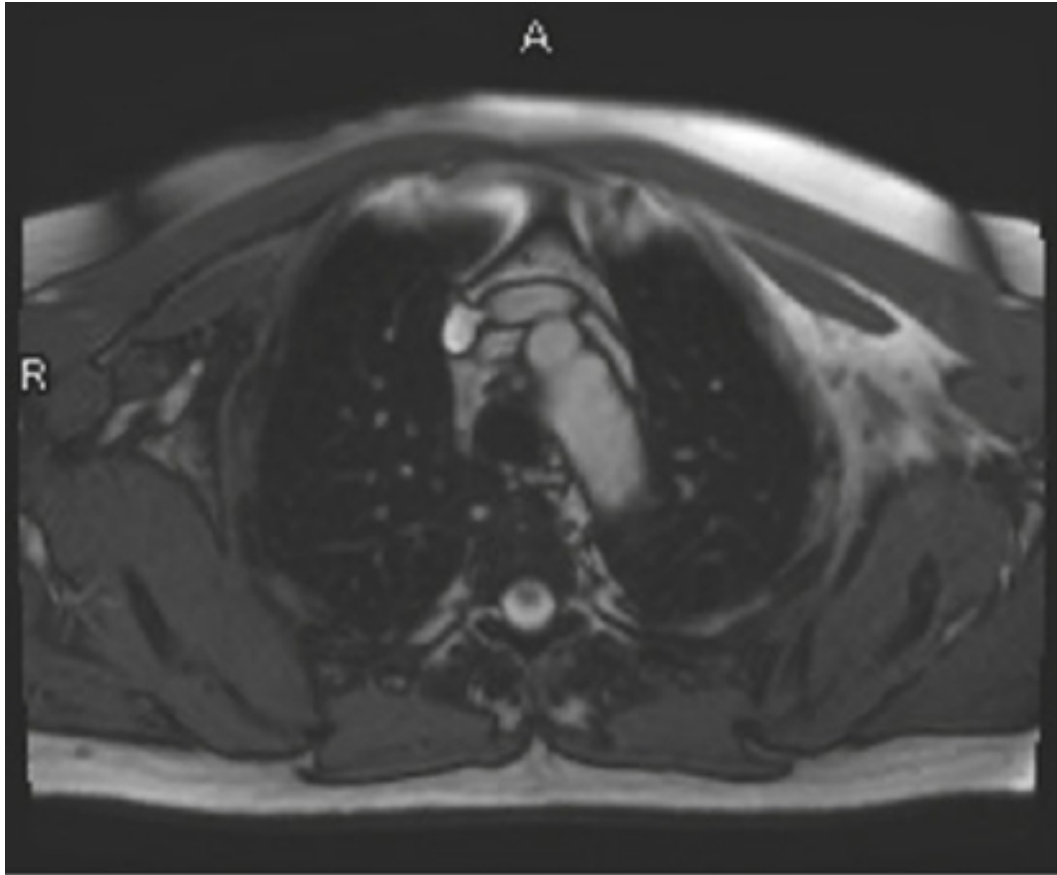


Fig. 2.15b Example axial chest wall image. [📄](#)

Adaptive Techniques ([Figs. 2.16a, b](#))



Fig. 2.16a If the patient is unable to lie in the prone position, position supine and use the spine and body array coils to acquire the images. [📄](#)



Fig. 2.16b If the patient is unable to lie flat or tolerate coils on their back then they can be scanned in a prone position using the spine coil to acquire images from the anterior chest wall. [📄](#)

When it is not possible to position in the standard position for the imaging of the chest wall, we can position the patient as shown in [Figs.](#)

[2.16a, b.](#)

STERNOCLAVICULAR JOINTS

The sternoclavicular joint is formed from the articulation of the medial aspect of the clavicle and the manubrium of the sternum. MRI is useful in sternoclavicular imaging to demonstrate anatomy in high detail and gives excellent tissue contrast. It is an essential tool in the evaluation of soft tissue injury and in the assessment of pathological conditions where pain is indicated.

Indications

- Infections of the bone joint and soft tissue
- Intra-articular fractures or stress fractures involving the acromioclavicular joint
- Tumours and lesions of the clavicle
- Clavicular tuberculosis
- Myeloma
- Metastasis
- Ligament tear
- Non-union of clavicle following trauma

Imaging Procedure ([Fig. 2.17](#))



Fig. 2.17 Standard positioning. [🔗](#)

- Position the patient head-first prone, ensuring that the affected clavicle is over the spine coil. This will minimise breathing artefact.

- Position the body coil under the patient on the spine coil and ask the patient to lie on it.
- Place pads for support.
- Centre for localiser with laser light over the level of the sternoclavicular joint.

Sequence Planning ([Fig. 2.18a](#), [Fig. 2.18b](#) and [Fig. 2.18c](#))



Fig. 2.18a [📄](#)



Fig. 2.18b [↗](#)

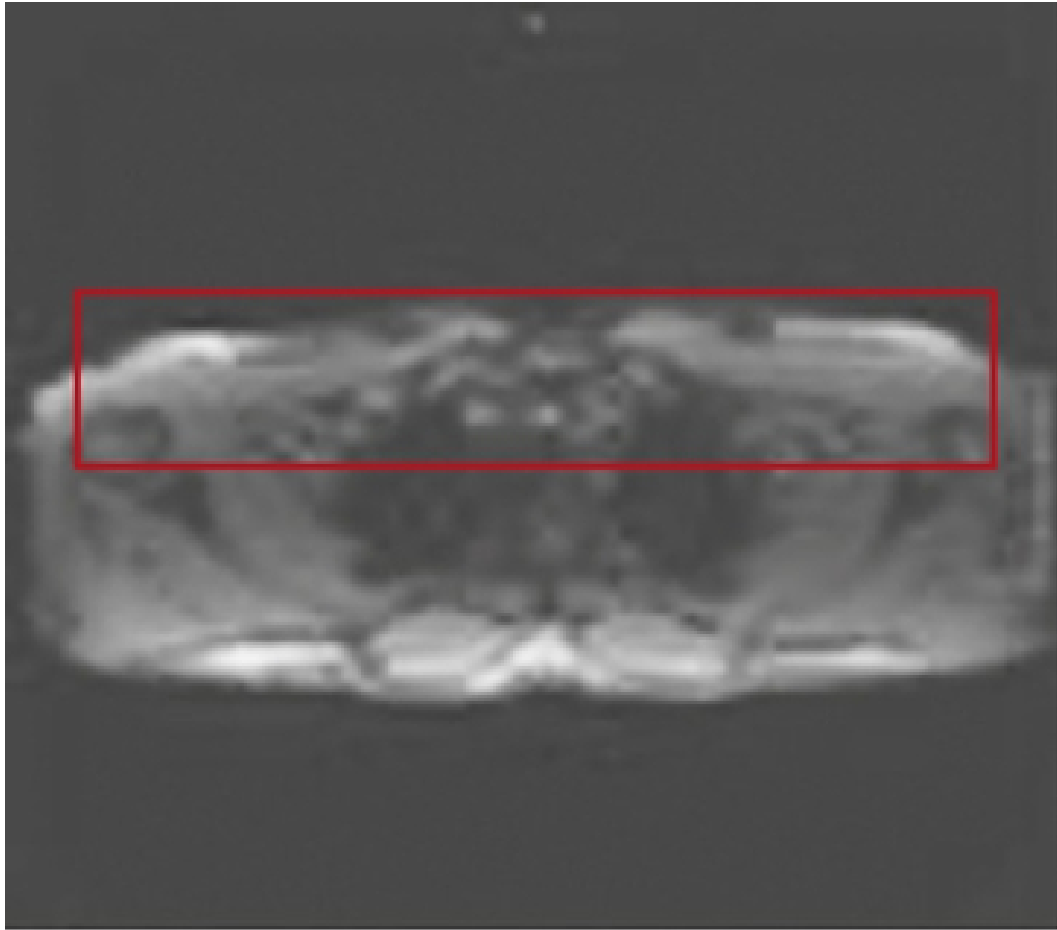


Fig. 2.18c [🔗](#)

Planning sagittal sequence: angle the planning block parallel to the manubrium of the sternum on a coronal image ([Fig. 2.18b](#)). Check the planning block in the other two planes ([Figs. 2.18a, c](#)). Ensure an appropriate angle is set in the axial plane, perpendicular to the sternum's manubrium ([Fig. 2.18c](#)).

Planning coronal sequence: plan the coronal slices on the sagittal plane and position the planning block parallel to the manubrium of the sternum.

Planning axial sequence: angle the planning block perpendicular to the manubrium of the sternum on a sagittal image. Check the planning block in the other two planes. Ensure an appropriate angle is given in the coronal plane, perpendicular to the manubrium of the sternum.

Saturation bands can be used to reduce breathing artefact.

Example sequences: sternoclavicular joints							
Routine	3 plane localiser	Ax T2	Ax PD FS	Cor T2 STIR	Cor T1	Cor T2	Sag T2 STIR

PD, proton density.

Acquired Images: Examples ([Figs. 2.19a, b](#))



Fig. 2.19a Example T2 axial image through the sternoclavicular joints. [↗](#)



Fig. 2.19b Example coronal STIR image. [↗](#)

Adaptive Techniques ([Fig. 2.20](#))



Fig. 2.20 Patient positioned supine as unable to lie in a prone position. Use spine coils and a flexible or body array to acquire images. [📄](#)

The reasons for adapting techniques can include patients' inability to lie prone due to mobility issues or large body habitus.

SHOULDER

MRI is the standard non-invasive diagnostic modality that provides a comprehensive and accurate assessment for both osseous and soft tissue pathological conditions of the shoulder. The glenohumeral or shoulder joint is a synovial joint that attaches the upper limb to the axial skeleton. It is a ball-and-socket joint acting along with the pectoral girdle. The shoulder joint allows for a wide range of motion at the upper limb: flexion, extension, abduction, adduction, external/lateral rotation, internal/medial rotation and circumduction. In fact, it is the most mobile joint of the human body. This shoulder function comes at the cost of stability, however, as the bony surfaces offer little support. Instead, the surrounding shoulder muscles and ligamentous structures offer joint security: the capsule, ligaments and tendons of the rotator cuff muscles. Due to this mobility–stability compromise, the shoulder joint is one of the most frequently injured joints of the body.

Indications

- Degenerative joint disorders
- Rotator cuff disorders and/or tears
- Occult fracture
- Abnormalities caused by trauma
- Infections
- Tumour/neoplasm
- Pain and swelling
- Avascular necrosis
- Nerve impingement
- Ligament tear

Imaging Procedure ([Fig. 2.21](#))



Fig. 2.21 Standard positioning. [↗](#)

- Position the patient head-first supine.
- Position the affected shoulder within the dedicated shoulder coil ensuring that the palm of the hand faces upwards.
- Use cushions and pads as appropriate to ensure the shoulder remains immobilised and straight throughout the scan.
- Centre for the localiser with the laser light over the centre of the shoulder coil.

Sequence Planning ([Fig. 2.22a](#), [Fig. 2.22b](#) and [Fig. 2.22c](#))



Fig. 2.22a [📄](#)

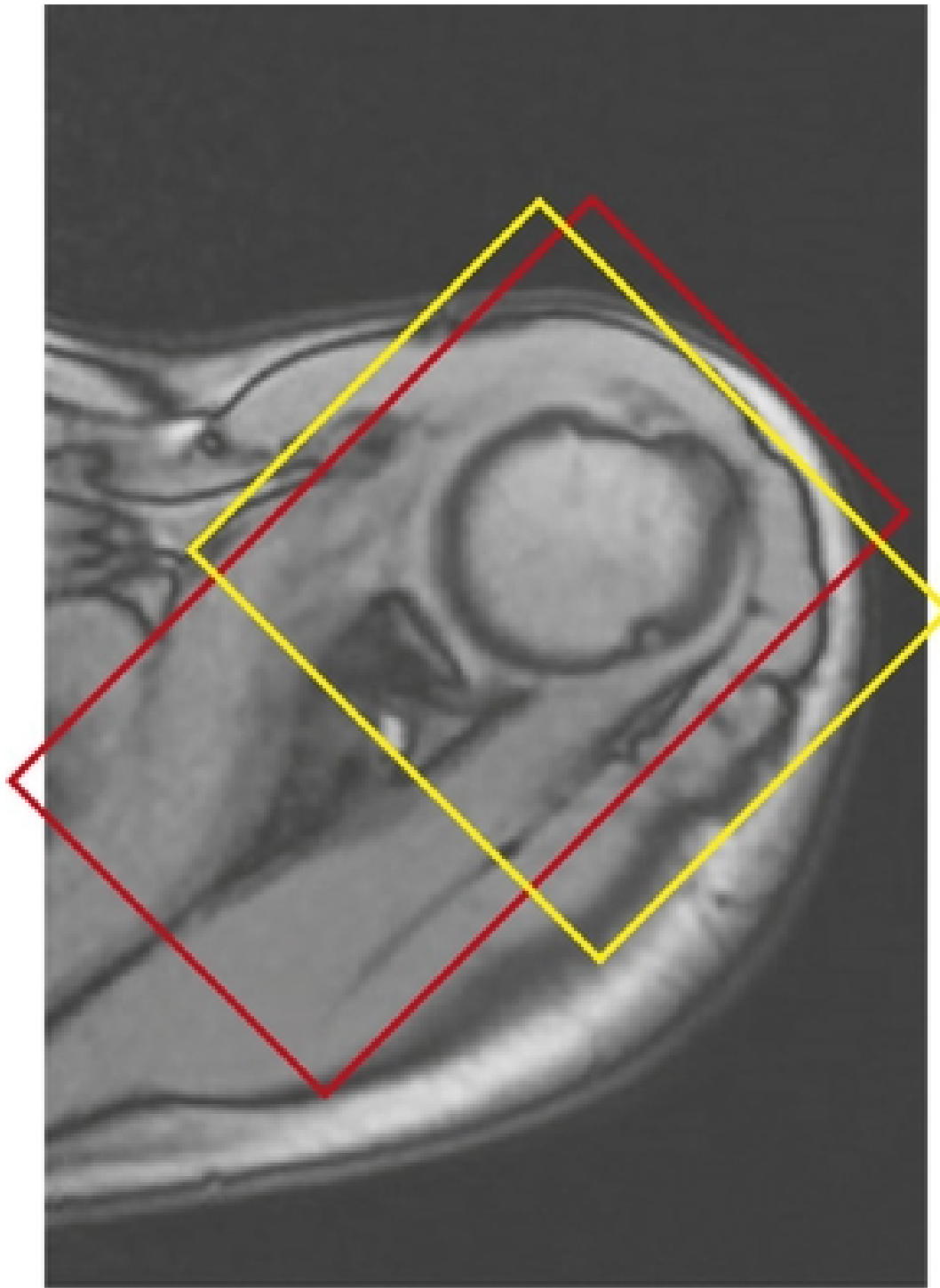


Fig. 2.22b [📄](#)



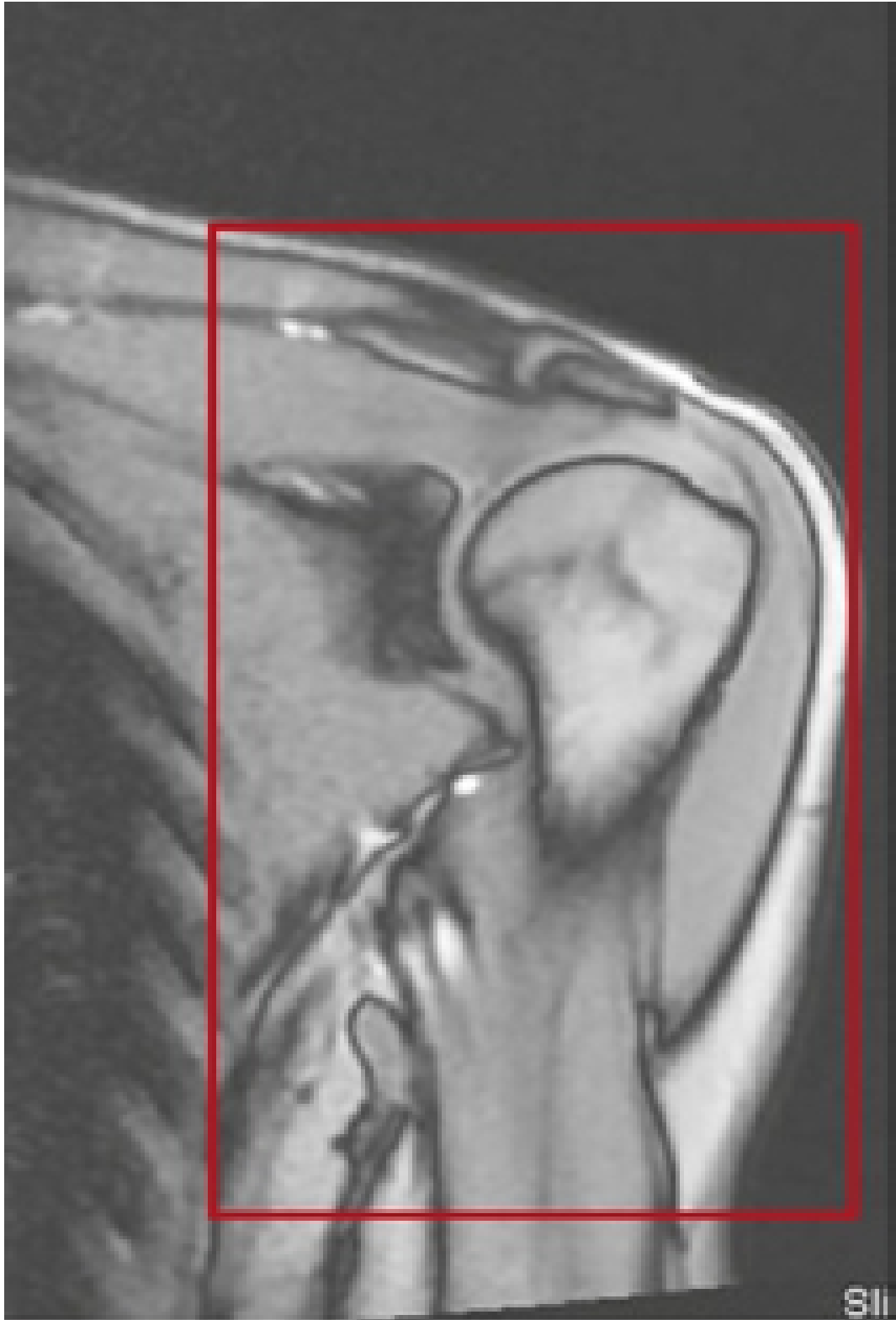


Fig. 2.22c [c](#)

Planning axial sequence: plan the axial slices on a coronal image and angle perpendicular to the glenohumeral joint. Check the block in the other two planes, ensuring an appropriate angle in the sagittal plane perpendicular to the head of humerus. Slices should cover from the acromioclavicular joint to below the glenohumeral joint ([Fig. 2.22c](#)).

Planning coronal sequence: plan on an axial image and angle the block parallel to the supraspinatus tendon (see [Fig. 1.2e](#)). Check the block in the other two planes, ensuring an appropriate angle in the sagittal plane parallel to the humerus. Slices should cover the entire joint from the coracoid process to posterior to the head of humerus (red box in [Fig. 2.22b](#)).

Planning sagittal sequence: plan on an axial image and angle the block perpendicular to the supraspinatus tendon (yellow box in [Fig. 2.22b](#)). Check the block in the other two planes, ensuring an appropriate angle in the coronal plane parallel to the humerus ([Fig. 2.22a](#)). Slices should include the entire shoulder joint.

The addition of a saturation band may aid in minimising the effect of breathing artefact.

Example sequences: shoulder						
Routine	3 plane localiser	Ax T1	Ax T1 STIR	Sag T2 FS	Sag T1	Cor T2
Additional	Ax T1 FS pre-contrast Ax T1 FS and Sag FS T1 post-contrast					

Acquired Images: Examples ([Fig. 2.23a](#), [Fig. 2.23b](#) and [Fig. 2.23c](#))

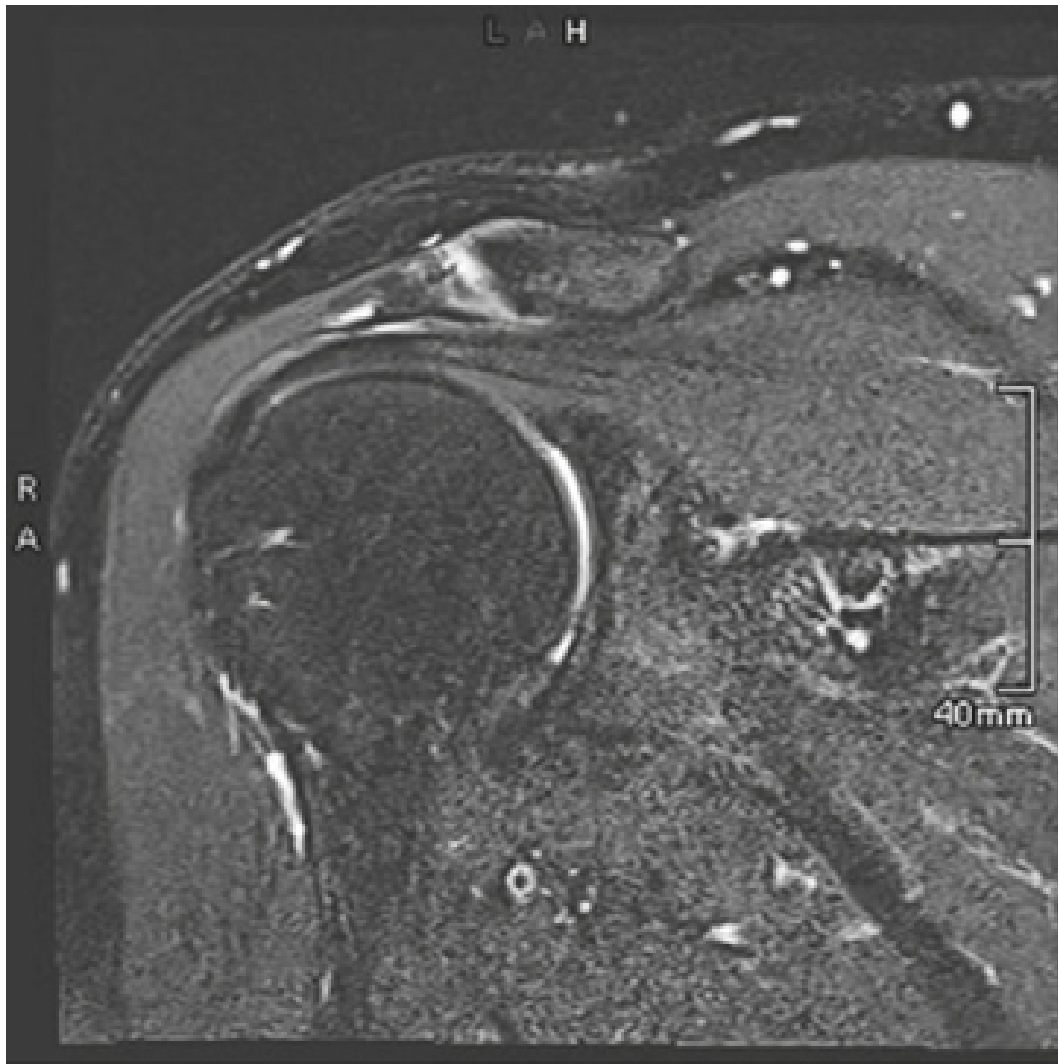


Fig. 2.23a Example coronal STIR. [🔗](#)



Fig. 2.23b T2 gradient echo, water excitation axial image. [📄](#)



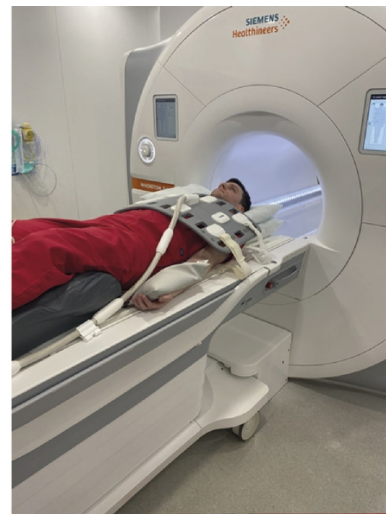
Fig. 2.23c Example coronal T1. [🔗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection is indicated for all standard shoulder imaging where there is suspected neoplasm or investigation of swelling. For the investigation of labral/cuff tears or instability, an arthrogram may be required (see [Section 3](#): an arthrogram involves the injection of gadolinium into the joint capsule of the shoulder joint under fluoroscopy guidance, followed by an MRI scan).
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.24a, b](#))



Figs. 2.24a and b A flexible coil is used in a patient who is unable to tolerate positioning in the dedicated shoulder coil due to pain. This is also a useful technique in a patient with large body habitus. [📄](#)

When it is not possible to position in a dedicated shoulder coil, the body array or a large flexible coil can be placed over the affected side. Every effort must be made to ensure that the shoulder that is being scanned is as far away from the side of the scanner as possible, as this can create an edge-of-field artefact, rendering the images non-diagnostic. This is especially relevant for FS sequences.

BREAST

MRI is a well-established method in breast imaging, with many clinical applications, including the non-invasive differentiation between benign and malignant breast lesions, preoperative staging, detection of scar tissue versus recurrence, implant assessment and the evaluation of high-risk patients. At present, dynamic contrast-enhanced MRI is the most sensitive imaging technique for breast cancer diagnosis. It has excellent specificity while preserving its sensitivity along with additional functional parameters such as DWI and apparent diffusion coefficient mapping, MR spectroscopic imaging has been investigated and implemented into the clinical routine. MRI is the most sensitive imaging modality used for looking at the anatomy of the breast. It is the ultimate supplementary imaging modality in addition to mammography and ultrasound. Screening breast with MR has shown increased sensitivity rates in the detection of lesions. MR has the ability to pinpoint smaller nodules that cannot be visualised using alternative modalities.

Indications

The most common indication is cancer extent/progression after a positive biopsy.

- Dense breasts that are difficult to assess on mammogram
- Inflammatory change
- Unexplained swelling of breast with negative mammography/ultrasound
- Chemotherapy response
- To check for residual disease after a lumpectomy
- Post-operative reconstruction
- High-risk patients for surveillance purposes

- To assess the stability of silicone implants/rupture
- Patients with nipple discharge with inconclusive findings from other modalities

Imaging Procedure ([Fig. 2.25](#))



Fig. 2.25 Standard positioning. [📄](#)

- Position the patient head-first prone.
- Position the patient's breast tissue in the dedicated breast coil.
- Use cushions and pads as appropriate to ensure the patient's breasts remain still throughout the scan.
- Centre for the localiser with the laser light over the centre of the shoulder blades.
- Both breasts will be scanned as part of a standard MRI examination.

Sequence Planning ([Fig. 2.26a](#), [Fig. 2.26b](#) and [Fig. 2.26c](#))



Fig. 2.26a [🔗](#)

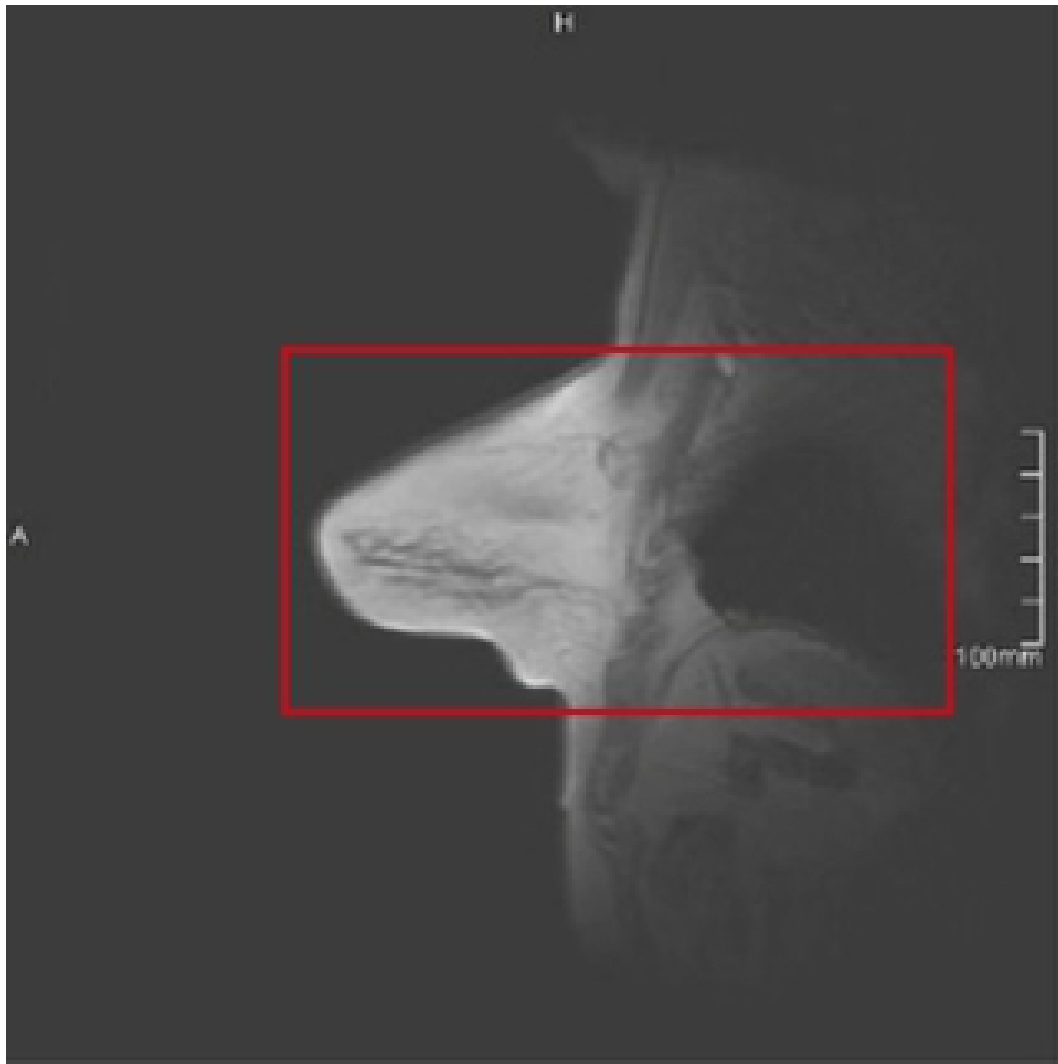


Fig. 2.26b [🔗](#)



Fig. 2.26c [↗](#)

Planning axial sequence: plan using the sagittal images aligning the block parallel to both breasts. Verify positioning in the other two planes, ensuring the coronal angle is parallel to the nipples ([Fig. 2.26b](#)).

Planning coronal sequence: plan on axial images and angle the block horizontally to the breasts ([Fig. 2.26a](#)). Verify positioning in the other two planes, ensuring the block is perpendicular to the breast in the sagittal

plane. Phase direction should be right to left to minimise artefact from cardiac motion ([Fig. 2.26c](#)).

Planning sagittal sequence: plan using the axial images and angle slices parallel to the breast. In the coronal plane ensure that the block is angled vertically through the breasts. Ensure phase direction is head to foot to minimise artefact from chest and cardiac motion.

Ensure field of view (FOV) is adequate to cover the breasts and axillary lymph nodes.

Example sequences: breast lesion protocol						
Routine	3 plane localiser	Ax T2	Ax T1	Ax T2 SPAIR	Ax T1 SPAIR	Cor T1 SPAIR
Post-contrast	Cor T1 SPAIR	Dynamic Ax T1 SPAIR subtraction scan				
Example sequences: implant protocol						
Routine	3 plane localiser	Ax T1	Ax T2	Ax STIR watersat silicone sequence	t RT and LT Sag STIR watersat silicone sequence	

SPAIR, spectral attenuated inversion recovery.

Acquired Images: Examples ([Figs. 2.27a, b](#))

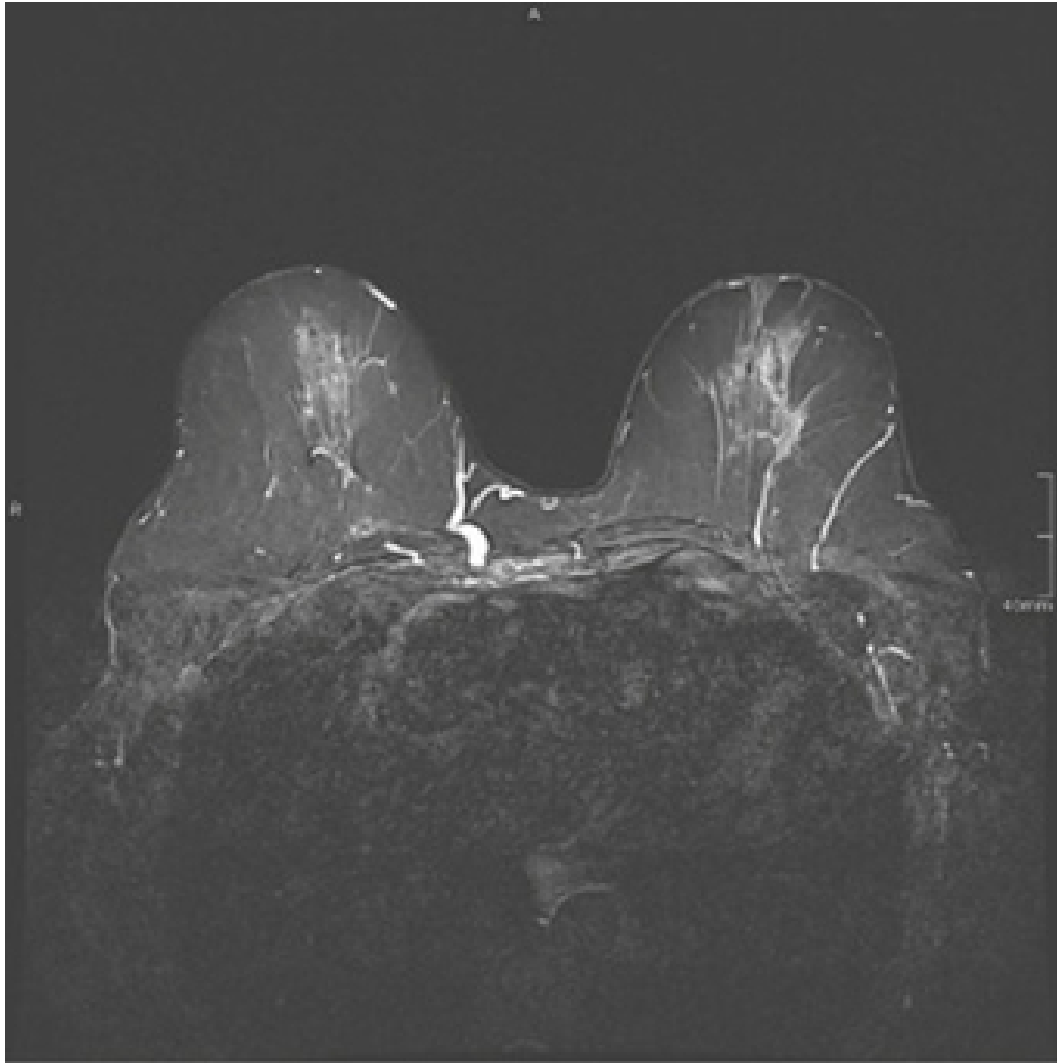


Fig. 2.27a Example axial image through both breasts. It is important in the axial planes to include the axilla within the FOV, to allow assessment of the axillary lymph nodes. [↗](#)



Fig. 2.27b Example of post-contrast axial breast image. [📄](#)

Contrast Medium and Injection Data

- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Intravenous contrast enhancement (if indicated in protocol)

- Contrast is indicated in most breast imaging, as it aids with the detection and characterisation of breast lesions. It is especially the case for patients in whom mammography and ultrasound may not have provided sufficient information.
- Dynamic contrast using an injector pump is recommended at a flow rate of 1–2 mL/sec.
- Tracking the contrast uptake and washout over a series of dynamic sequential images can differentiate between benign and malignant lesions.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques

The reasons why adaptive technique needs to be considered include body habitus, difficulty lying prone and breathing difficulties; however, due to the sensitive nature and pinpoint accuracy required when imaging the breast adaptive technique is rarely, if ever, used. It may be possible if the patient is small enough to lie laterally to acquire images using a flexible coil wrapped across the chest, but images would be suboptimal due to the fact the breast tissue is not in a prone position.

SOFT TISSUE NECK

MRI is used in imaging the neck to evaluate extracranial nervous system anatomy to aid diagnosis of infection and inflammatory conditions in the vertebra and surrounding tissues. It allows characterisation of a variety of soft tissue lesions found in the neck, allowing diagnosis of pathologies with clear evaluation of anatomy in relation to surrounding nerves and other structures. MRI is seen by clinicians as essential for pre-surgery planning and as with other modalities such as CT and positron emission (PET)-CT, is

used in oncology staging to define the extent of a primary tumour, to assess for recurrence and in the assessment of metastatic disease (3–5).

Indications

- Oncology staging/treatment planning/follow-up post-treatment
- Trauma
- Upper airway obstruction/altered swallow sensation
- Vocal cord paralysis
- Soft palate changes
- Soft tissue swelling/mass/lump

Imaging Procedure ([Fig. 2.28](#))



Fig 2.28 Standard positioning. [📄](#)

- Position the patient head-first supine in the head and neck coil
- Place extra padding around the head if needed to ensure comfort and to immobilise the patient.
- Place cushion under the knees to maximise comfort.
- Centre for the localiser with the laser light mid-neck, approximately 1 cm below the chin.

Explain to the patient the importance of trying not to swallow or cough during scan acquisition.

Sequence Planning ([Fig. 2.29a](#), [Fig. 2.29b](#) and [Fig. 2.29c](#))



Fig. 2.29a [📄](#)

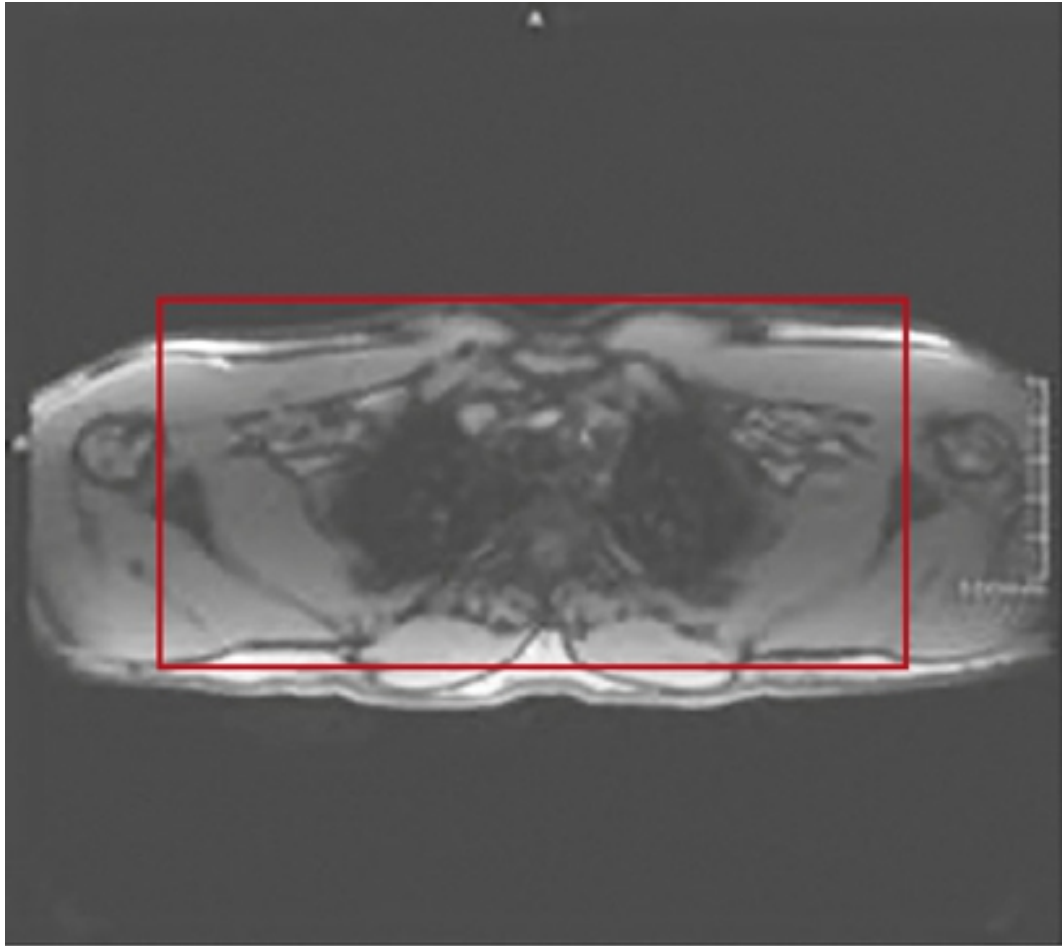


Fig. 2.29b [↗](#)

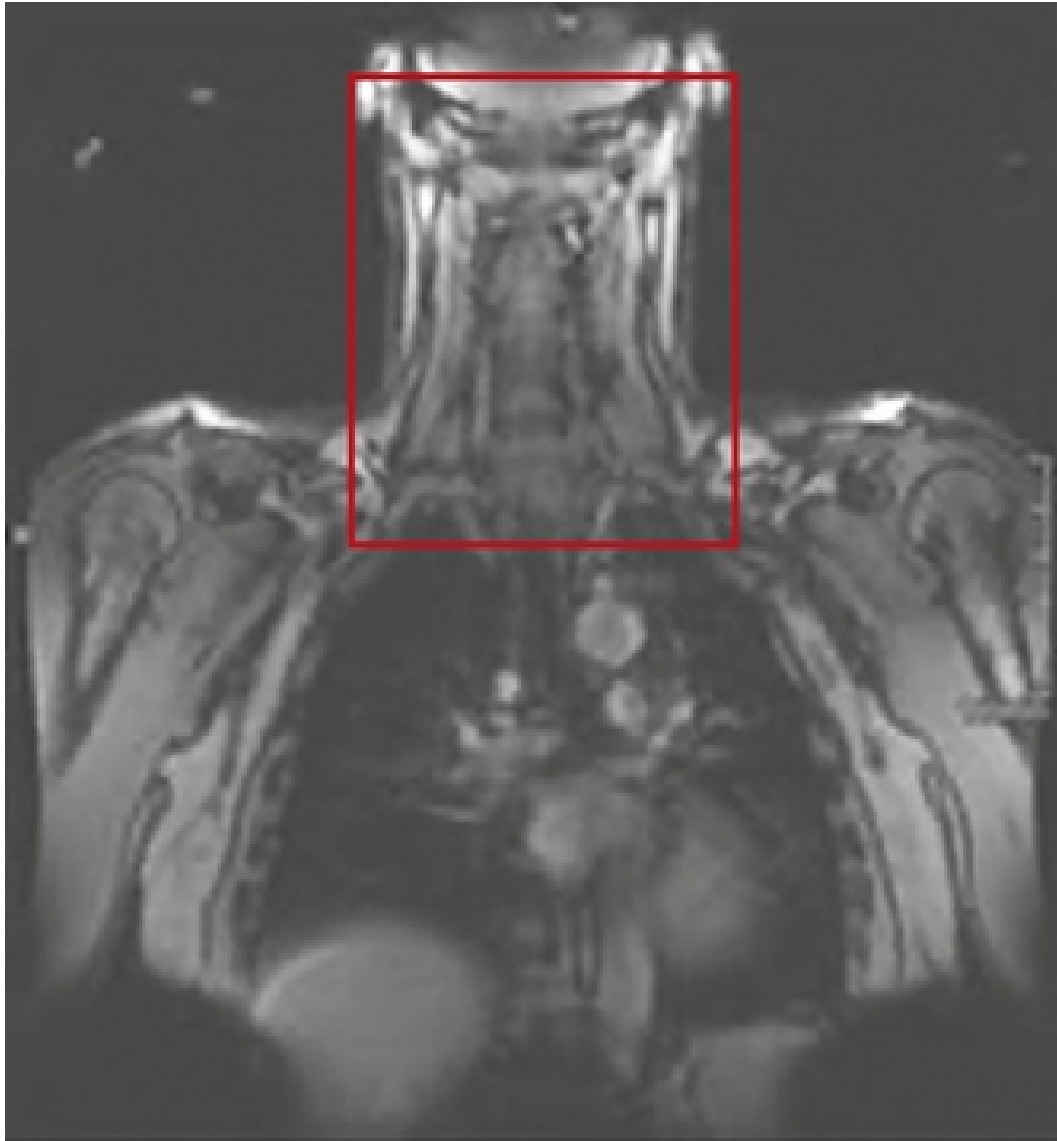


Fig. 2.29c [c](#)

Planning coronal sequence: angle slices parallel to the spinal cord covering from the tip of nose to the posterior aspect of the spinal processes. Cover from the frontal sinus to the clavicle ([Fig. 2.29a](#)). Check slices are horizontal in the coronal plane and ensure all soft tissues are covered ([Fig. 2.29b](#)).

Planning the axial sequence: angle the block horizontally on a sagittal image, parallel to the hard palate, covering from the frontal sinus to the

clavicle ([Fig. 2.29a](#)).

Planning sagittal sequence: angle parallel to the spinal cord on a coronal image ([Fig. 2.29c](#)).

The addition of a saturation band may aid in minimising the effect of breathing artefact.

Example sequences: soft tissue neck						
Routine	3 plane localiser	Cor T1	Cor T2 STIR	Ax T2 whole neck	Ax T2 STIR whole neck	Ax T1 whole neck
Additional	Sag T2 SPAIR if lesion is midline	Ax T2 SPAIR if lesion is identified	Ax T1 FS pre- contrast	Cor and Ax T1FS pre- and post-contrast		

Acquired Images: Examples ([Fig. 2.30a](#), [Fig. 2.30b](#) and [Fig. 2.30c](#))



Fig. 2.30a Example of a coronal STIR soft tissue neck image. [↗](#)

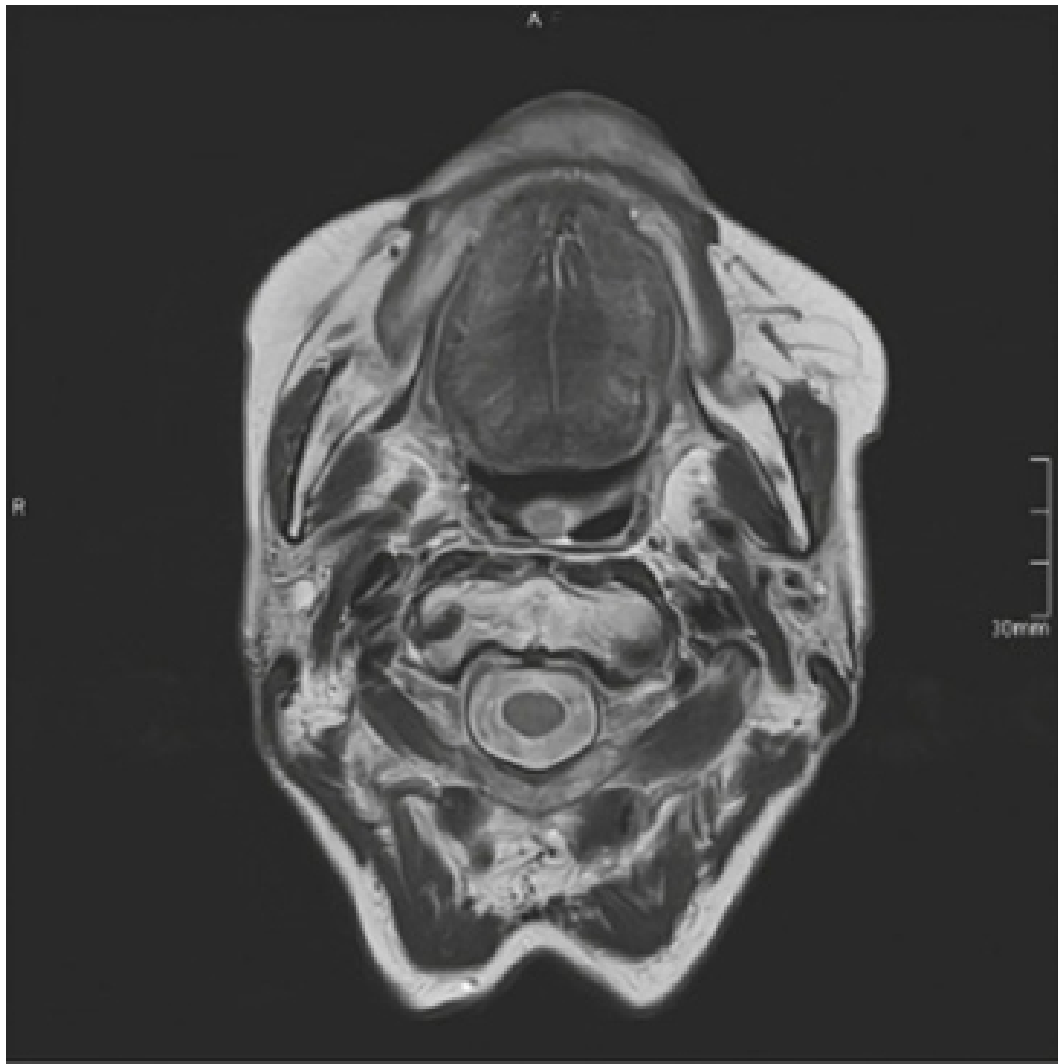


Fig. 2.30b Example of a T1 axial soft tissue neck image. [↗](#)



Fig. 2.30c Example of a T2 sagittal soft tissue neck image. [↗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard neck imaging is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.31a](#), [Fig. 2.31b](#) and [Fig. 2.31c](#))



Fig. 2.31a Anterior coils have been removed in a patient who cannot tolerate the head coil and a flexible coil has been placed across the neck. Images will be acquired with the posterior head and neck coils and the anterior flexible coil. [↗](#)



Fig. 2.31b Anterior coils have been removed in a patient with severe claustrophobia. Images will be acquired using the posterior coils only. This will affect image quality, but the resultant images may provide the clinician with enough information to make a diagnosis. For this reason, this should be used as a last resort when other alternative coils have been tried. [📄](#)



Fig. 2.31c Use of a tilted head and neck coil on a modern scanner in a patient who is unable to lie flat.[\[4\]](#)

Patients suffering from extreme claustrophobia may not be able to tolerate the anterior portion of head coil, or the neck coil to be placed across their head and neck. It may not be possible to position some patients due to physical limitations such as severe kyphosis, if they are experiencing pain when lay flat, or due to large body habitus.

When the patient cannot be positioned in the dedicated head and neck coil then the below alternatives can be used.

UPPER ABDOMEN: KIDNEYS AND ADRENALS

Whilst CT is the preferred diagnostic test for renal imaging, MRI is often used as an alternative when iodinated contrast is contraindicated due to allergy or poor renal function, or where characterisation of complicated renal lesions is required. Non-contrast MRI is the best non-invasive

modality in the detection and characterisation of many diseases of the kidneys and adrenal glands ([6](#)). In and out of phase T1-weighted imaging is valuable in distinguishing between benign adenomas and malignant masses, and T2-weighted sequences are sensitive in the investigation of tumours such as renal cell carcinoma and pheochromocytoma ([7](#)). Contrast-enhanced MRI allows functional assessment by providing dynamic evaluation of tissue perfusion ([8](#)).

Indications

- Adrenal adenomas and tumours
- Investigation of hormonal imbalances
- Haematuria
- Assessment of known malignant and benign renal lesions
- Assessment of polynephritis and kidney disease

Imaging Procedure ([Fig. 2.32](#))

- Position the patient head-first supine with arms by side.
- Place body array over abdomen from the middle of the sternum down to the anterior superior iliac spine.
- Use cushions and pads as appropriate to ensure legs and elbows are comfortable.
- Centre for the localiser with the laser light over the middle of the body array.



Fig. 2.32 Standard positioning. [🔗](#)

Sequence Planning ([Fig. 2.33a](#), [Fig. 2.33b](#) and [Fig. 2.33c](#))

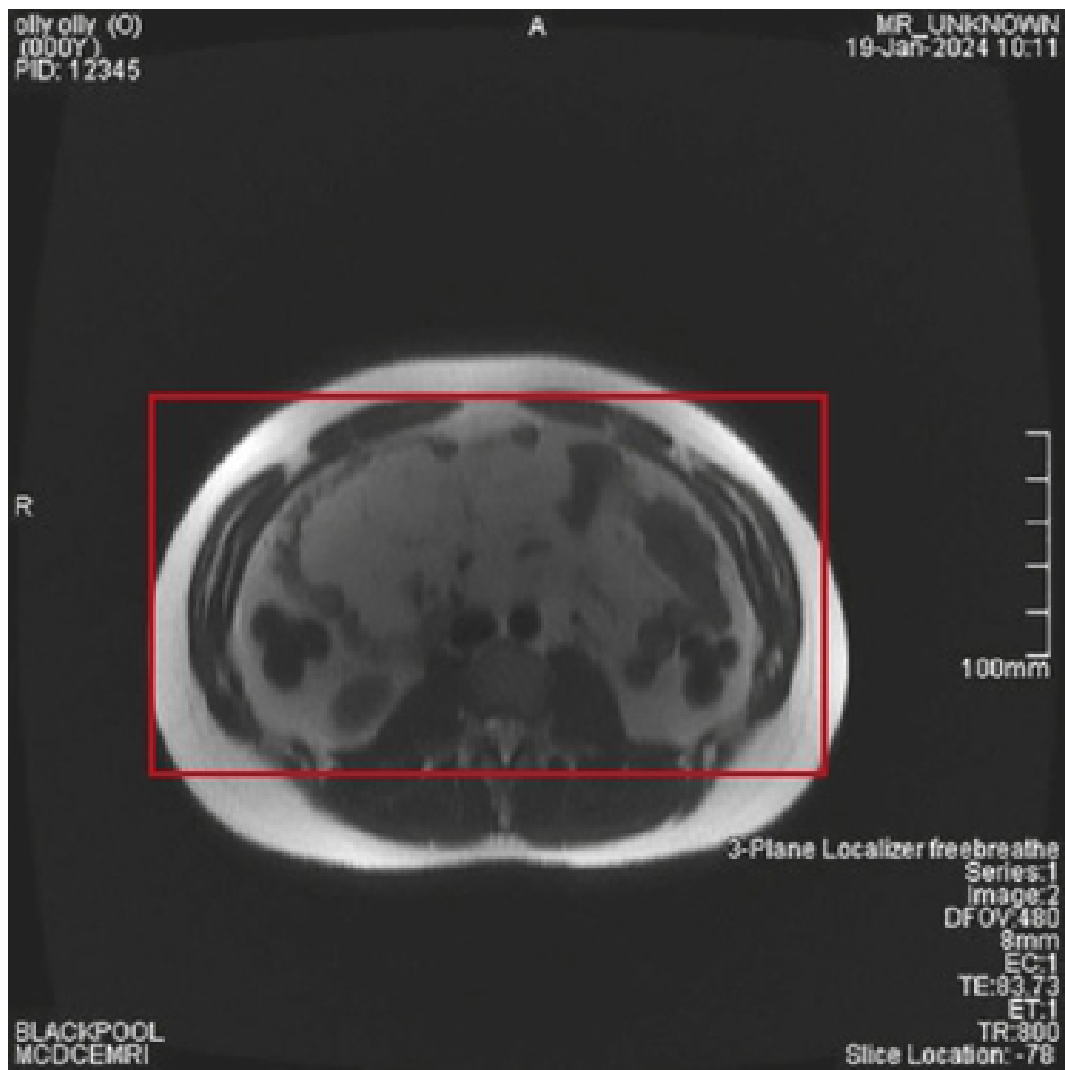


Fig. 2.33a



Fig. 2.33b

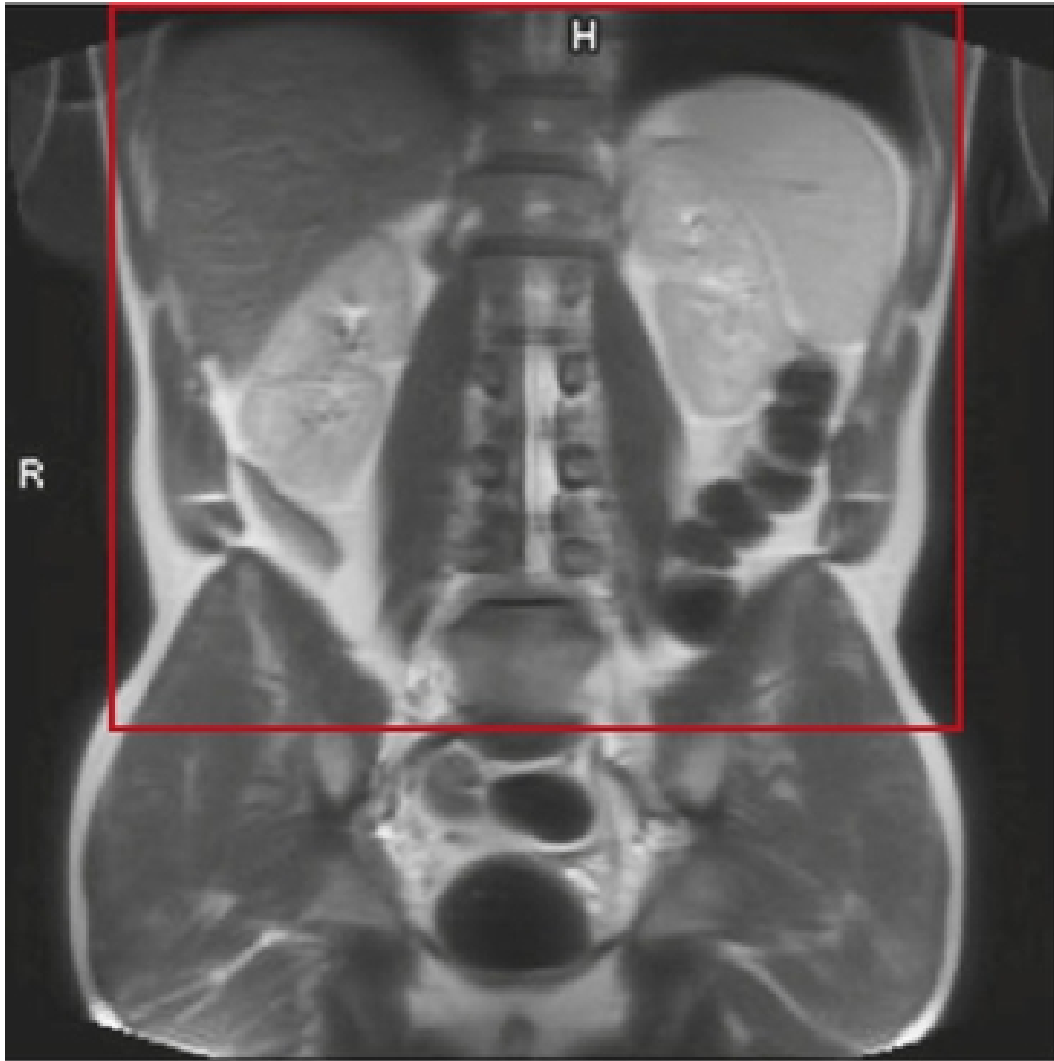


Fig. 2.33c

Planning coronal sequence: angle on an axial image parallel to midline along right and left kidneys. In the sagittal plane angle the slices along the long axis of the kidney ([Fig. 2.33a](#)). Ensure slices cover both kidneys.

Planning axial sequence: angle on the coronal image so that the slices are perpendicular to the thoracic vertebra ([Fig. 2.33c](#)). In the sagittal plane angle the block perpendicular to the long axis of the kidney ([Fig. 2.33b](#)).

Example sequences: kidneys/adrenals
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Example sequences: kidneys/adrenals	
Routine	3 plane localiser Cor T2 HASTE Ax T2 HASTE Cor FS T2 HASTE thick slab Ax T2 STIR Ax in and out of phase Cor VIBE FS
Additional contrast enhanced	Ax T1 at 30 sec/60 sec/120 sec/5 min/10 min post-contrast
Additional for urography	Empty bladder prior to the start of the scan Large FOV Post-contrast scans Cor VIBE FS sequence at 5 and 10 min

VIBE, volume interpolated breath-hold examination.

Acquired Images: Examples ([Figs. 2.34a, b](#))



Fig. 2.34a Example of a T2 axial image of the kidneys. [↗](#)



Fig. 2.34b Example of a true fast imaging with steady-state free procession (FISP) coronal image of the kidneys. [📄](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in the protocol)

- Dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended in abdominal imaging.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

UPPER ABDOMEN: LIVER, PANCREAS AND BILIARY TREE

MRI is used in liver and pancreas imaging to demonstrate anatomy in high detail and gives excellent tissue contrast. Liver MRI is recommended to provide accurate staging following standard CT scan where indeterminate lesions of the liver and pancreas have been reported. The addition of DWI is useful in patients with colorectal cancer and liver diseases in order to plan treatment. When liver specific contrast agents are used in MRI there is increased sensitivity and specificity when compared with CT ([9](#)).

MR cholangiopancreatography (MRCP) sequences are heavily T2-weighted to demonstrate inherent differences in T2-weighted contrast between stationary fluid filled structures, so that static or slow moving fluids within the biliary tree and pancreatic duct appear of high signal intensity on images ([10](#)) (see [Fig. 2.37a](#)).

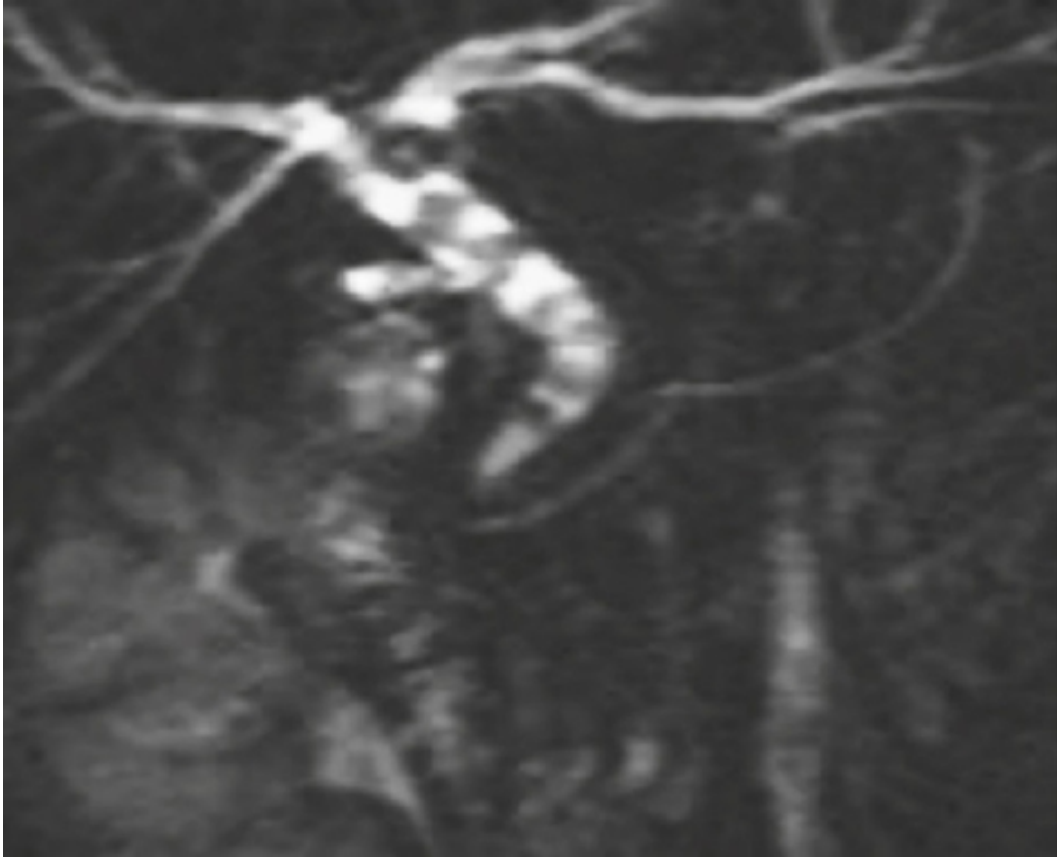


Fig. 2.37a Example of a T2 HASTE thick slab image. Multiple stones can be seen within the common bile duct. [📄](#)

Indications

Assessment of fatty liver

Assessment of iron content

Haemochromatosis

Detection of focal lesions, for example metastases, nodular hyperplasia and hepatic adenoma

Lesion characterisation

Follow-up scan/evaluation for response following treatment

Evaluation of vascular structures

Biliary stones or obstruction

Imaging Procedure ([Fig. 2.35](#))

- Position the patient headfirst supine with a body array over the abdomen; the top of the coil should be level with the armpit.
- Place padding under the knees and elbows to ensure comfort and to immobilise the patient and maximise comfort.
- Centre for the localiser with the laser light over the mid-abdomen.



Fig. 2.35 Standard positioning. [📄](#)

Sequence Planning: MRCP ([Fig. 2.36a](#), [Fig. 2.36b](#) and [Fig. 2.36c](#))

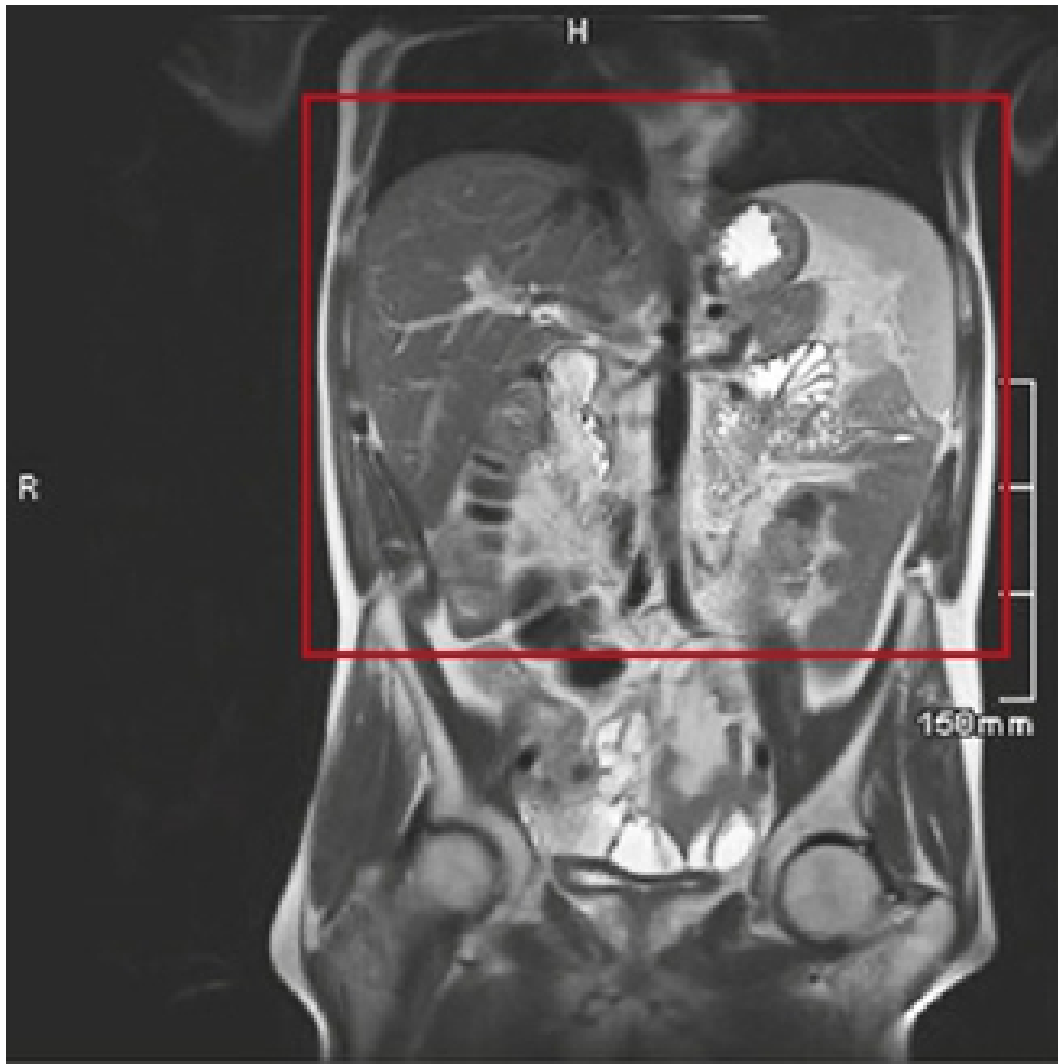


Fig. 2.36a [📄](#)



Fig. 2.36b [↗](#)

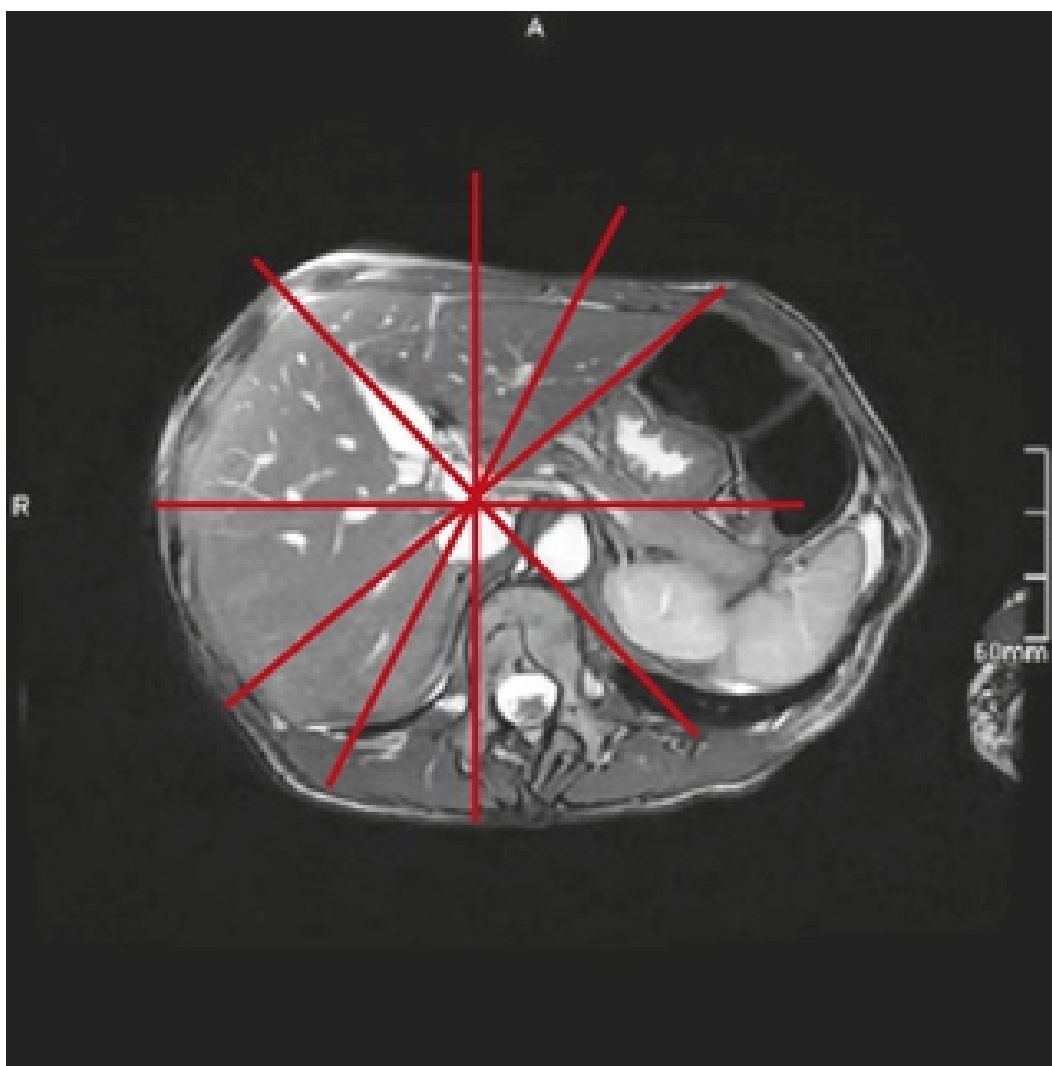


Fig. 2.36c

Planning coronal sequence: angle slices on the axial image covering the whole of the liver. In the sagittal plane, align slices vertically across the liver ([Fig. 2.36a](#)).

Planning axial sequence: plan image with slices horizontal to the liver on a coronal image. In the sagittal plane, align slices horizontally across the liver ([Fig. 2.36b](#)). Ensure the whole liver is covered and that phase direction is anterior–posterior.

Coronal oblique radial slices: plan the thick T2 HASTE slabs on an axial image, positioning the centre of the slab over the common bile duct.

Check positioning in the other two planes ([Fig. 2.36c](#)).

T2 3D-triggered sequence: review the coronal oblique thick slabs and copy the angle that best demonstrated the common bile duct and pancreatic duct. Ensure the slab covers the whole of the common bile duct and pancreatic duct. Position respiratory navigator boxes as per scanner manufacturer instructions.

Example sequences: MRCP

- 3 plane localiser
- Cor T2 TRUFI
- Ax T2 HASTE
- Ax T1 in and out of phase
- Cor T2 Fat-sat thick slabs $\times 6$
- Ax T2 HASTE thin slices centred over junction of common bile duct/pancreatic duct
- T2 Space-triggered sequence

TRUFI, true fast imaging with steady-state precession.

Acquired Images: MRCP ([Figs. 2.37a, b](#))



Fig. 2.37b Example of a T2 FS axial image of the common bile duct. [🔗](#)

Sequence Planning: Liver ([Fig. 2.38a](#), [Fig. 2.38b](#) and [Fig. 2.38c](#))

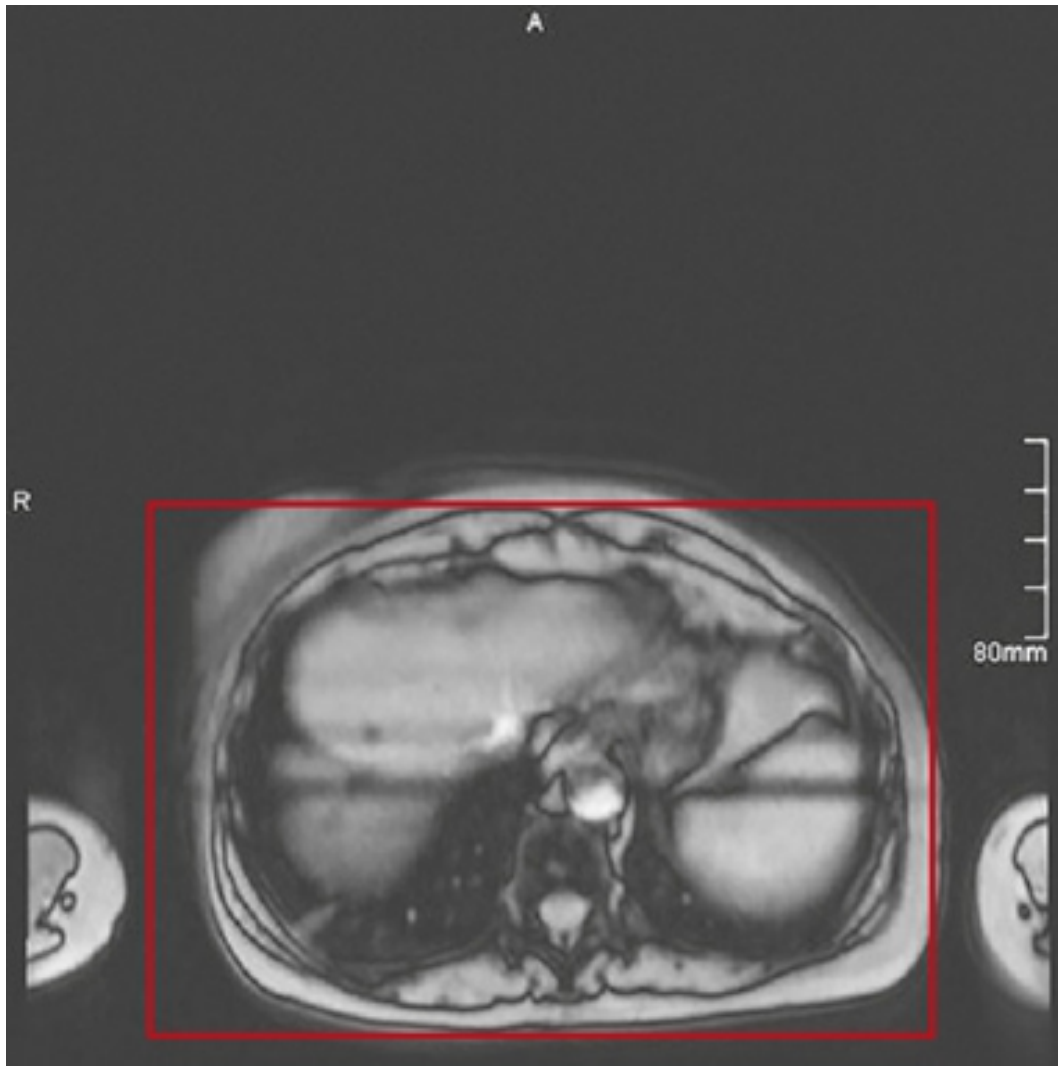


Fig. 2.38a [📄](#)

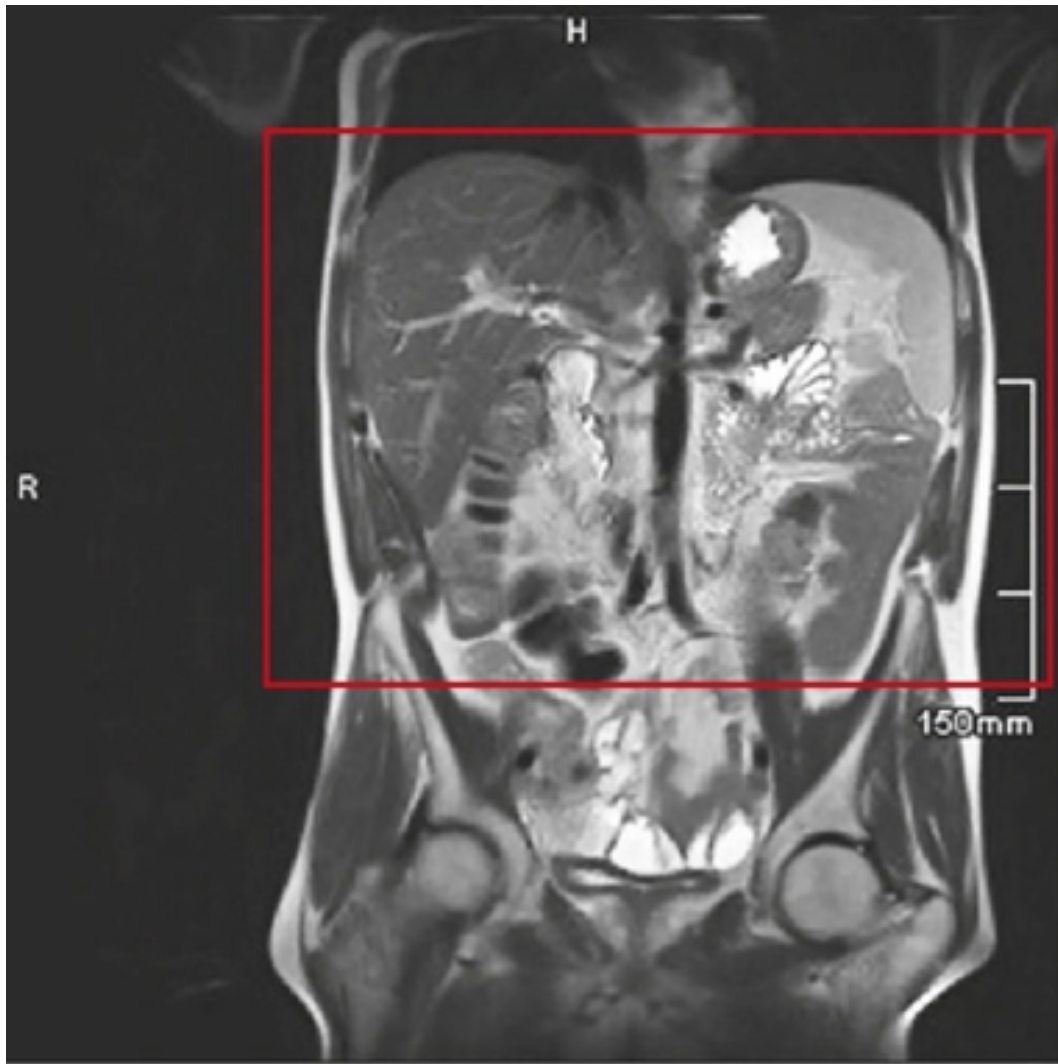


Fig. 2.38b [↗](#)

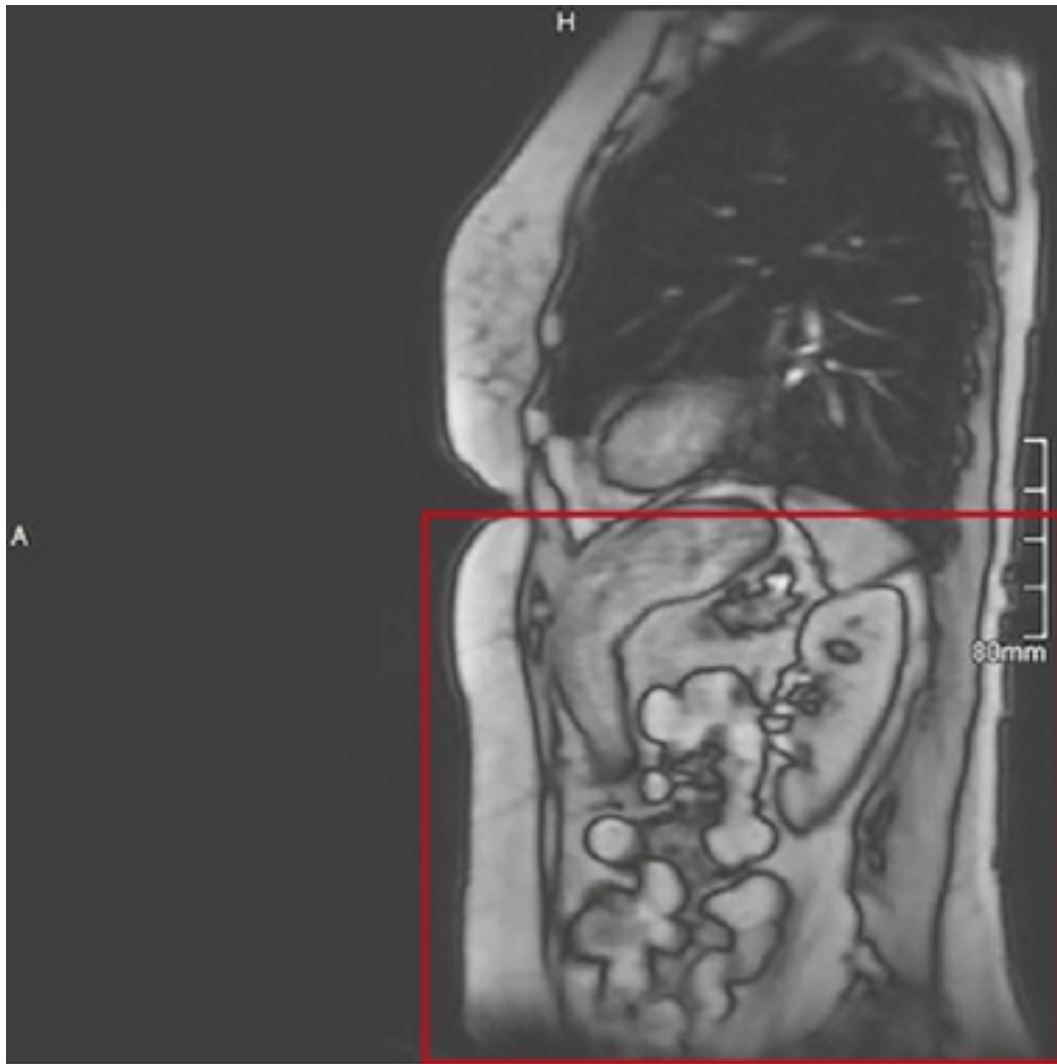


Fig. 2.38c

Planning axial sequence: angle slices on the coronal image in an axial plane horizontally across the liver. In the sagittal plane align slices vertically across the liver. Ensure the whole of the liver is covered ([Fig. 2.38a](#), [Fig.39](#) and [Figure c](#)).

Planning coronal sequence: plan horizontally across the liver on an axial image. In the sagittal plane align slices vertically across the liver. Ensure the whole of the liver is covered.

Planning bolus track: for dynamic contrast sequences plan over the aorta, ensuring the slice is angled parallel to the aorta in the sagittal plane

([Fig. 2.39a](#)).

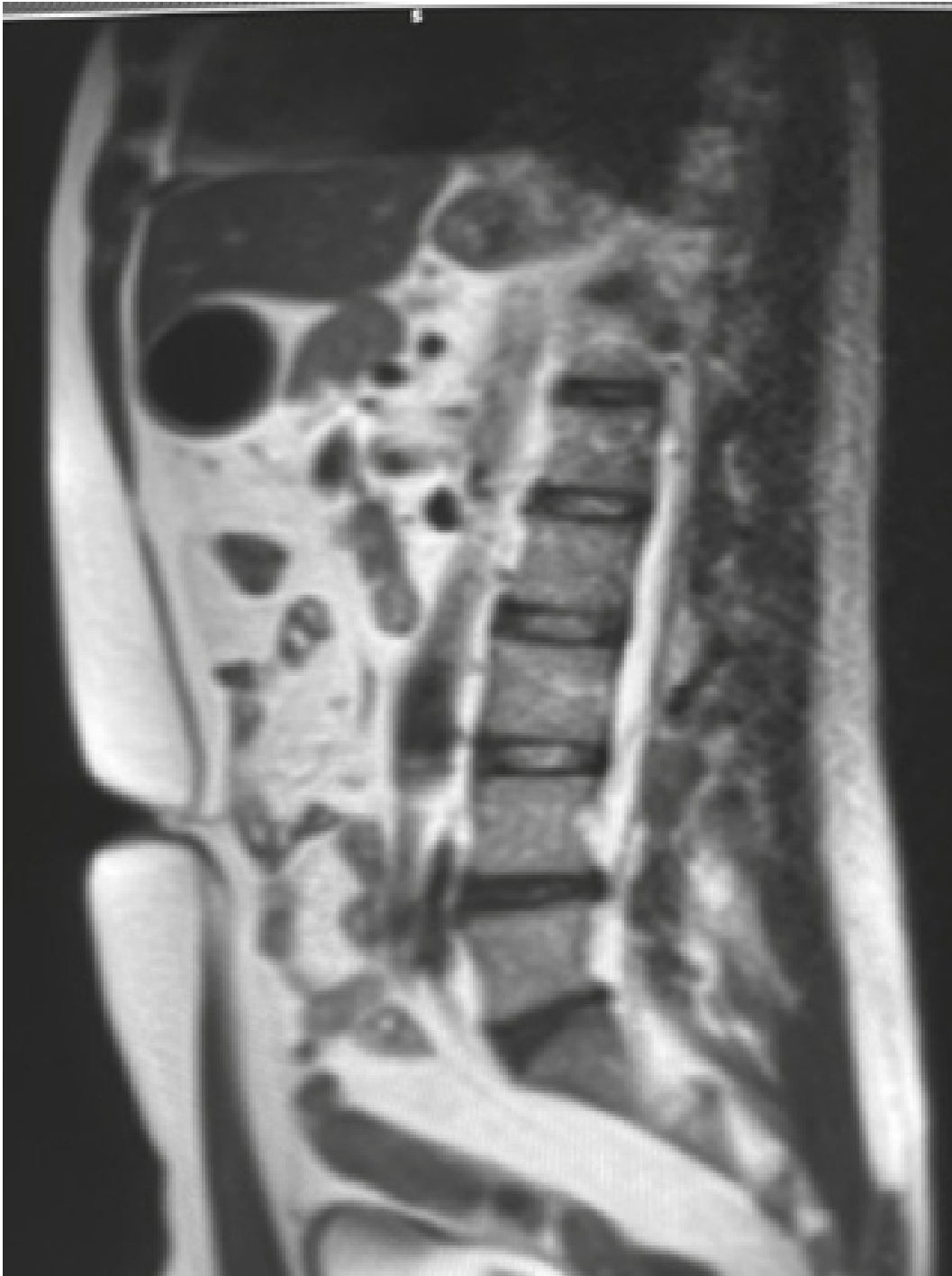


Fig. 2.39a Example of sagittal localiser image demonstrating the aorta. For bolus track planning this can be used to ensure the bolus track slice is angled perpendicular to the aorta. Cross-check with the upper axial slices that the bolus tracking slice falls over the aorta. [↗](#)

Example sequences: liver						
Routine	3 plane localiser	Cor T2 TRUFI	Ax T1FS VIBE	Ax T1 FS CAIPIR-INHA	DWI (copy axial to T2 slice positions)	Ax HASTE low and high TE
Additional post-contrast	Ax T1 FS VIBE at 30 sec/60 sec/120 sec/5 min/10 min post-contrast		t Ax T1 VIBE 20 min post- contrast where Gadotexate disodium has been given to classify hepatic mass lesions			
Additional pancreas	Ax FLASH 2D	Ax HASTE T2	Ax FS HASTE		Ax T1 FS VIBE at 30 sec/60 sec/120 sec/5 min/post-contrast	
Additional haemochromatosis/iron content		Ax T2 GRE	T2* multi-gradient recalled echo sequence			

Acquired Images: Liver Examples ([Figs. 2.39a, b](#))



Fig. 2.39b Example axial image through the liver. This image can be used to cross-check planning over the aorta for the bolus track contrast scan. [🔗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended in abdominal imaging.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques for Upper Abdomen ([Fig. 2.40](#))

When it is not possible to position in the standard position for the imaging of the upper abdomen due to claustrophobia then we can position the patient as shown here.



Fig. 2.40 Feet-first supine positioning in a patient who is claustrophobic. [↗](#)

SMALL BOWEL

MRI enterography has become the preferred technique for imaging of the small bowel, particularly in the adult population. It is used to investigate known or suspected bowel pathology. It is useful in the evaluation of small bowel diseases as it is less invasive than endoscopic and surgical techniques, more accessible and useful as an initial diagnostic test to provide an overview of small bowel and mesenteric anatomy. It is ideal for younger patients, as it does not have the risks associated with imaging techniques that use ionising radiation and is especially beneficial where repeated follow-up investigations are needed. With good patient preparation and scanning techniques MRI may provide similar diagnostic accuracy to intubation methods ([11](#)). As well as allowing evaluation of anatomy of the mesentery, it allows evaluation of the other organs within the abdomen and pelvis ([12](#)).

The examination involves oral ingestion of contrast, usually an hour prior to scan. Examples include Kleanprep, mannitol and water, as per a locally agreed radiologist protocol. An antispasmodic such as hyoscine butylbromide may be given to reduce bowel spasm and to minimise movement artefact caused by peristalsis on images. Dynamic contrast allows detection of inflammation and assessment of vascular structures.

Indications

- Crohn's disease
- Evaluation of small bowel benign and neoplastic lesions
- Evaluation of non-inflammatory small bowel entities such as coeliac disease
- Evaluation of mesenteric involvement in non-Hodgkin's and highgrade lymphoma

Imaging Procedure ([Fig. 2.41](#))



Fig. 2.41 Standard positioning. [📄](#)

- Oral bowel contrast media an hour prior to the start of the scan.
- Position the patient head-first prone with arms by side. Prone positioning reduces the volume of abdomen, requiring fewer slices during planning, therefore reducing breathhold duration.
- Position the body array across the abdomen, using the large flex coil as well if needed to allow coverage from the middle of the sternum to the symphysis pubis.
- Use cushions and pads as appropriate to ensure the patient is comfortable.

- Centre for the localiser with the laser light over the middle of the abdomen.

Sequence Planning ([Fig. 2.42a](#), [Fig. 2.42b](#) and [Fig. 2.42c](#))

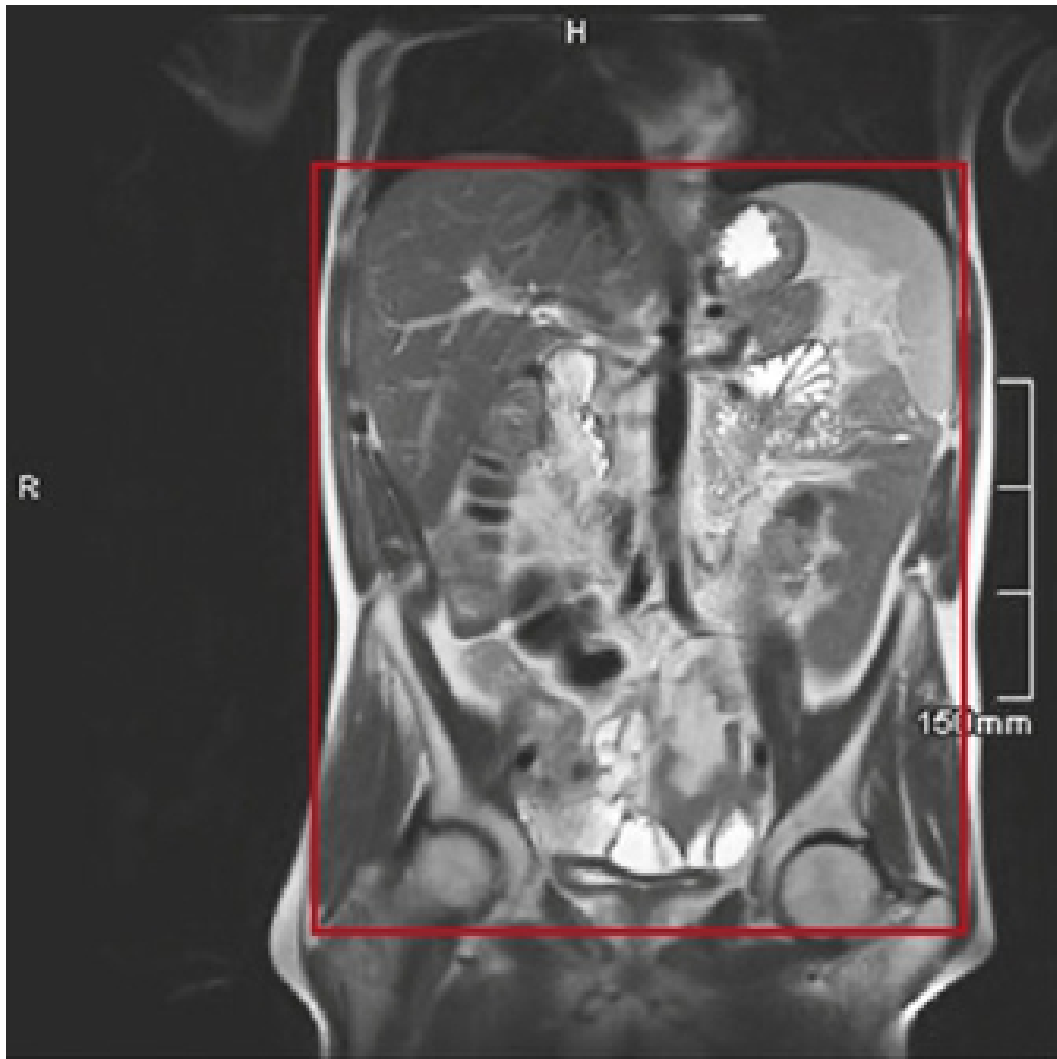


Fig. 2.42a [📄](#)



Fig. 2.42b [↗](#)

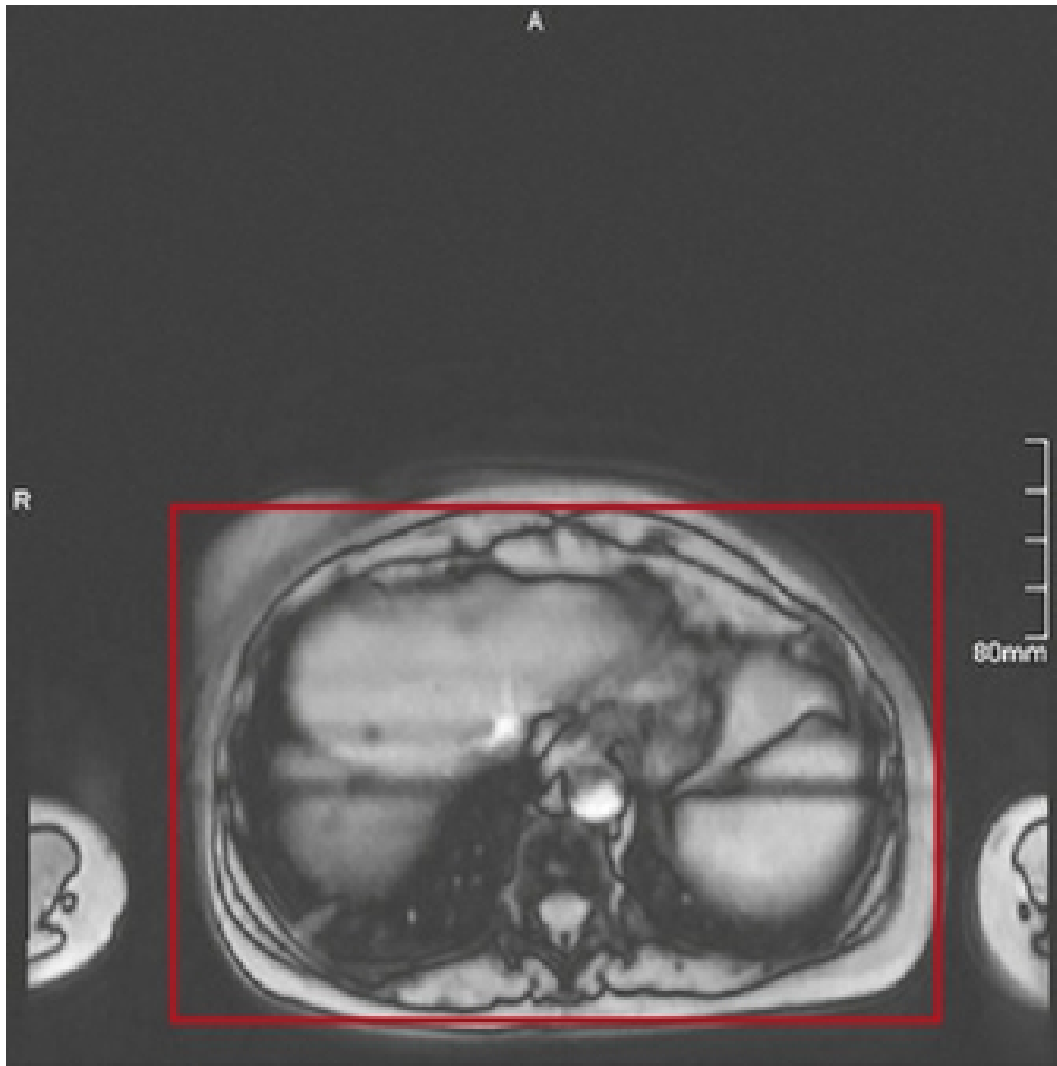


Fig. 2.42c

Planning coronal: angle the block horizontally across the abdomen on an axial image ([Fig. 2.42c](#)). Check coverage on a coronal image ([Fig. 2.42a](#)) and that the FOV is central on a sagittal image ([Fig. 2.42b](#)).

Planning axial sequence: angle the block across the abdomen on a coronal image, covering from the stomach to the pubic symphysis ([Fig. 2.42a](#)). Two blocks may be needed to cover the required anatomy if the

patient is tall. Cover from the diaphragm to the bladder to include the entire small bowel.

Example sequences: small bowel	
Routine	• 3 plane localiser • Cor T2 TRUFI • Cor T2 FS TRUFI • Ax T2 TRUFI • Assess whether oral preparation has reached the small bowel and whether it is present in the caecum. Give antispasmodics at this point if indicated in protocol • Ax HASTE • Cor HASTE • Cor HASTE FS • Ax/Cor VIBE FS pre-contrast • Ax/Cor FS VIBE 30/70/120 sec post-contrast

Acquired Images: Examples ([Fig. 2.43a](#), [Fig. 2.43b](#) and [Fig. 2.43c](#))

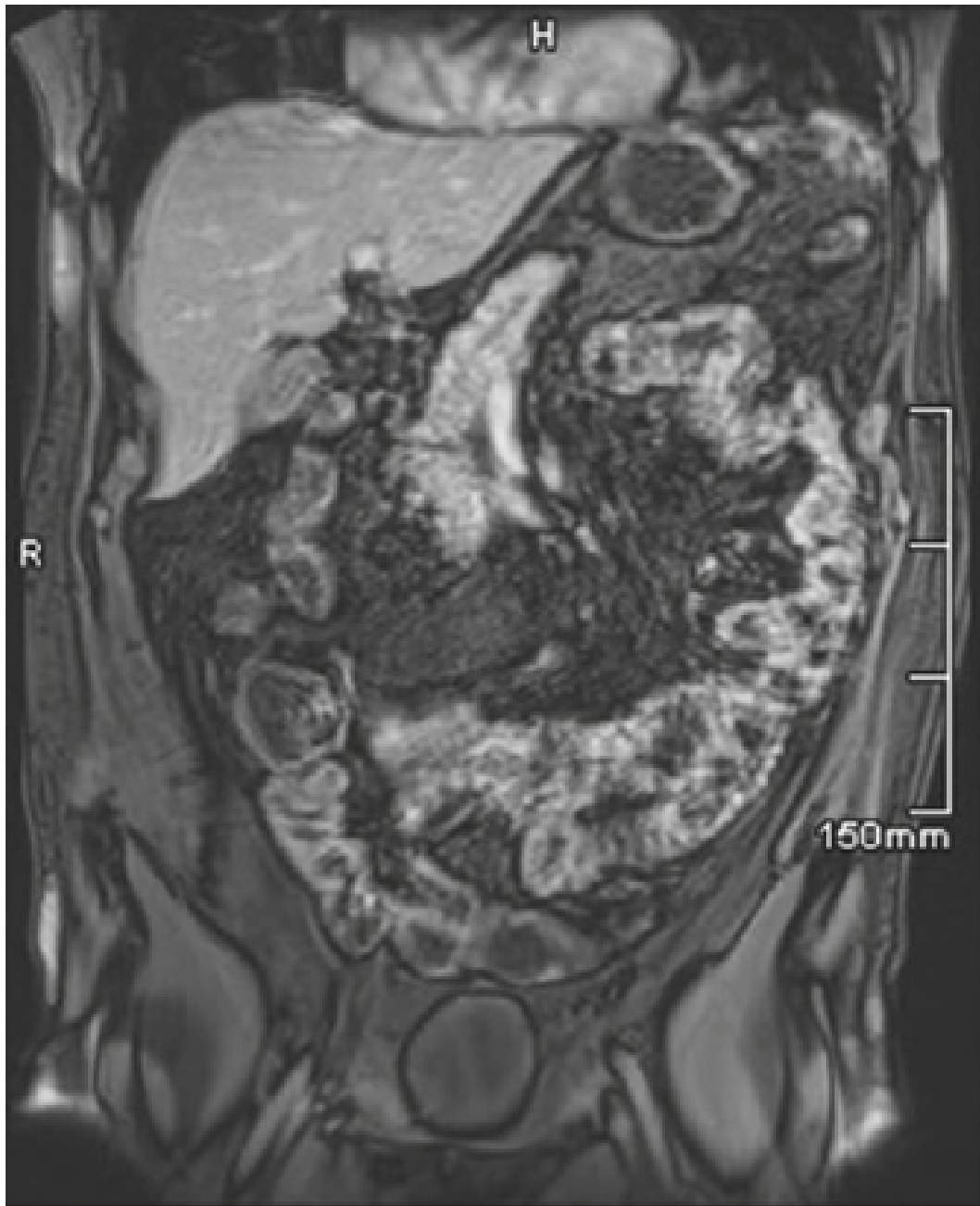


Fig. 2.43a Example of the coronal VIBE sequence. [↗](#)



Fig. 2.43b Example of a coronal image demonstrating the presence of oral contrast media in the small bowel. [↗](#)

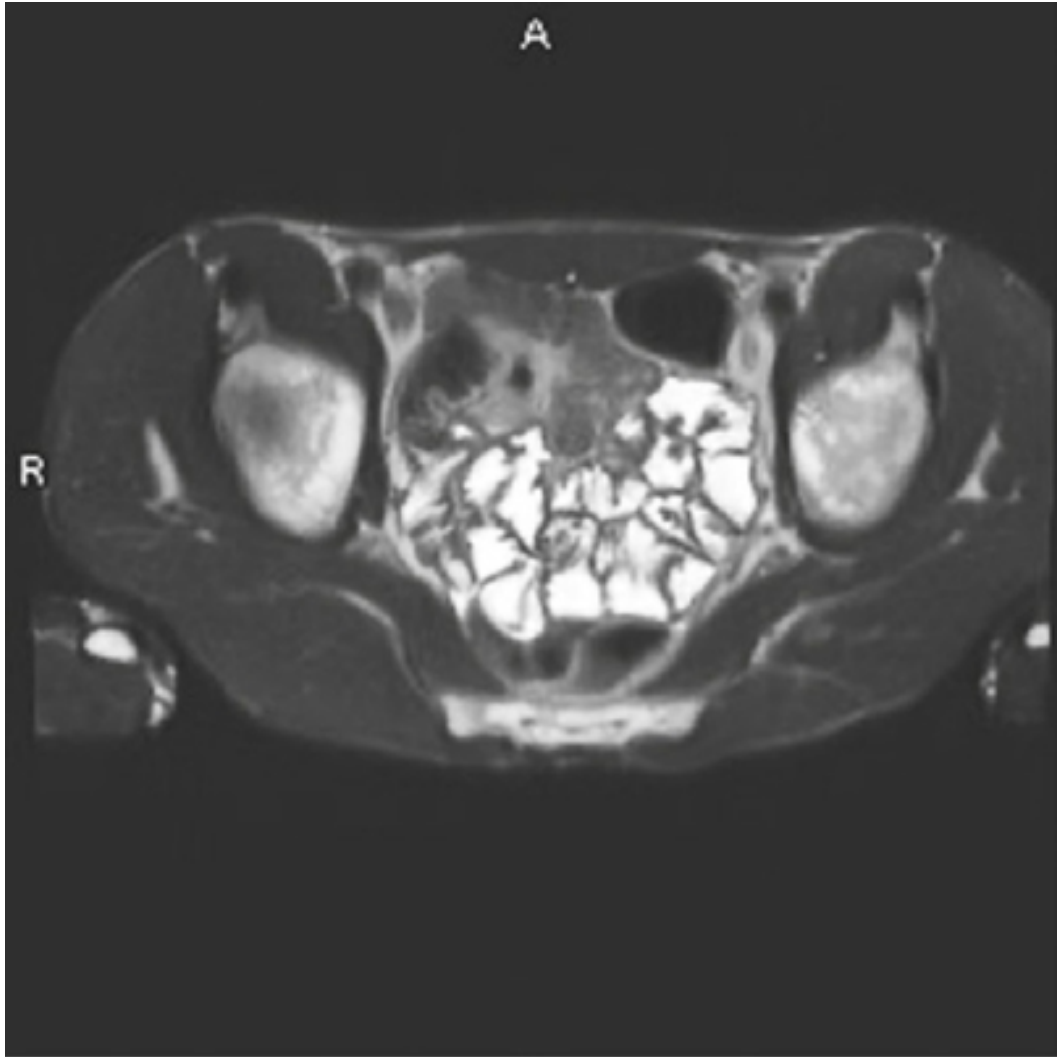


Fig. 2.43c Example of an axial image demonstrating the presence of oral contrast media in the small bowel. [↗](#)

It is important to ensure that the oral contrast media has reached the caecum on initial images, as this will confirm contrast enhancement of the entire small bowel from the duodenum to the ileum ([Figs. 2.43b, c](#)).

Contrast Medium, Injection Data and Medications

Intravenous contrast enhancement (if indicated in protocol)

- Dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended in abdominal imaging.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.
- Antispasmodics can be given to reduce movement artefact on the images from peristalsis.

Adaptive Techniques for Upper Abdomen ([Fig. 2.44a](#), [Fig. 2.44b](#), [Fig. 2.44c](#) and [Fig. 2.44d](#))



Fig. 2.44a Feet-first supine in a patient who has claustrophobia or poor mobility and cannot lie prone. [↗](#)



Fig. 2.44b Feet-first prone in a patient who has claustrophobia. [↗](#)

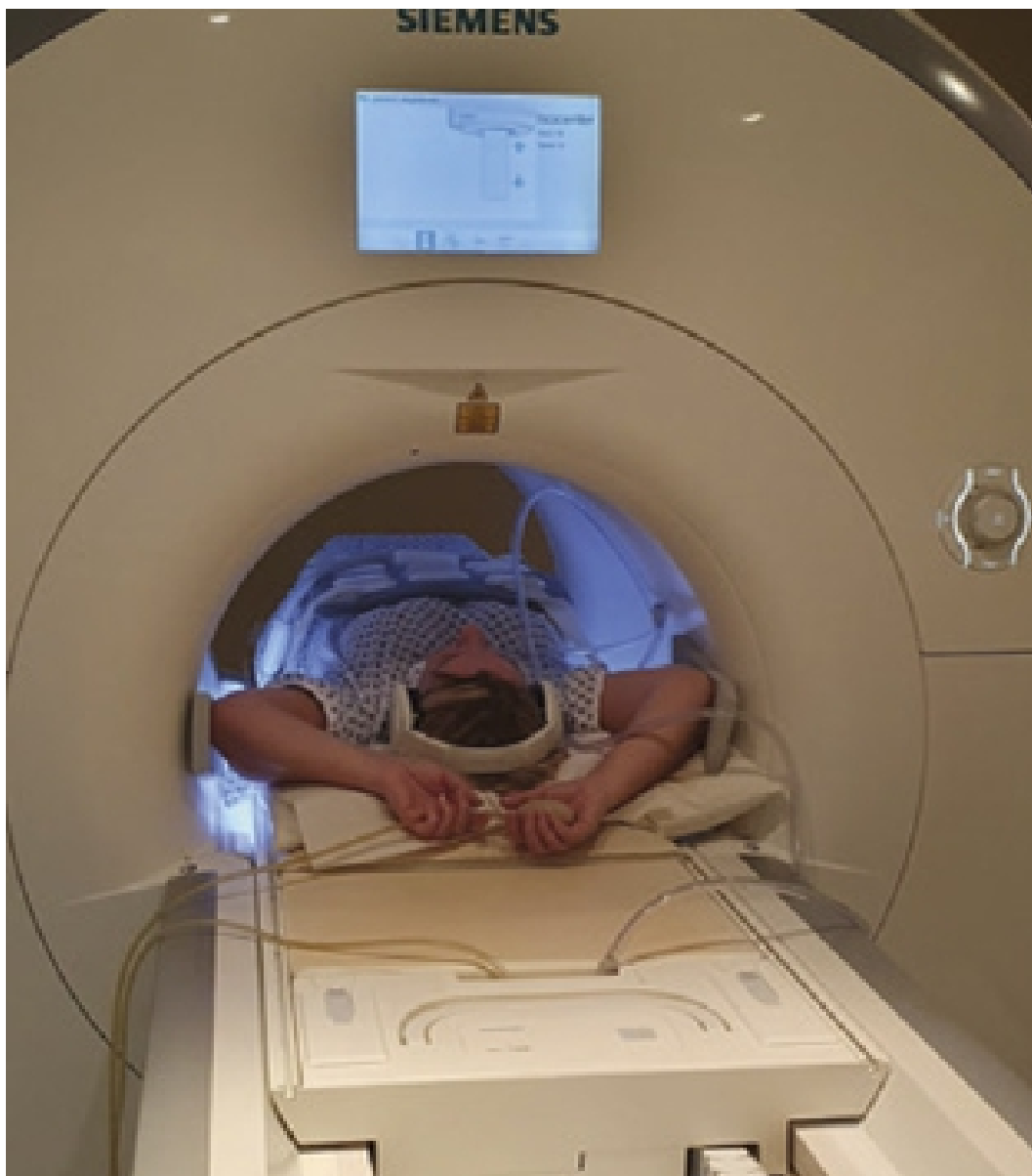


Fig. 2.44c In a patient with large body habitus where arms cannot comfortably fit at the side it is possible to perform the scan with arms above the head with pads next to the elbows to aid comfort throughout the scan. [🔗](#)



Fig. 2.44d Head-first supine in a patient who is unable to lie prone. [↗](#)

When it is not possible to position in the standard position for the imaging of the small bowel due to claustrophobia or mobility issues then we can position the patient as below.

CERVICAL SPINE

MRI is the most sensitive imaging modality used for looking at soft tissues and structures of the cervical spine along with spinal alignments and/or disc herniation. It is most commonly the modality of choice for neck pain. Degenerative diseases in the cervical spine are the most common causes of neurological disorders in the older population and the progress of such may lead to other diseases such as spondylosis and disc herniation.

Indications

- Pain/neuropathy of arms, hands and fingers
- Imaging prior to spinal surgery
- Injury or spinal trauma
- Infection in or near the spine
- Abnormal curvature of the spine
- Cancer or tumours of the spine
- Evaluation/monitoring of a syrinx
- Evaluation/monitoring of myelopathy
- Spinal birth defects

Imaging Procedure ([Fig. 2.45](#))



Fig. 2.45 Standard positioning. [📄](#)

- Position the patient head-first supine.

- Position the patient's head in the head and neck coil.
- Place the anterior part of the head/ neck coil over the patient.
- Use cushions and pads as appropriate to ensure the head remains still throughout the scan.
- Centre for the localiser with the laser light over 2.5 cm below the chin with the chin in a 'chin-down' position.

Sequence Planning ([Fig. 2.46a](#), [Fig. 2.46b](#) and [Fig. 2.46c](#))

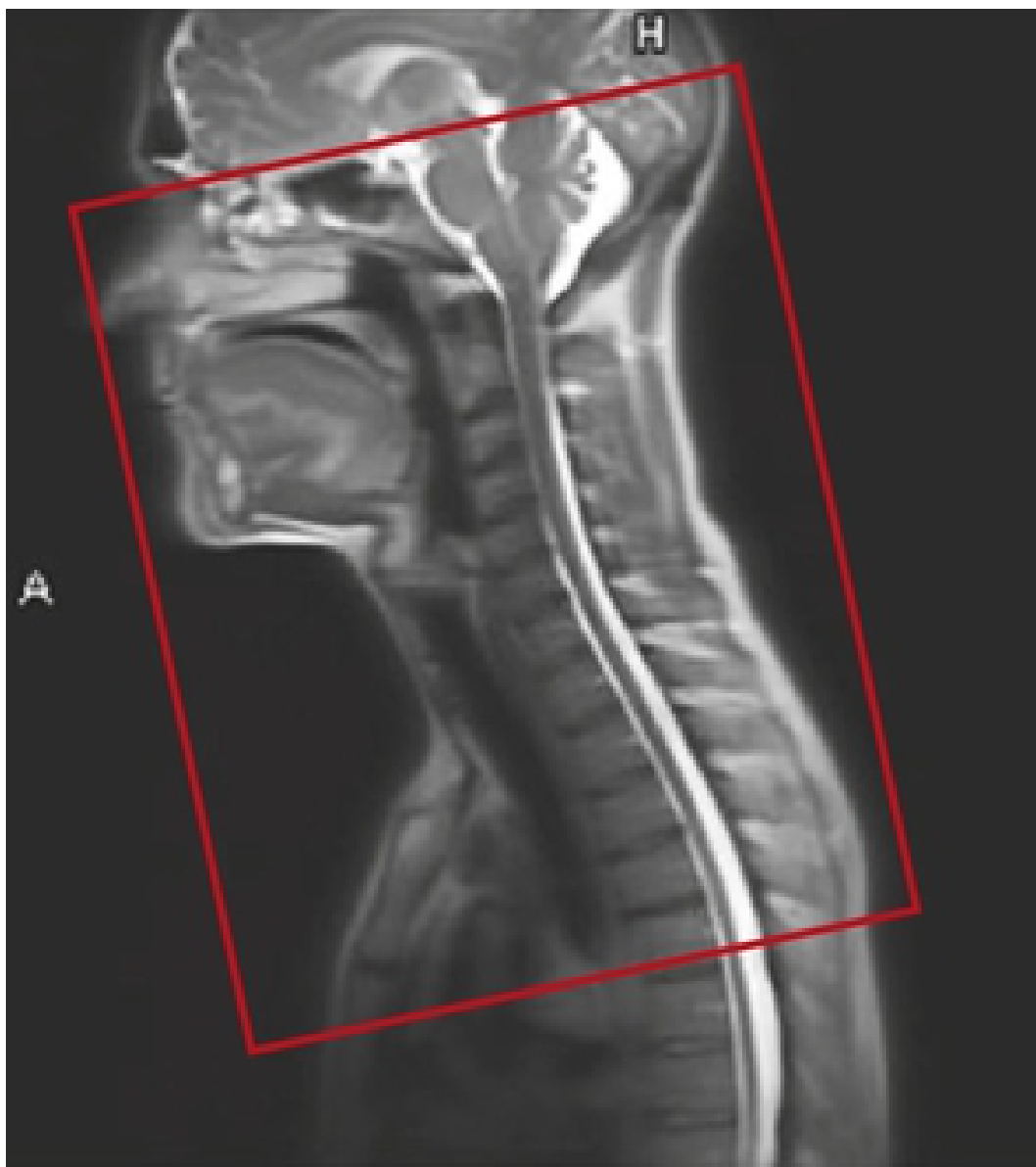


Fig. 2.46a [📄](#)

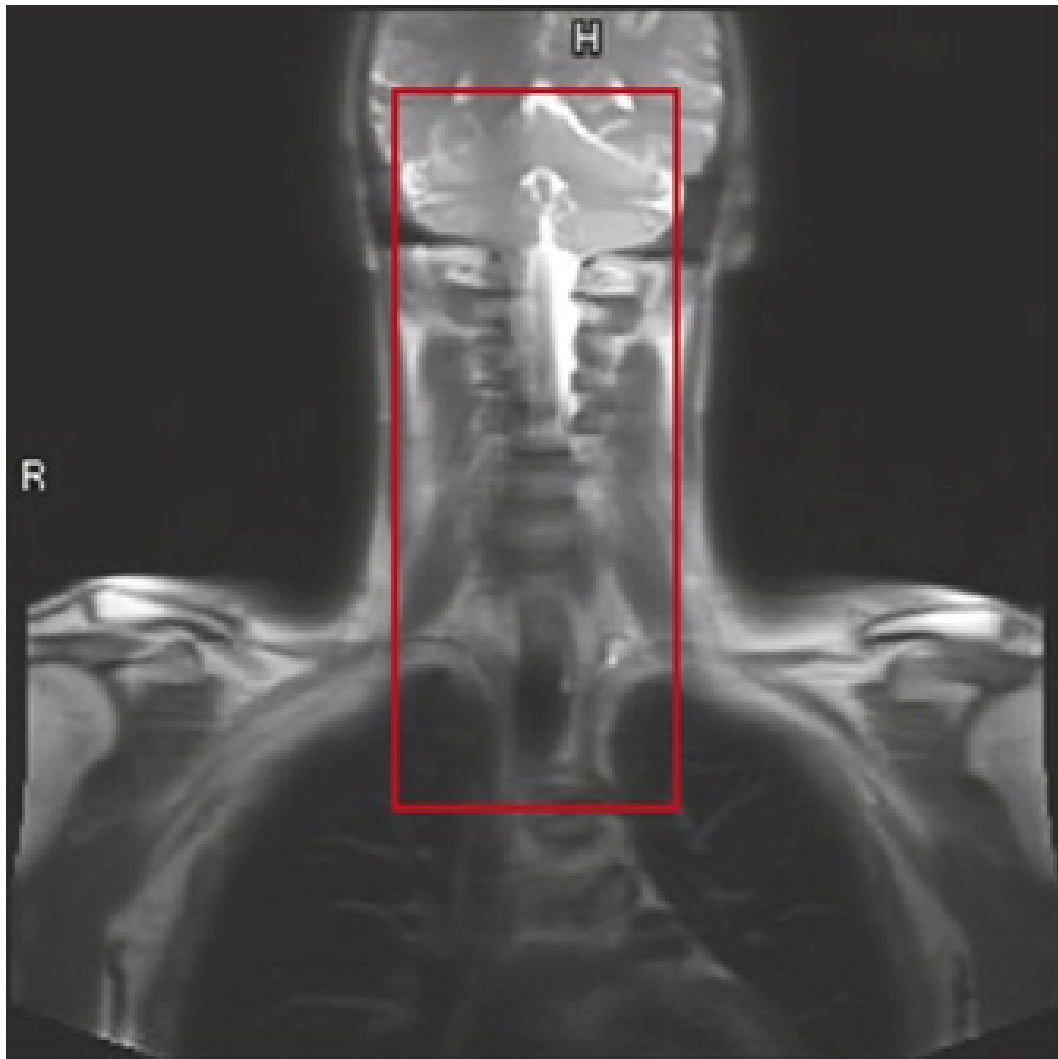


Fig. 2.46b [📄](#)

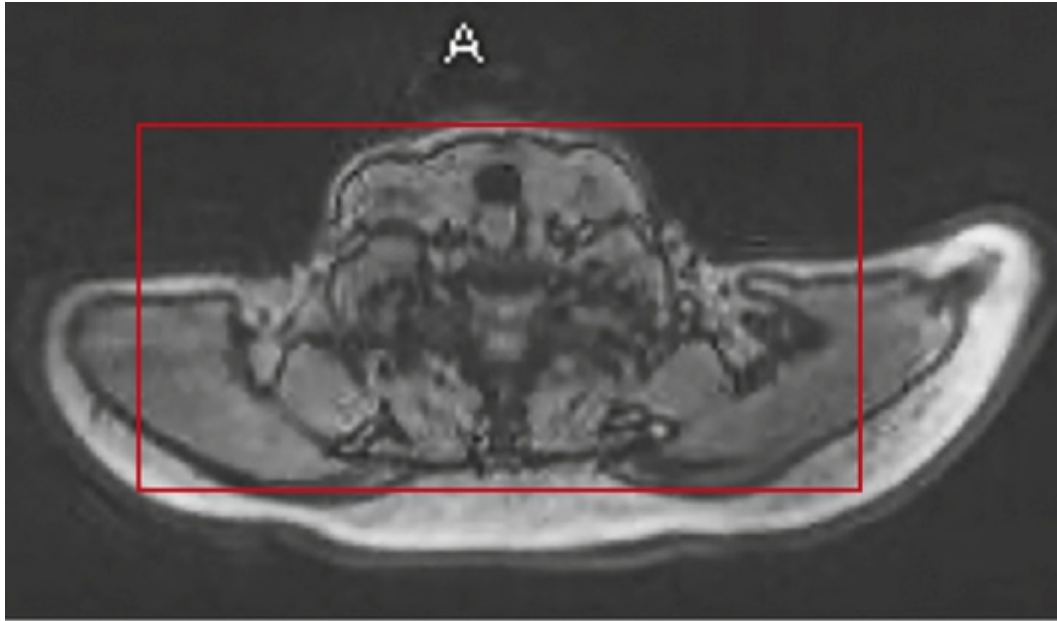


Fig. 2.46c

Planning sagittal sequence: plan using the coronal images; angle the slices parallel to the spinal cord ([Fig. 2.46b](#)) checking positioning in the other two planes. FOV should be suitable to cover from the upper border of the pons to below the level of T3 and ensure enough slices to cover from the left to the right lateral borders of the transverse processes.

Planning axial sequence: plan using the sagittal images and slices parallel to the spinal cord ([Fig. 2.46a](#)). Angle the block parallel to the disc spaces in the coronal plane. Cover from the level of C2 to T1. Plan additional coverage at levels where pathology has been noted when the sagittal T2 sequence was reviewed.

Planning sagittal sequence: plan using the coronal images; angle the slices parallel to the spinal cord ([Fig. 2.46b](#)) ensure the area of interest is covered ([Fig. 2.46c](#)) Check positioning in the other two planes.

Placement of a saturation band parallel to the oesophagus will minimise movement artefact on the sagittal images.

Example sequences: thoracic spine				
Routine	3 plane localiser	Sag T2	Sag T1	Ax T2 GRE
Additional	Sag STIR	Ax T2 TSE (can be used when a high signal is seen in the spinal cord on the Ax T2 GRE to help differentiate between pathology and flow artefact, or when there is susceptibility artefact from fixed dental braces on GRE images)		
Contrast	Pre- and post-Sag T1 and Ax T1	Post-contrast Sag T1 FS		

Acquired Images: Examples ([Fig. 2.47a](#), [Fig. 2.47b](#) and [Fig. 2.47c](#))



Fig. 2.47a Example of a sagittal T2 image of the cervical spine. [🔗](#)



Fig. 2.47b Example of a multiple echo data image combination (MEDIC) axial image of the cervical spine at the level of C5/6. [↗](#)

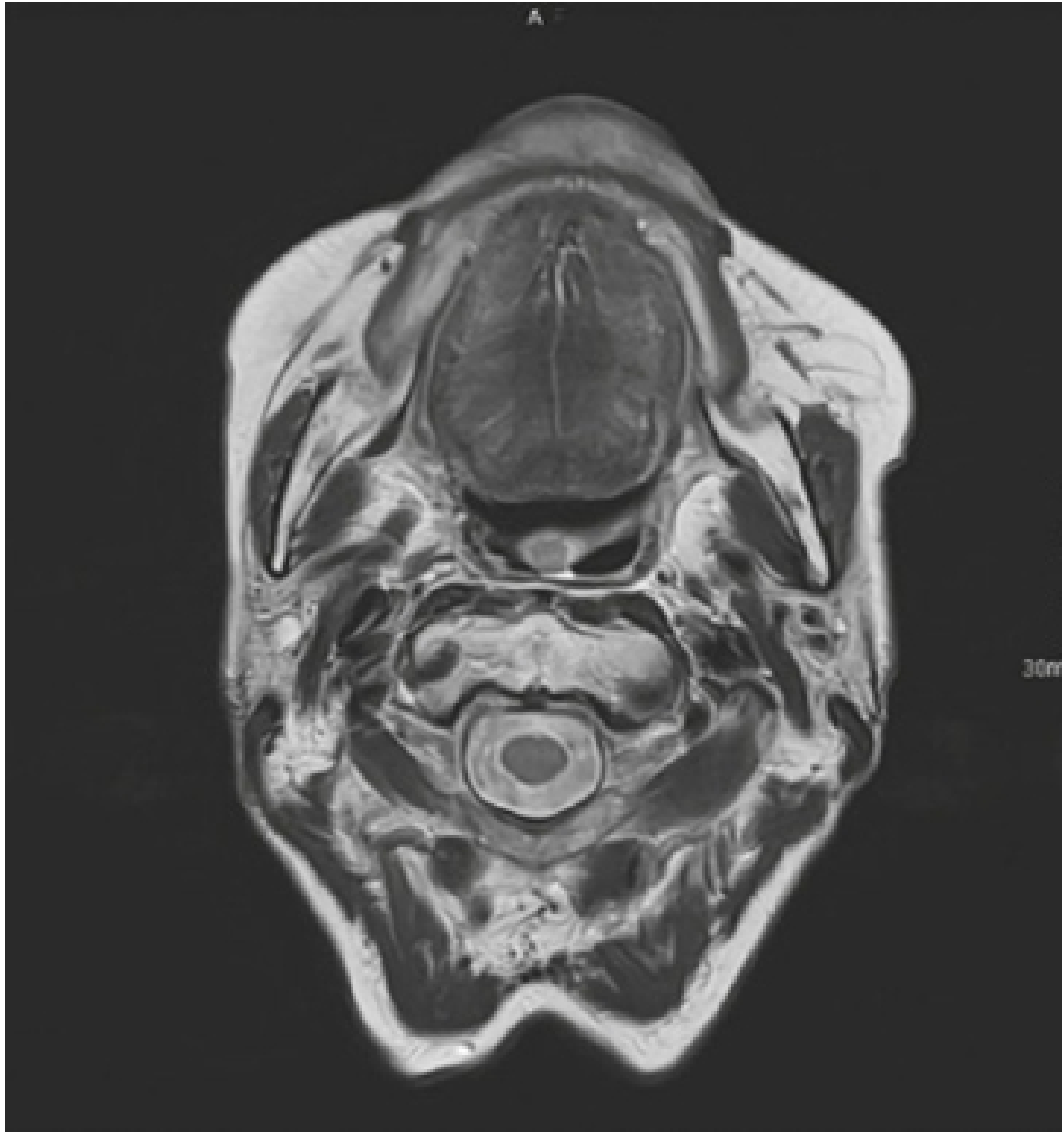


Fig. 2.47c Example of a T1 axial image of the cervical spine at the level of C1. [↗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as inflammatory change or osteomyelitis. Hand injection is suitable.
- Where vascular imaging is indicated, for example where a spinal AVM is suspected, dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Technique ([Fig. 2.48](#))

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, scoliosis or kyphosis then adaptive techniques can be used to demonstrate the anatomy of the cervical spine to acquire a diagnostic image.



Fig. 2.48 The anterior coil has been removed in a patient who has severe claustrophobia. This enables signal to be received from the cervical spine using the posterior coil only. [↗](#)

THORACIC SPINE

MRI is the most sensitive imaging modality used for looking at soft tissues and structures of the thoracic spine along with spinal alignments and/or disc herniation. The thoracic spine consists of 12 vertebrae separated by intervertebral discs and is important as it has many responsibilities including protecting the spinal cord, anchoring the rib cage and supporting the neck and cervical spine. Both the cervical and lumbar spine provide mobility, while the role of the thoracic spine is to provide stability. The thoracic vertebrae increase in size as they move away from the neck and towards the lumbar spine to support the weight of the torso. The thoracic spine anchors the ribs and sternum allowing the protection of the inner organs.

Indications

- Localised upper back pain
- Neuropathic pain
- Infection or inflammatory process in or near the spine
- Injury or spinal trauma
- Abnormal curvature of the spine
- Cancer or tumours of the spine
- Imaging prior to spinal surgery
- Evaluation/monitoring of a syrinx
- Evaluation/monitoring of myelopathy
- Spinal tuberculosis

Imaging Procedure ([Fig. 2.49](#))

- Position the patient head-first supine.
- Position the patient's head in the dedicated head and neck coil.
- Place the anterior part of the head/ neck coil over the patient.

- Use cushions and pads as appropriate to ensure the head remains still throughout the scan.
- Centre for localiser with laser light over T4/5 area.



Fig. 2.49 Standard positioning. [📄](#)

Sequence Planning ([Figs. 2.50a, b](#))



Fig. 2.50a [📄](#)

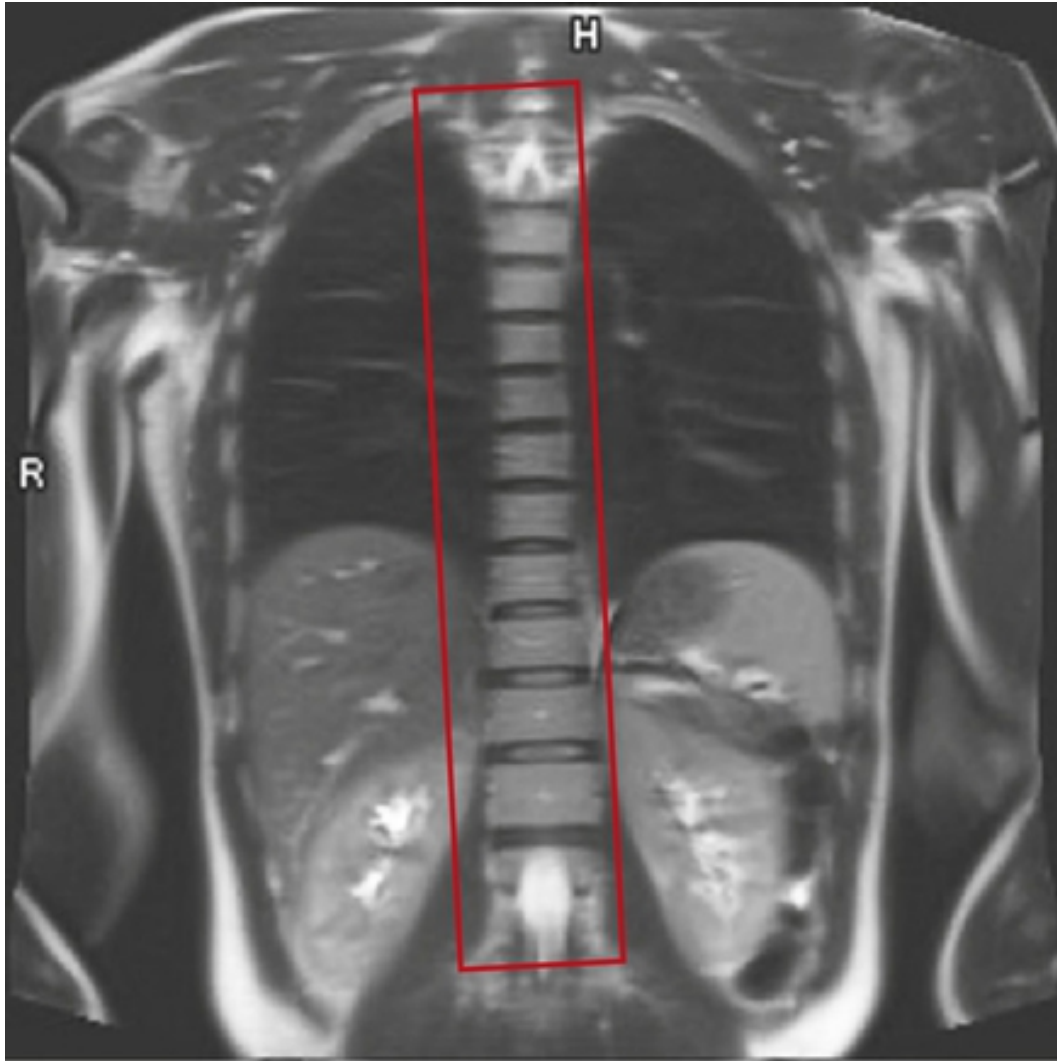


Fig. 2.50b [📄](#)

Planning sagittal sequence: ensure the sagittal localiser has a large FOV, covering from above C1 down to T12 to allow accurate counting ([Fig. 2.50b](#)). Plan using the coronal images and angle the slices parallel to the spinal cord, checking positioning in the other two planes. FOV should be suitable to cover from T1 to T12 and ensure enough slices to cover from the left to the right lateral borders of the transverse processes. Placement of a saturation band anterior and parallel to the block will minimise movement chest artefact.

Planning axial sequence: plan using the sagittal images and angle the slices perpendicular to the spinal cord ([Fig. 2.50a](#)). Angle the block perpendicular to the disc spaces in the coronal plane. On a routine thoracic spine examination axial coverage will be defined in the local protocol by the radiologist. Ensure axial images are planned at levels where pathology has been identified on the sagittal sequence.

Example sequences: thoracic spine				
Routine	3 plane localiser	Sag T2	Sag T1	Ax T2 TSE
Additional	Sag STIR	Ax SPACE sequence	Coronal T2 (useful in patients with scoliosis)	
Contrast	Pre- and post-Sag T1 and Ax T1		Post-contrast Sag T1 FS	

Acquired Images: Examples ([Fig. 2.51a](#), [Fig. 2.51b](#) and [Fig. 2.51c](#))



Fig. 2.51a Example of a T2 sagittal image. [🔗](#)



Fig. 2.51b Example of a T1 sagittal image. [↗](#)

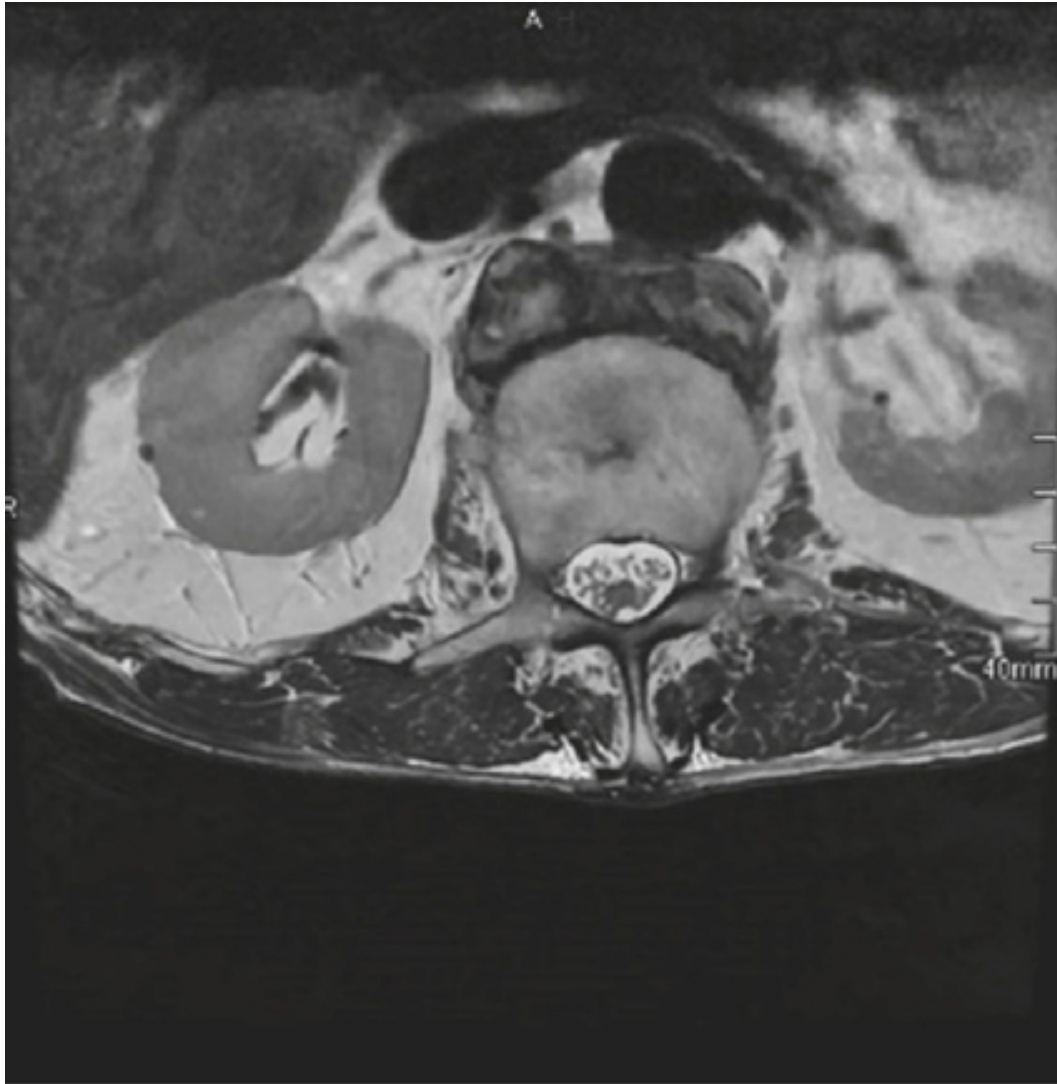


Fig. 2.51c Example of an axial image at the level of T12. [↗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as inflammatory change or osteomyelitis. Hand injection is suitable. Where vascular imaging is indicated, for example where a spinal AVM is suspected, dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.52a](#), [Fig. 2.52b](#) and [Fig. 2.52c](#))



Fig. 2.52a Use of a tilted head coil on modern scanner in a patient who is unable to lie flat. [↗](#)



Fig. 2.52b Flexible coil placed over the neck in a patient who has claustrophobia and cannot tolerate the anterior head coil. [📄](#)



Fig. 2.52c The anterior head coil has been removed in a patient who has severe claustrophobia and cannot tolerate any anterior coils.[📄](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, scoliosis or kyphosis then adaptive

techniques can be used to demonstrate the anatomy of the thoracic spine to acquire a diagnostic image.

LUMBAR SPINE

MRI is the most sensitive, non-invasive imaging modality used for looking at soft tissues and structures of the lumbar spine along with the surrounding organs. It is one of the more commonly received outpatient MRI scan referrals. The lumbar spine comprises the lower end of the spinal column between the last thoracic vertebra (T12) and the first sacral vertebra (S1). The spinal cord in this region has protection from five vertebrae (L1–L5) that allow for the dispersion of axial forces.

Indications

- Pain after injury
- Pain with neuropathy
- Cauda equina syndrome
- Spinal tuberculosis
- Monitoring of previous spinal surgery
- Sciatica and/or claudication
- Prolapsed/herniated discs prior to surgery
- Inflammation/infection
- Myelopathies
- Disc herniation
- Spinal cord damage
- Tumours

Imaging Procedure ([Fig. 2.53](#))

- Position the patient head-first supine.

- Position the patient on the spinal coil.
- Use cushions and pads as appropriate to ensure the patient remains still throughout the scan.
- Centre for the localiser with the laser light at the level of the iliac crest.



Fig. 2.53 Standard positioning. [📄](#)

Sequence Planning ([Fig. 2.54a](#), [Fig. 2.54b](#) and [Fig. 2.54c](#))

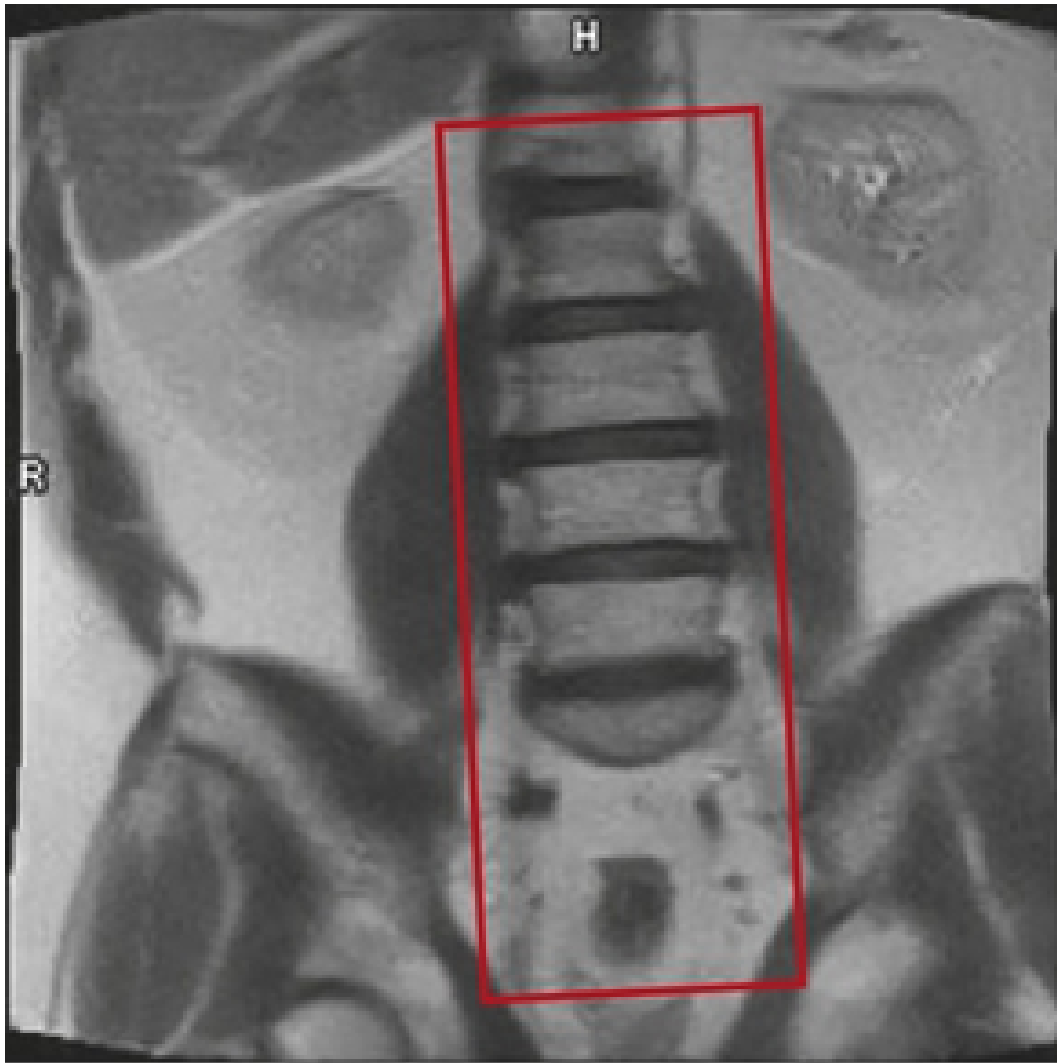


Fig. 2.54a [🔗](#)

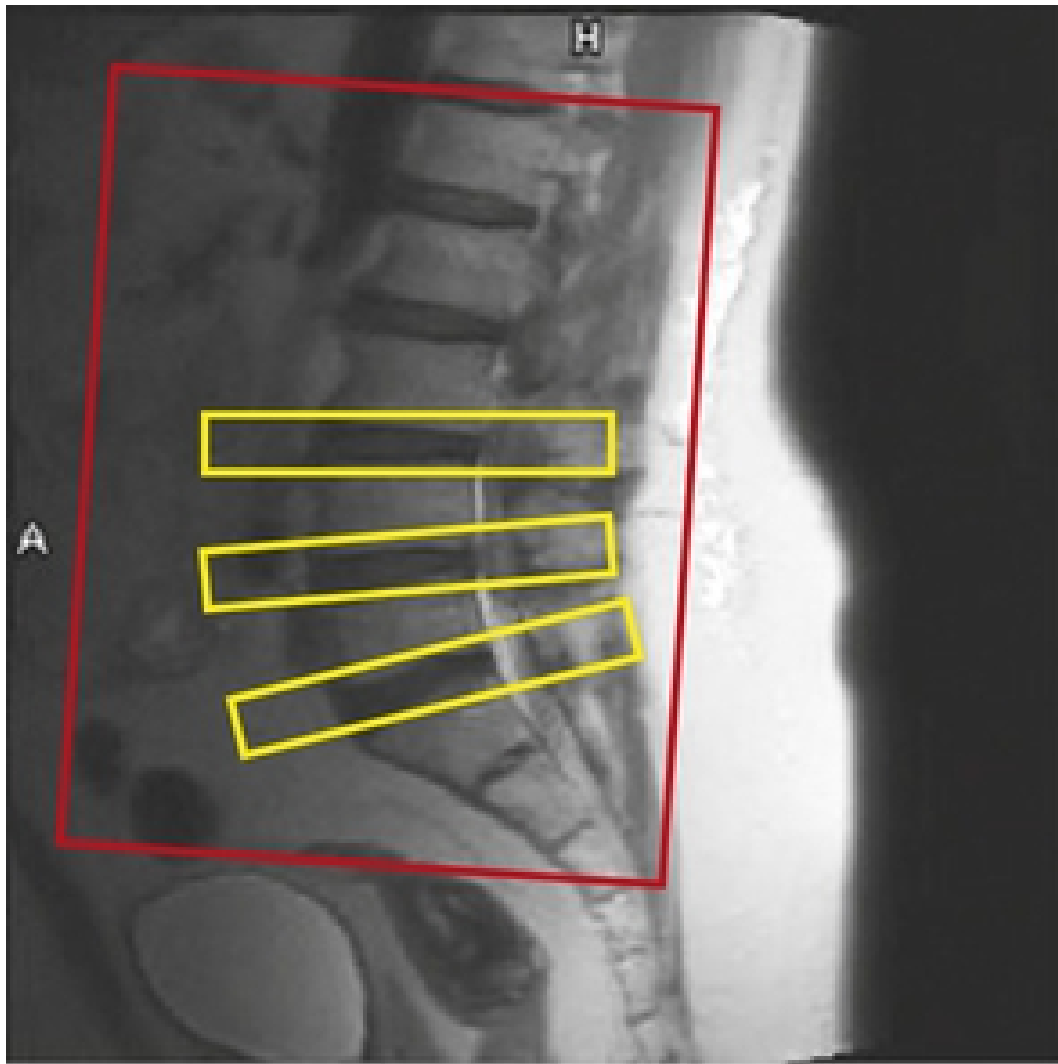


Fig. 2.54b [🔗](#)

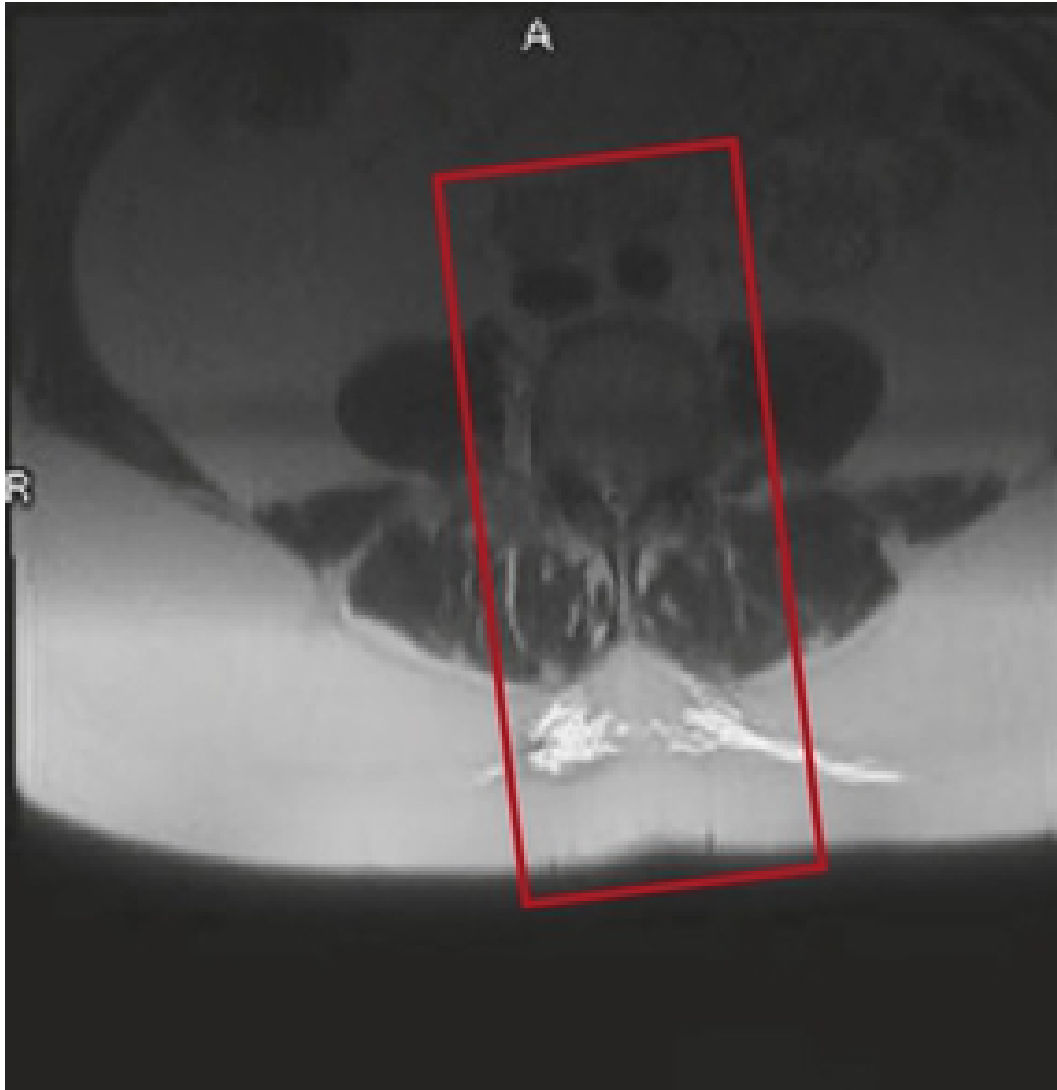


Fig. 2.54c [🔗](#)

Planning sagittal sequence: plan using the coronal images; angle the slices parallel to the spinal cord, checking positioning in the other two planes. The FOV should be suitable to cover from the level of T11 to the coccyx and ensure enough slices to cover from the left to the right lateral borders of the transverse processes ([Fig. 2.54a](#)).

Planning axial sequence: plan using the sagittal images and angle the slices parallel to the disc spaces in both the coronal and sagittal planes. Cover from the level of L1 to L5/S1, with additional coverage at levels

where pathology has been noted when the sagittal T2 sequence was reviewed. Some departments will concentrate solely on the bottom three discs if no pathology is seen so the angle is correct through the disc spaces (yellow boxes in [Fig. 2.54b](#)).

Check coverage and that the FOV is central in the coronal plane ([Fig. 2.54c](#)).

Placement of an anterior saturation band parallel to the spine will minimise movement artefact on the sagittal images.

Example sequences: lumbar spine					
Routine	3 plane localiser	Sag T2	Sag T1	Ax T2	Ax T1
Additional	Sag STIR				
Contrast	Pre- and post-Sag T1 and Ax T1	Post-contrast Sag T1 FS			

Acquired Images: Examples ([Fig. 2.55a](#), [Fig. 2.55b](#) and [Fig. 2.55c](#))



Fig. 2.55a Example of T2 Sagittal image through the midline.[↗](#)



Fig. 2.55b Example of T1 sagittal image through the midline.[↗](#)

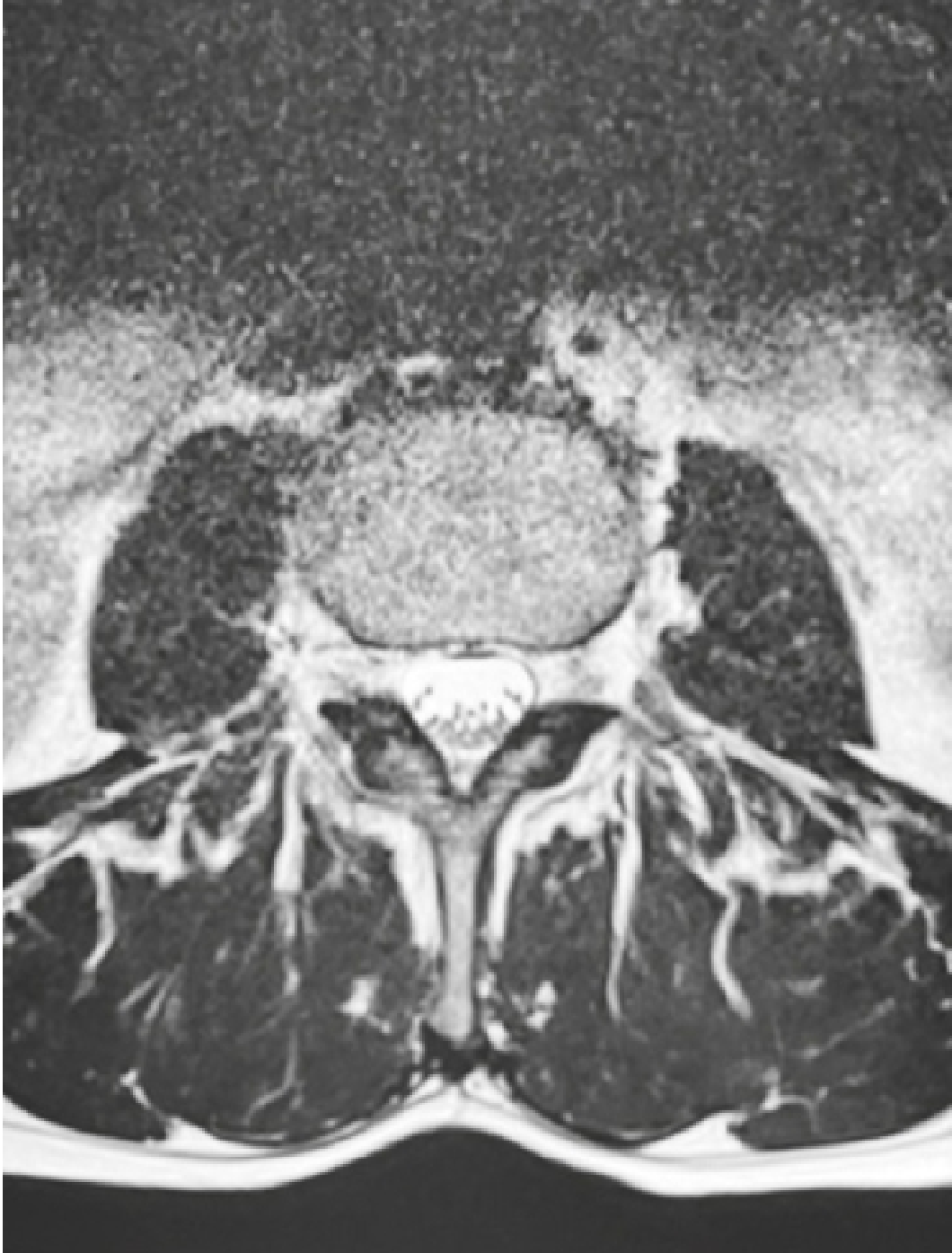


Fig. 2.55c Example of T2 axial image. [d](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard lumbar spine imaging is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.56a](#), [Fig. 2.56b](#) and [Fig. 2.56c](#))



Fig. 2.56a Feet-first supine in a patient who has claustrophobia. [📄](#)



Fig. 2.56b Feet-first prone in a patient who is unable to lie supine. [↗](#)



Fig. 2.56c Feet first in a left lateral decubitus position in a patient who is unable to lie flat. [📄](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia adaptive techniques can be used to demonstrate the anatomy of the lumbar spine to acquire a diagnostic image. By positioning the patient feet first in the scanner, the images can still be achieved and they are less likely to experience feelings of claustrophobia. Alternatively, as with the thoracic spine if the patient is unable to lie flat on their back, then they can be lay lateral decubitus with the phased array coil placed over their side, or prone.

HUMERUS

The humerus is essential to the upper limbs' skeletal and muscular systems. A variety of shoulder motions are made possible by the glenohumeral joint, which is where the proximal end of the humerus articulates with the scapula. Elbow flexion and extension are possible due to the hinge joint formed by its distal end with the forearm's ulna and radius bones. Additionally, the humerus provides attachment sites for several muscles, enabling actions like lifting, pushing and arm rotation. For this reason, the humerus is crucial for upper body strength and arm mobility. MRI is a non-invasive way to determine a number of issues arising from the humerus.

Indications

- Nerve impingement
- Avascular necrosis
- Infection
- Occult fracture

- Soft tissue masses
- Neoplasm of joint or soft tissue
- Fractures in children
- Ligament tear

Imaging Procedure ([Fig. 2.57](#))

- Position the patient head-first supine.
- Position the upper arm by the side of the patient as close to the isocenter of the table as practicably possible.
- Place a body array over the entire upper arm to cover both the shoulder and elbow.
- Use cushions, pads and immobilisation devices as appropriate to ensure the humerus stays immobilised and straight throughout the scan.
- Centre for localiser with the laser light over the centre of the humerus.



Fig. 2.57 Standard positioning. [📄](#)

Sequence Planning ([Fig. 2.58a](#), [Fig. 2.58b](#) and [Fig. 2.58c](#))



Fig. 2.58a [↗](#)



Fig. 2.58b [↗](#)

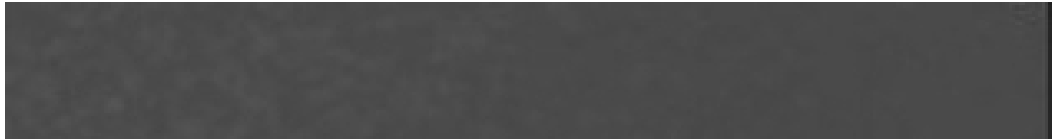




Fig. 2.58c [📄](#)

Planning axial sequence: plan the axial slices on the coronal plane and angle the slices perpendicular to the humerus ([Fig. 2.58c](#)). The phase direction should ideally be anteroposterior to avoid wrap-around and motion artefacts from the chest.

Planning sagittal sequence: angle the planning block perpendicular to the scapular blade on an axial image ([Fig. 2.58a](#)). Saturation bands may be used to reduce the motion from breathing.

Coronal planning: plan the coronal slices on the axial plane and angle the planning block parallel to the scapula ([Fig. 2.58b](#)). The addition of saturation bands will reduce any motion created by breathing or arterial artefact.

Example sequences: humerus						
Routine	3 plane localiser	Ax T1	Ax T1 STIR	Sag T1	Sag T2 FS	Cor T2
Additional	Ax T1 FS pre-contrast Ax T1 FS and Sag FS T1 post-contrast					

Acquired Images: Examples ([Figs. 2.59a, b](#))

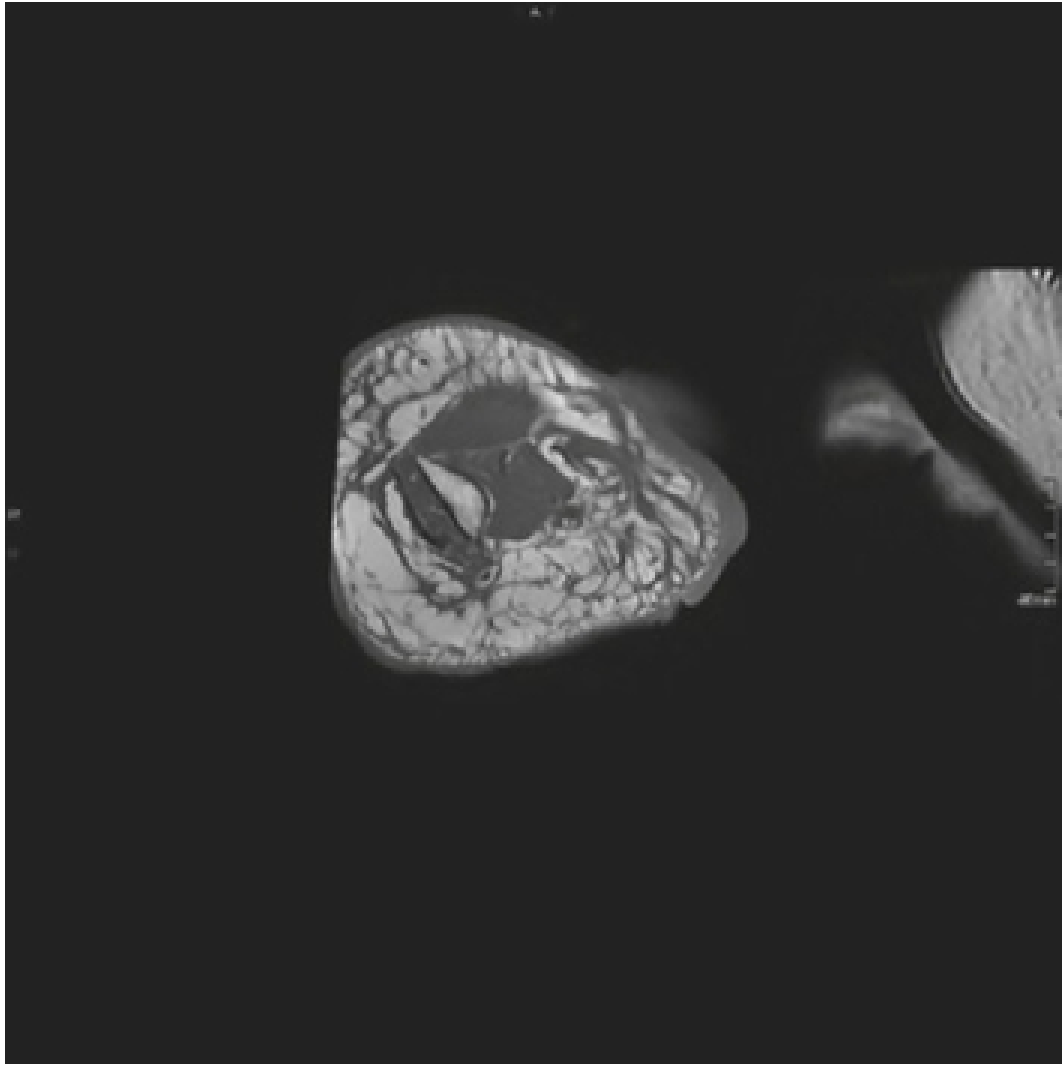


Fig. 2.59a Example of a STIR axial image of the humerus. [↗](#)



Fig. 2.59b Example of a T1 coronal image of the humerus. [↗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Contrast may be given where tumour or infection is indicated to show any enhancement. Hand injection for all standard humerus imaging is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.60](#))

The reason that adaptive techniques need to be considered is generally due to pain, or the patient's large body habitus not allowing for standard positioning.



Fig. 2.60 When it is not possible to position a dedicated coil, a flexible coil can be used over the patient's upper arm to encompass the humerus. [↗](#)

ELBOW

The elbow is a complex joint and is most commonly injured in athletes. Imaging by means of MRI is an important adjunct to a physical examination to facilitate accurate diagnosis. Almost all movements of the upper extremities during routine daily life and many athletic activities require a painless and stable elbow joint. Studying the elbow is a diagnostic challenge because of its complex anatomy. MRI is an extremely important tool in the evaluation of common elbow disorders, the spectrum of which ranges from obvious acute lesions to chronic overuse injuries whose imaging manifestations can be subtle.

Indications

- Evaluation of cartilaginous defects
- Marrow abnormality/bone contusions, stress fractures or oedema
- Soft tissue masses
- Nerve issues
- Synovial disorders such as osteochondritis, osteomyelitis and osteoarthritis
- Tendon/muscle issues and ligament tears
- Foreign bodies within the joint
- Bursitis
- Occult fracture

Imaging Procedure ([Fig. 2.61](#))

- Position the patient head-first prone with hand supinated.
- Wrap the small flex coil around the elbow.
- Place a sandbag over the wrist to help the patient to remain still.
- Use cushions and pads as appropriate to ensure the elbow stays immobilised and straight throughout the scan.
- Centre for the localiser with the laser light over the centre of the elbow joint.



Fig. 2.61 Standard positioning. [📄](#)

Sequence Planning ([Fig. 2.62a](#), [Fig. 2.62b](#) and [Fig. 2.62c](#))

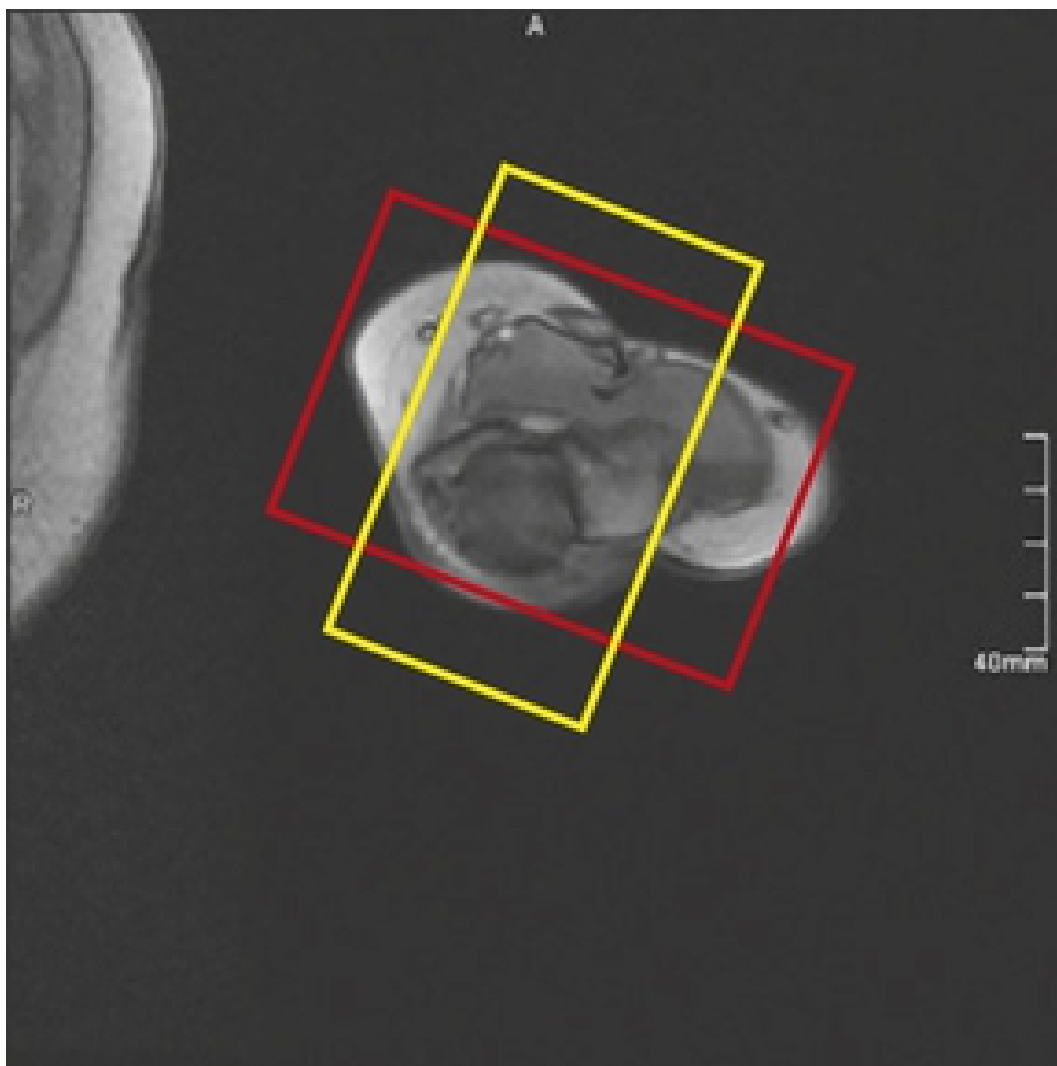


Fig. 2.62a [📄](#)



Fig. 2.62b [↗](#)



Fig. 2.62c [📄](#)

Planning axial sequence: angle the positioning block parallel to the medial and lateral humeral epicondyles on a coronal image ([Fig. 2.62b](#)).

Planning sagittal sequence: angle the positioning block perpendicular to the medial and lateral humeral epicondyles on an axial image (yellow box in [Fig. 2.62a](#)). Check adequate phase oversampling and that the FOV is central in the sagittal plane ([Fig. 2.62c](#)).

Planning coronal sequence: angle the positioning block parallel to the medial and lateral humeral epicondyles on an axial image (red box in [Fig. 2.62a](#)).

Saturation bands can be used to limit the amount of wrap.

Example sequences: elbow						
Routine	3 plane localiser	Ax PD SPAIR	Ax T1	Cor T1	Cor T1 STIR	Sag T2 GRE
Additional	Cor T2 double echo steady state (DESS) volume; Ax T1 FS pre-contrast; Ax T1 FS and Sag FS T1 post-contrast					

Acquired Images: Examples ([Fig. 2.63a](#), [Fig. 2.63b](#) and [Fig. 2.63c](#))



Fig. 2.63a Example of a STIR sagittal image of the elbow. [🔗](#)



Fig. 2.63b Example of a T1 coronal image of the elbow. [↗](#)



Fig. 2.63c Example of a T1 axial image of the elbow. [📄](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as inflammatory change. Hand injection is suitable.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.64a, b](#))

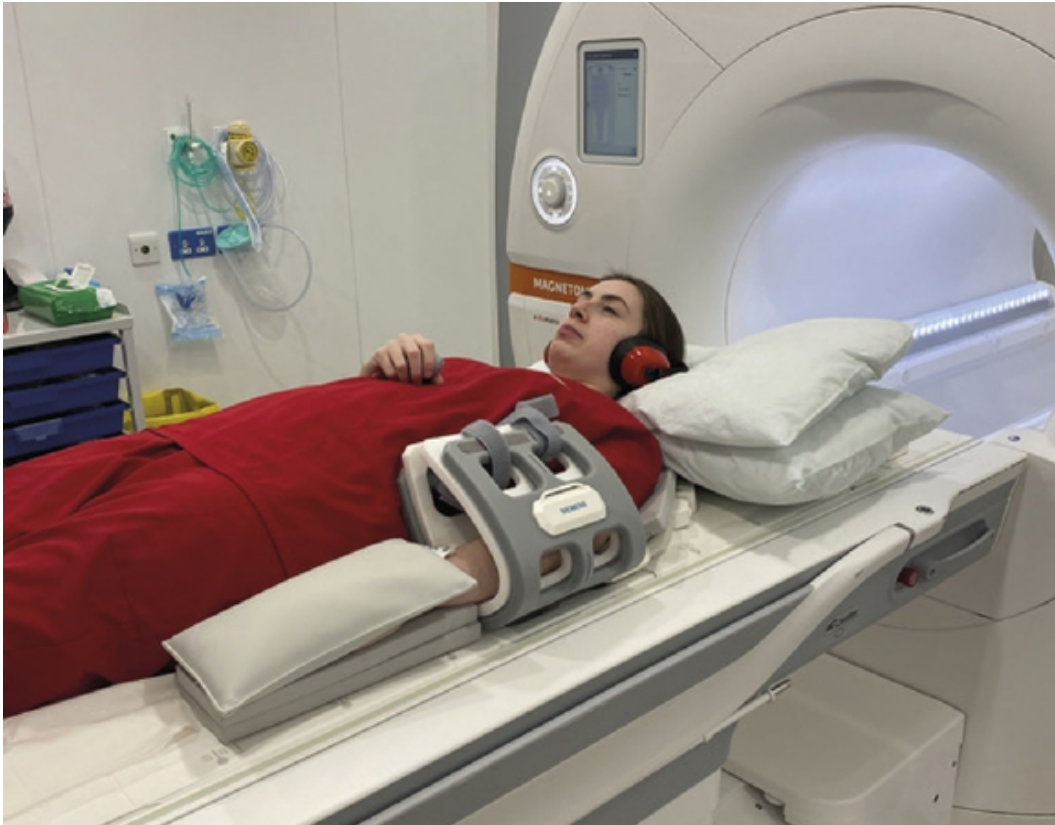


Fig. 2.64a Small flexible coil wrapped around the elbow in a patient who is unable to extend their arm above their head or lie prone. [📄](#)



Fig. 2.64b Dedicated knee coil can also be used as an alternative if the patient is unable to fully outstretch their arm. Pads are used to reduce any movement artefact. [↗](#)

When it is not possible to position in the standard way due to large body habitus, reduced mobility or inability to lie prone then there are other options. The patient can lie supine with the arm extended into 'superman' position, or with the arm by their side, with the small flex coil or body coil over the elbow. An alternative position would be to use the dedicated knee coil with the patient in a prone position with the arm extended.

WRIST, HAND AND FINGERS

MRI is the most sensitive imaging modality used for looking at the wrist and hand. This area is composed of numerous complex small structures with complex morphologies and anatomical variations. With the high spatial and contrast resolution that MR provides, characterisation of bone and soft tissue can be made without the use of ionising radiation.

Indications

- Occult osseous lesions/soft tissue masses
- Assessment of triangular fibrocartilage complex (TFCC)
- Trauma
- Fracture/non-union of fracture
- Ligament tears involving the fingers
- Extensor tendon injuries
- Ganglions/cysts
- Peripheral neuropathies involving the radial and ulnar nerves

Imaging Procedure ([Fig. 2.65](#))



Fig. 2.65 Standard positioning for hand/wrist/fingers. [📄](#)

- Position the patient head-first prone within the dedicated wrist and hand coil. Often referred to as the ‘superman position’.
- Ensure the rest of the patient is made as comfortable as possible in order for them to stay still throughout the scan.
- Place a sandbag over the forearm of the patient to immobilise the arm.
- Use cushions and pads as appropriate to ensure the hand/wrist stays immobilised and straight throughout the scan.
- Centre for the localiser with laser light over the centre of the hand or the wrist depending on the intended scan area.

Sequence Planning: Wrist ([Fig. 2.66a](#), [Fig. 2.66b](#) and [Fig. 2.66c](#))



Fig. 2.66a [↩](#)

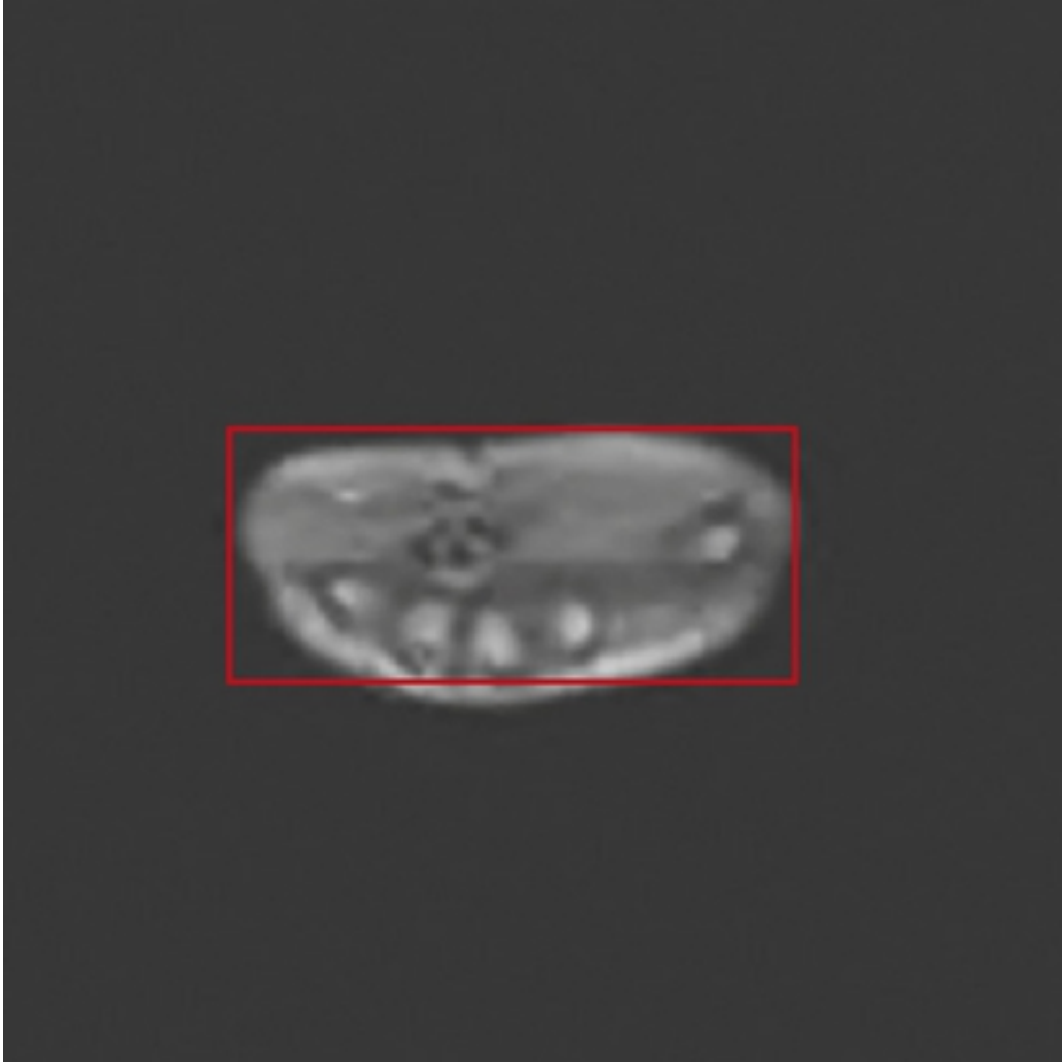


Fig. 2.66b [📄](#)



Fig. 2.66c [📄](#)

Planning axial sequence: angle the block horizontally across the carpal bones on a coronal image, with an appropriate angle in the sagittal plane to cover the entire wrist joint ([Fig. 2.66c](#)).

Planning coronal sequence: angle horizontally across the carpal bones on an axial image ([Fig. 2.66b](#)).

Planning sagittal sequence: angle the block perpendicular to the carpal bones on an axial image and check the FOV is central in the sagittal plane ([Fig. 2.66a](#)).

Example sequences: wrist							
Routine	3 plane localiser	Ax PD FS	Cor T1	Cor PD FS	Cor PD FS high- resolution slices through TFCC	Sag PD FS	
Additional	Ax oblique PD FS angled through scapho-lunate scaphoid						
Additional	Ax T1 FS pre-contrast Ax T1 FS, Cor T1 FS and Sag FS T1 post-contrast						

Acquired Images: Wrist Examples ([Fig. 2.67a](#), [Fig. 2.67b](#) and [Fig. 2.67c](#))

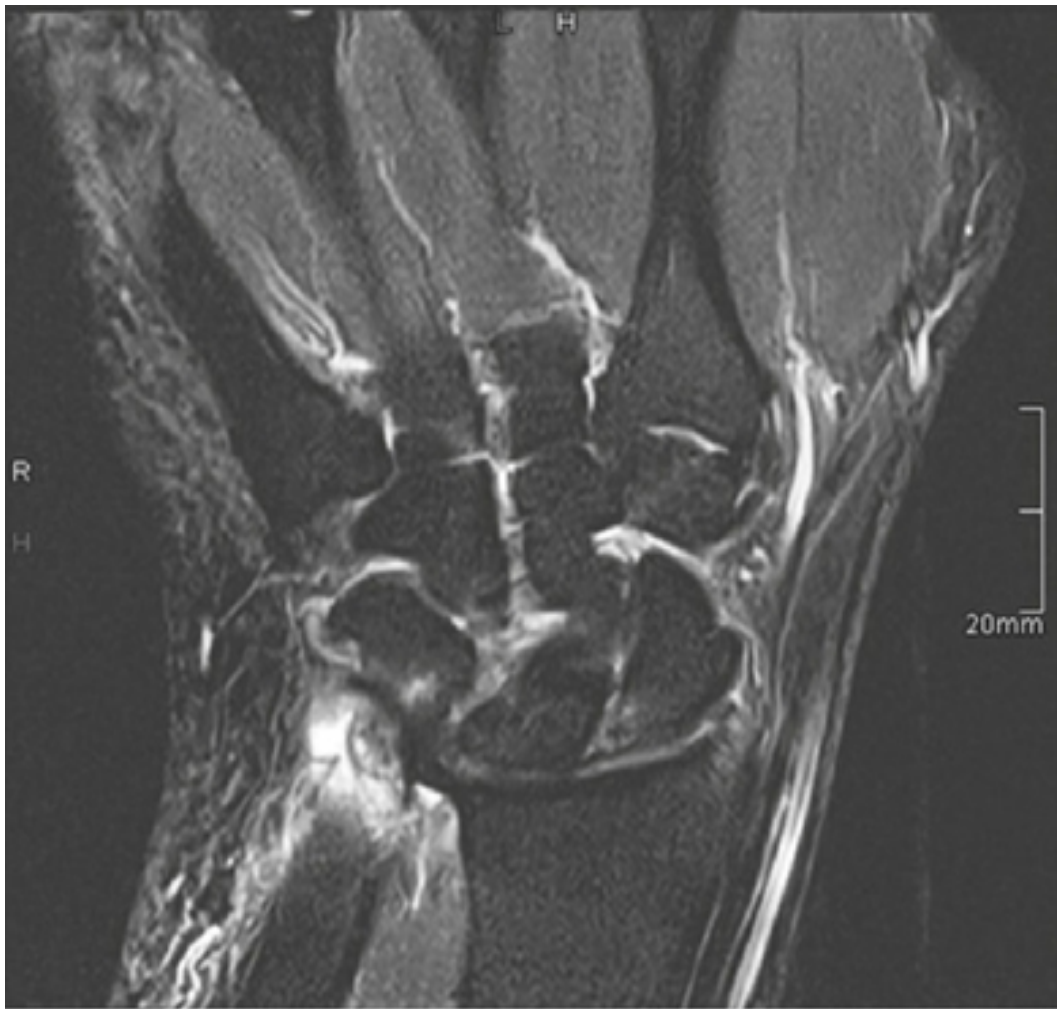


Fig. 2.67a Example of a coronal PD FS image. [📄](#)

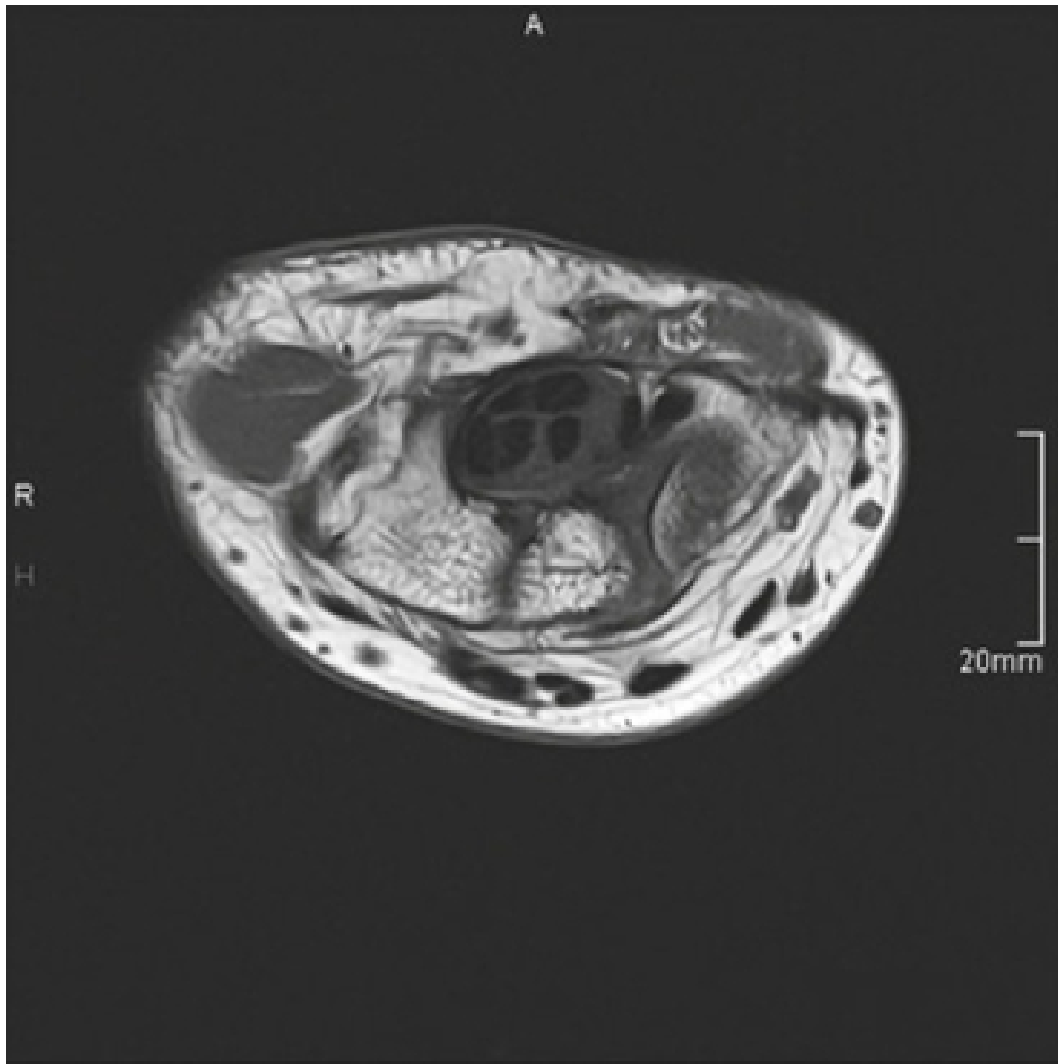


Fig. 2.67b Example of an axial T2 FLASH FS image. [↗](#)



Fig. 2.67c Example of a lateral T2 FLASH FS image. [↗](#)

Sequence Planning: Hand ([Fig. 2.68a](#), [Fig. 2.68b](#) and [Fig. 2.68c](#))



Fig 2.68a [↗](#)



Fig 2.68b [↗](#)

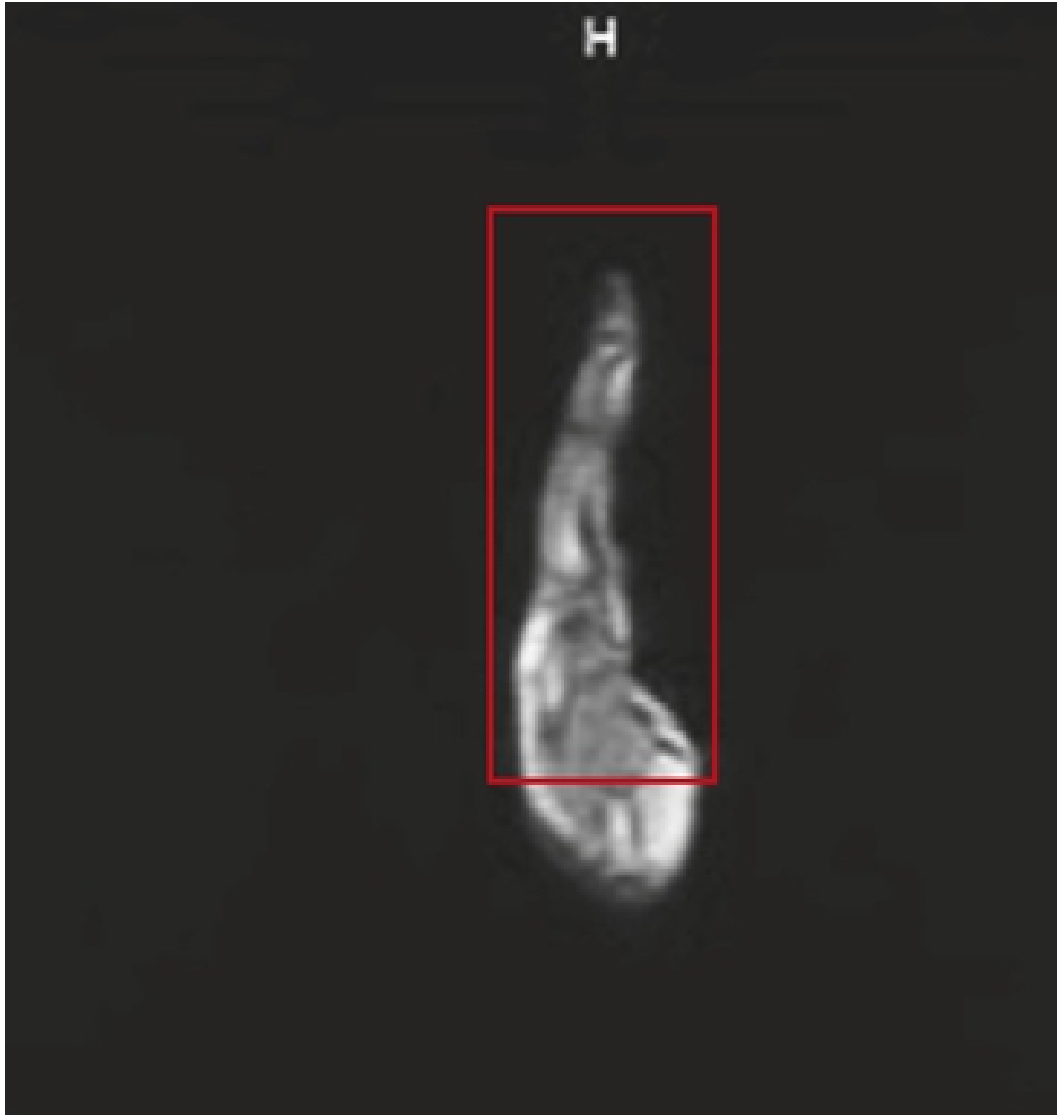


Fig 2.68c [↗](#)

Planning sagittal sequence: angle block vertically across carpal bones on an axial image ([Fig. 2.68a](#)).

Planning axial sequence: angle block perpendicular to the metacarpal and phalangeal bones on a coronal image ([Fig. 2.68b](#)).

Planning coronal sequence: angle the block parallel to the metacarpal bones on an axial image. In the sagittal plane angle parallel to the fingers ([Figs. 2.68a, c](#)).

Sequence Planning: Finger(s) ([Fig. 2.69a](#), [Fig. 2.69b](#) and [Fig. 2.69c](#))



Fig. 2.69a [↗](#)

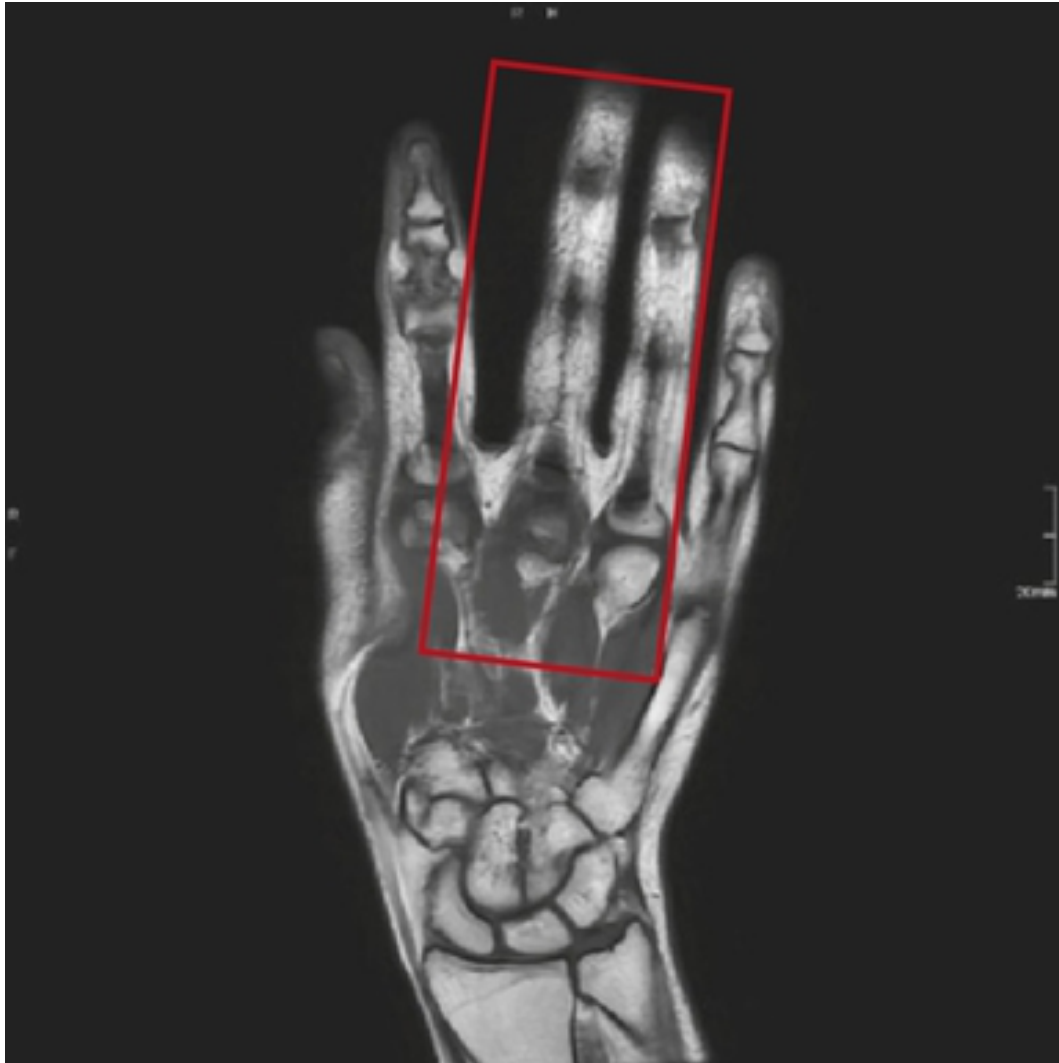


Fig. 2.69b [📄](#)

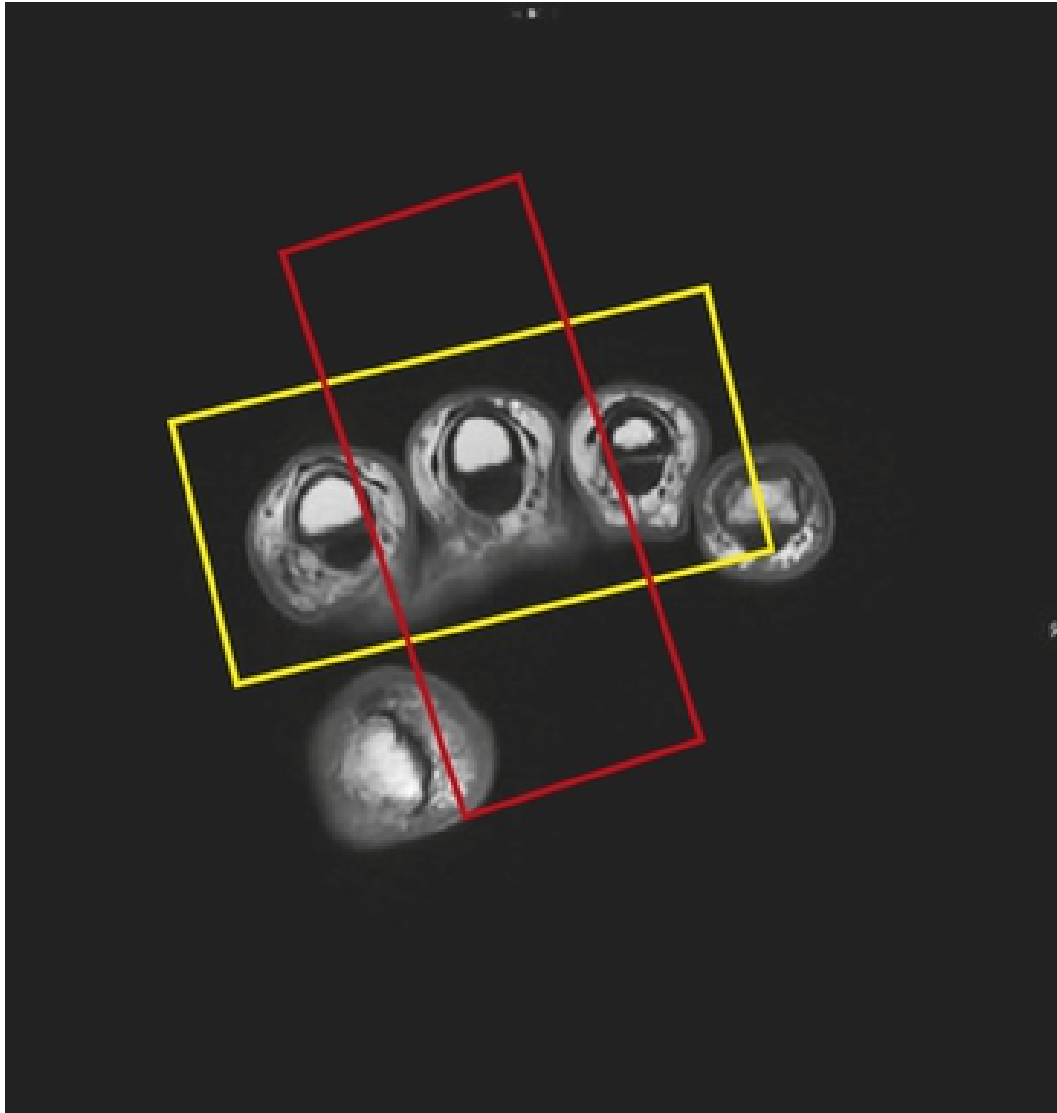


Fig. 2.69c [↗](#)

Planning axial sequence: angle block perpendicular to the pharangeal bones on a coronal image ([Fig. 2.69b](#)). Ensure coverage of all phalanges ([Fig. 2.69a](#)).

Planning coronal sequence: angle parallel to the pharangeal bones on the finger(s) of interest on an axial image (yellow box in [Fig. 2.69c](#)).

Planning sagittal sequence: angle block perpendicular to the pharangeal bones carpal bones on an axial image (red box in [Fig. 2.69c](#)).

Example sequence: hand						
Routine	3 plane localiser	Ax PD FS	Ax T1	Cor T1	Cor T2	Sag PD FS
Example sequences: finger						
Routine	3 plane localiser	Ax T1	Ax T2 FS	True Cor T1	True Cor T2 FS	True Sag T1, True Sag T1 STIR
Additional (tendon)		T1 VIBE	T2 DESS sequence			
Additional (arthritis)	Add STIR sequences					
Additional	Ax T1 FS pre-contrast Ax T1 FS, Cor T1 FS and Sag FS T1 post-contrast					

Acquired Images: Hand and Finger Examples ([Fig. 2.70a](#), [Fig. 2.70b](#) and [Fig. 2.70c](#))



Fig. 2.70a Example of a T1 coronal image of the hand. [↗](#)

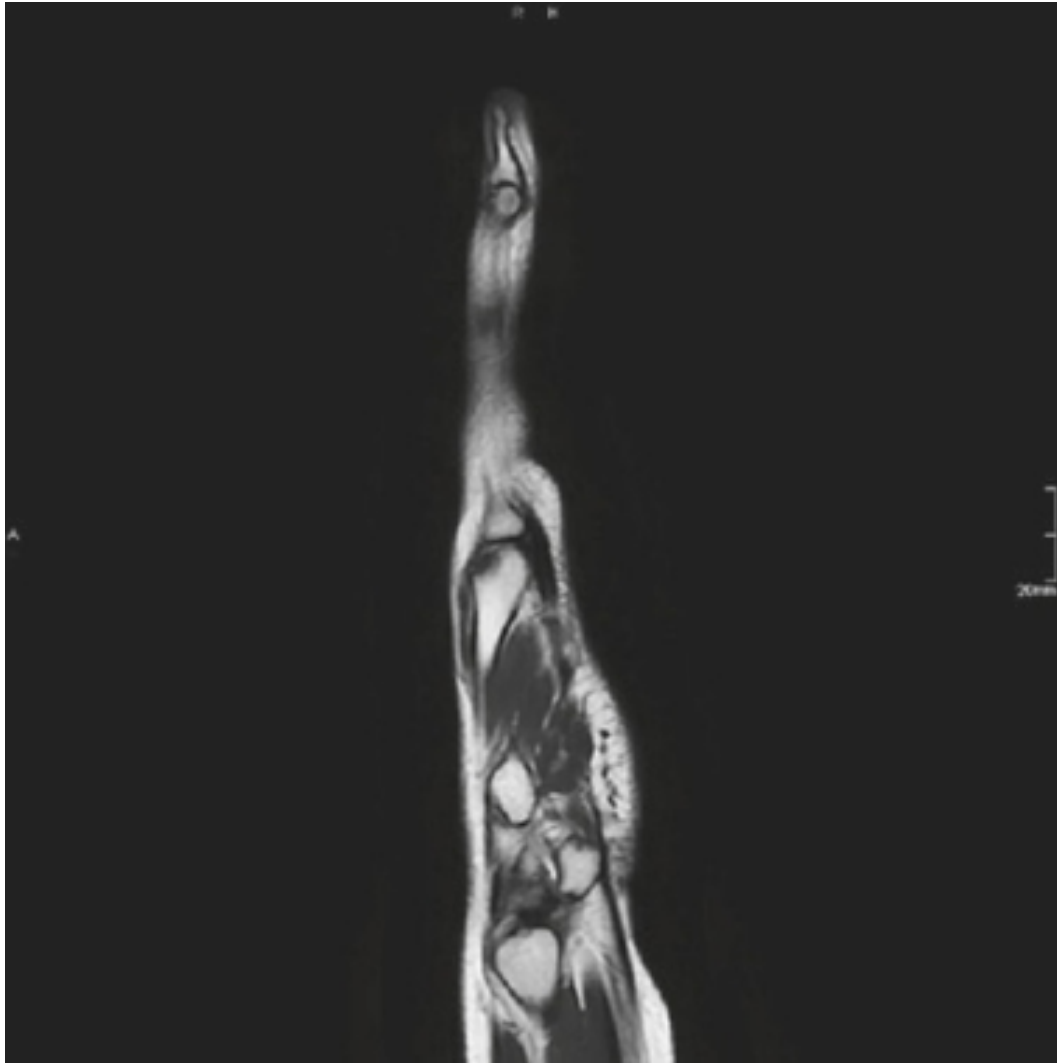


Fig. 2.70b Example of a T1 sagittal image of the hand. [↗](#)

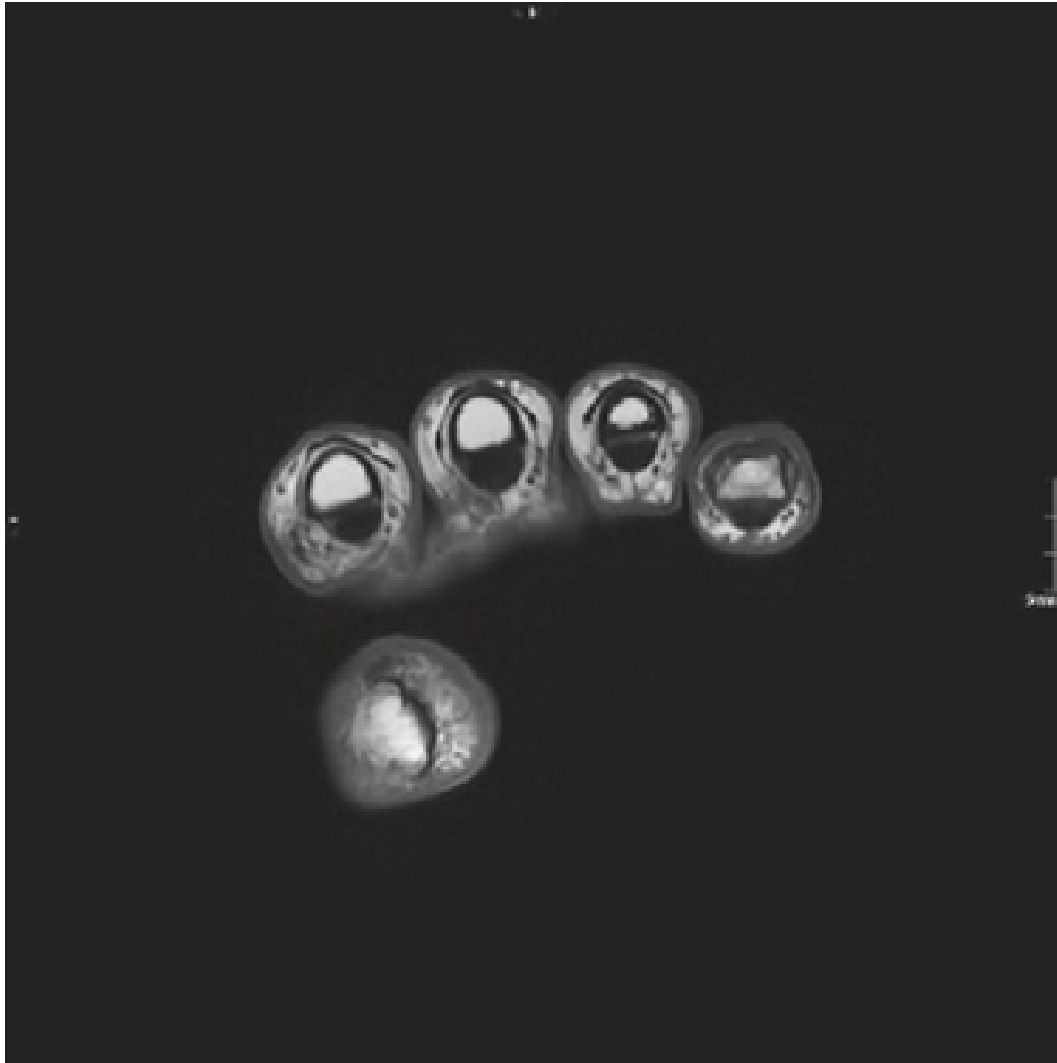


Fig. 2.70c Example of a T2 FS axial image of the hand.[📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Contrast can be given when tumour or infection is indicated.
- Hand injection for all standard hand and wrist imaging is adequate. For vascular angiography, a dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended.
- Contrast may also be injected in the form of a wrist arthrogram to evaluate TFCC (see [Section 3](#)).
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.71a](#), [Fig. 2.71b](#) and [Fig. 2.71c](#))



Fig. 2.71a A scan acquired with arm by side in a patient who has poor mobility and is unable to stretch their arm above their head. [↗](#)

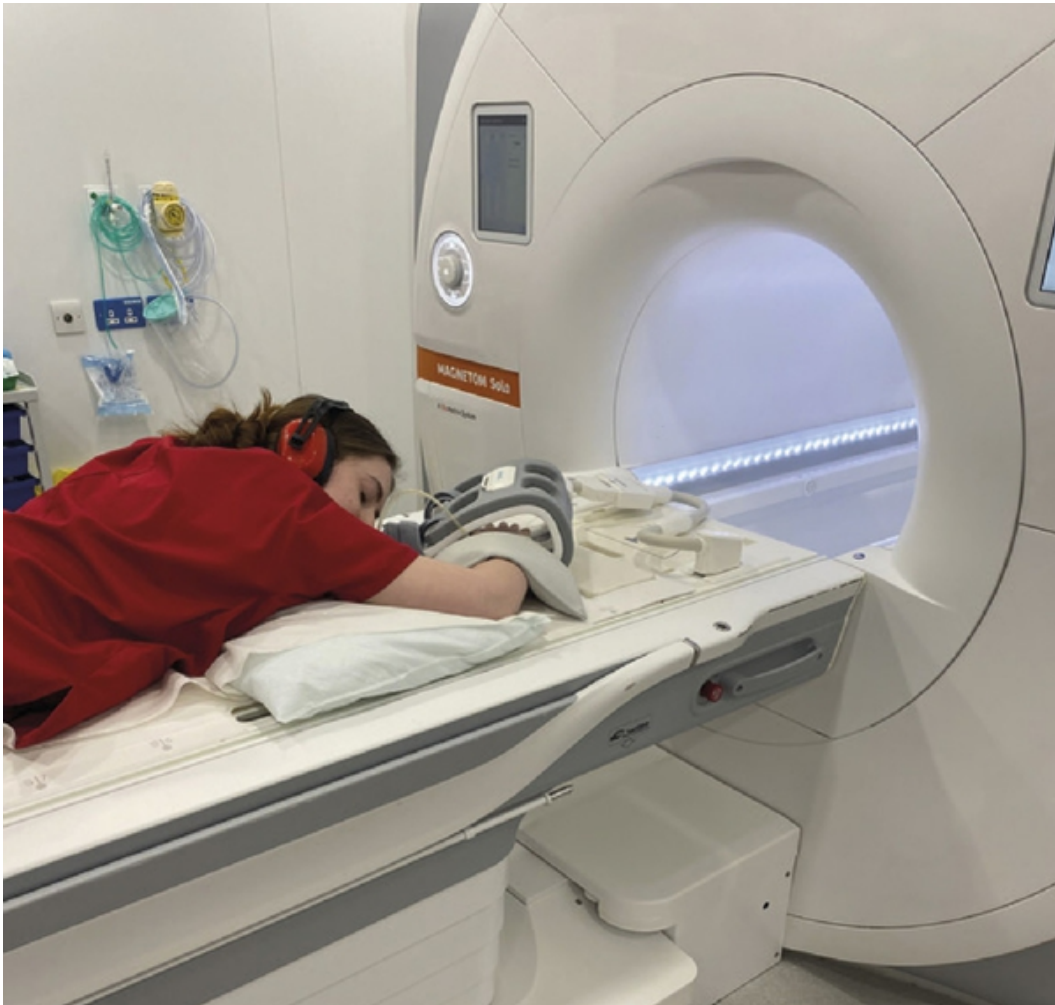


Fig. 2.71b Small flexible coil used in a patient who is unable to place their hand in the dedicated hand/wrist coil. [↗](#)

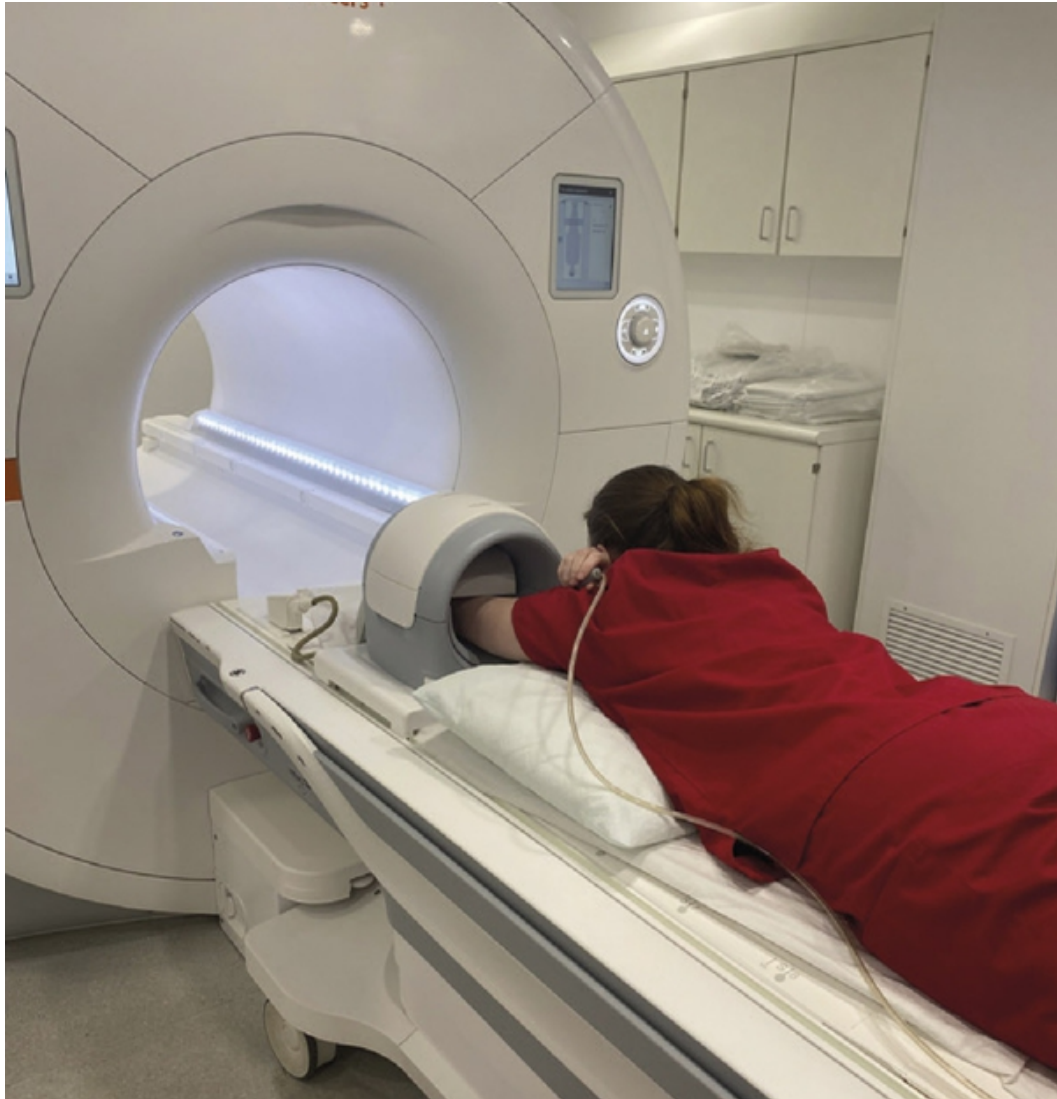


Fig. 2.71c Knee coil is used in a patient who is unable to tolerate the wrist/hand coil due to pain. [📄](#)

Generally, the reasons why adaptive technique is considered are due to the increased body habitus or poor mobility of the patient not allowing for standard positioning.

When it is not possible to position in dedicated coil the small flex coil can be wrapped around the patient's lower arm to encompass the wrist and hand. Alternatively, if the space allows the wrist hand coil can be used and the arm placed at the side of the patient.

SACROILIAC JOINTS

The sacroiliac joint articulates surfaces of the sacrum and the ilium and functions as the transition between the spine and the pelvis. The main roles of the sacroiliac joints are to provide stability and offset the load of the trunk to the lower limbs. The stability of the joint is provided by an extensive architecture of ligamentous structures which adds to the complexities of the joint and requires sensitive and specific diagnosis to allow for correct diagnosis. Amongst all of the available imaging techniques, MRI plays an important role in the diagnosis of sacroiliac disorders.

Indications

- Neoplasm
- Infection
- Inflammation (sacroilitis)
- Avascular necrosis
- Arthritis (rheumatoid arthritis and osteoarthritis)
- Ankylosing spondylitis
- Sacroiliac joint pain
- Psoriasis
- Gout

Imaging Procedure ([Fig. 2.72](#))



Fig. 2.72 Standard positioning. [📄](#)

- Position the patient head-first supine.
- Position the patient's head on a pillow with the spine over the spine coils.
- Use small cushions under the knees. Avoid using large pads that will elevate the thighs.
- Centre for the localiser just below the iliac crests.

Sequence Planning ([Fig. 2.73a](#), [Fig. 2.73b](#) and [Fig. 2.73c](#))

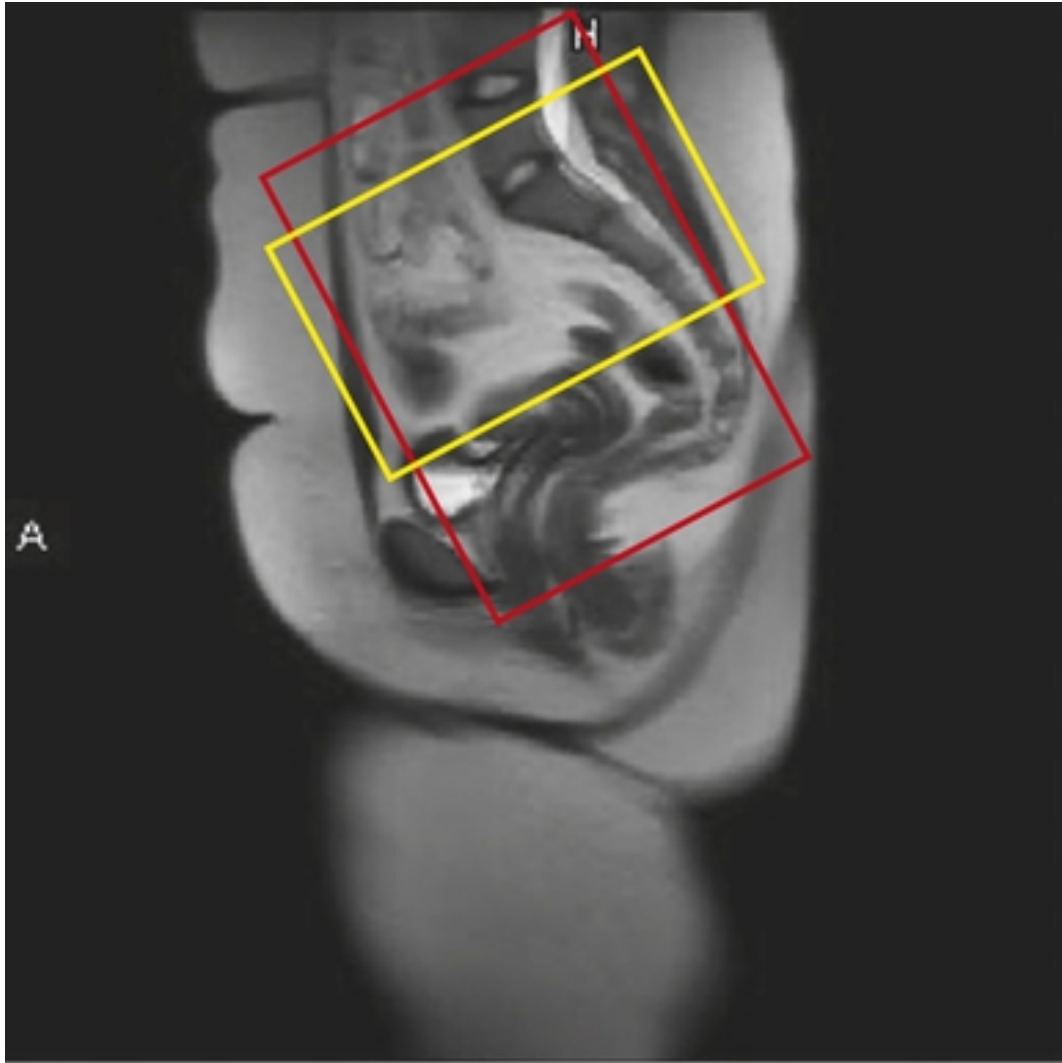


Fig. 2.73a [🔗](#)



Fig. 2.73b [📄](#)

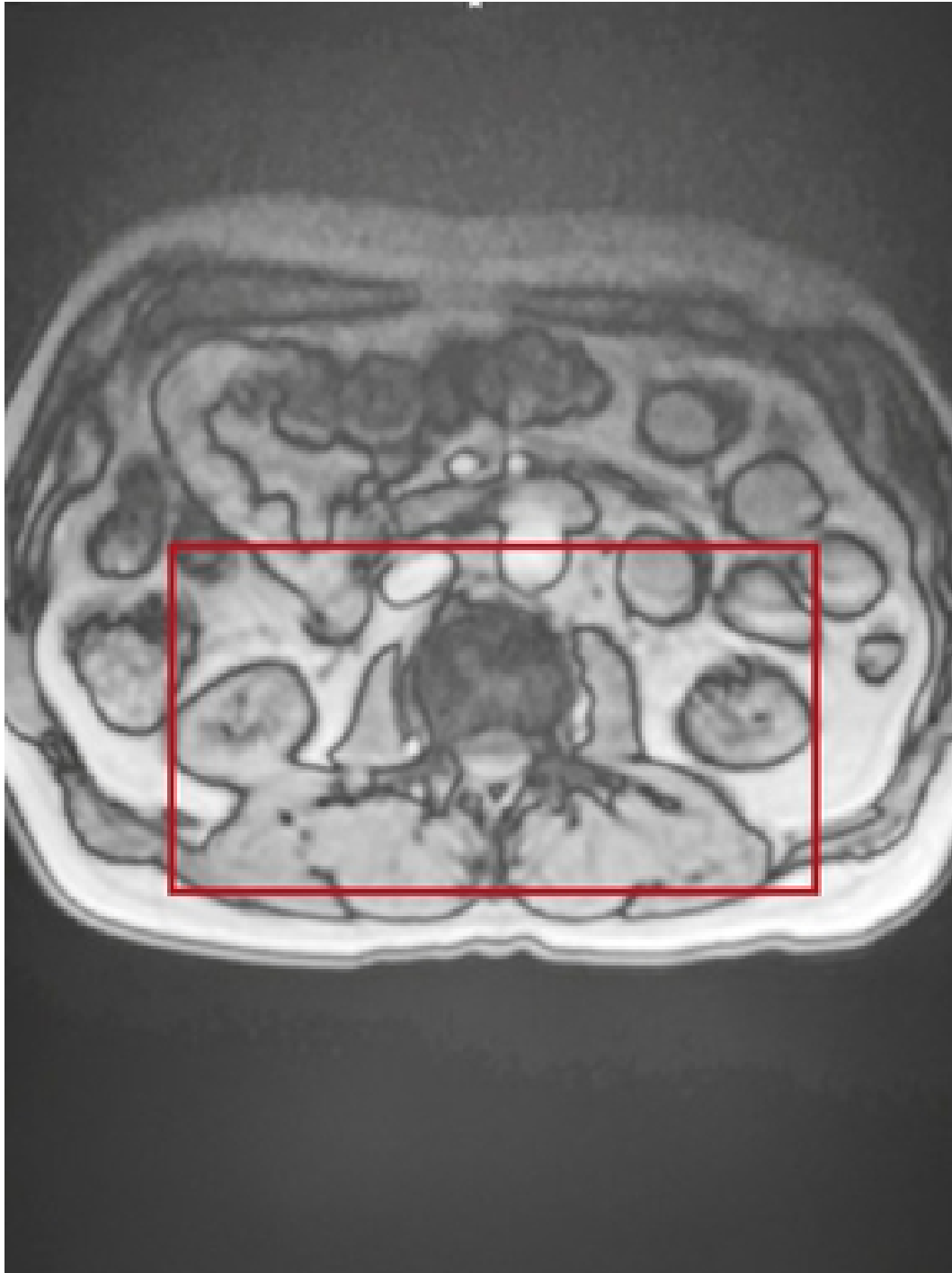


Fig. 2.73c [🔗](#)

Imaging of the sacroiliac joint scanning is often only carried out in the coronal and axial oblique planes.

Planning coronal sequence: plan the block parallel to the sacrum checking the positioning in the other two planes (red box in [Fig. 2.73a](#)).

Planning axial sequence: plan these slices perpendicular to the sacrum (yellow box in [Fig. 2.73a](#)). Ensure that all anatomy is covered as per [Figs. 2.37b,c](#).

Example sequences: sacroiliac joints, sacrum, coccyx					
Routine	3 plane localiser	Cor T2 STIR	Cor T1	Ax oblique T2	Ax oblique T2 FS

Acquired Images: Examples ([Figs. 2.74a, b](#))



Fig. 2.74a Example STIR coronal oblique image. [🔗](#)

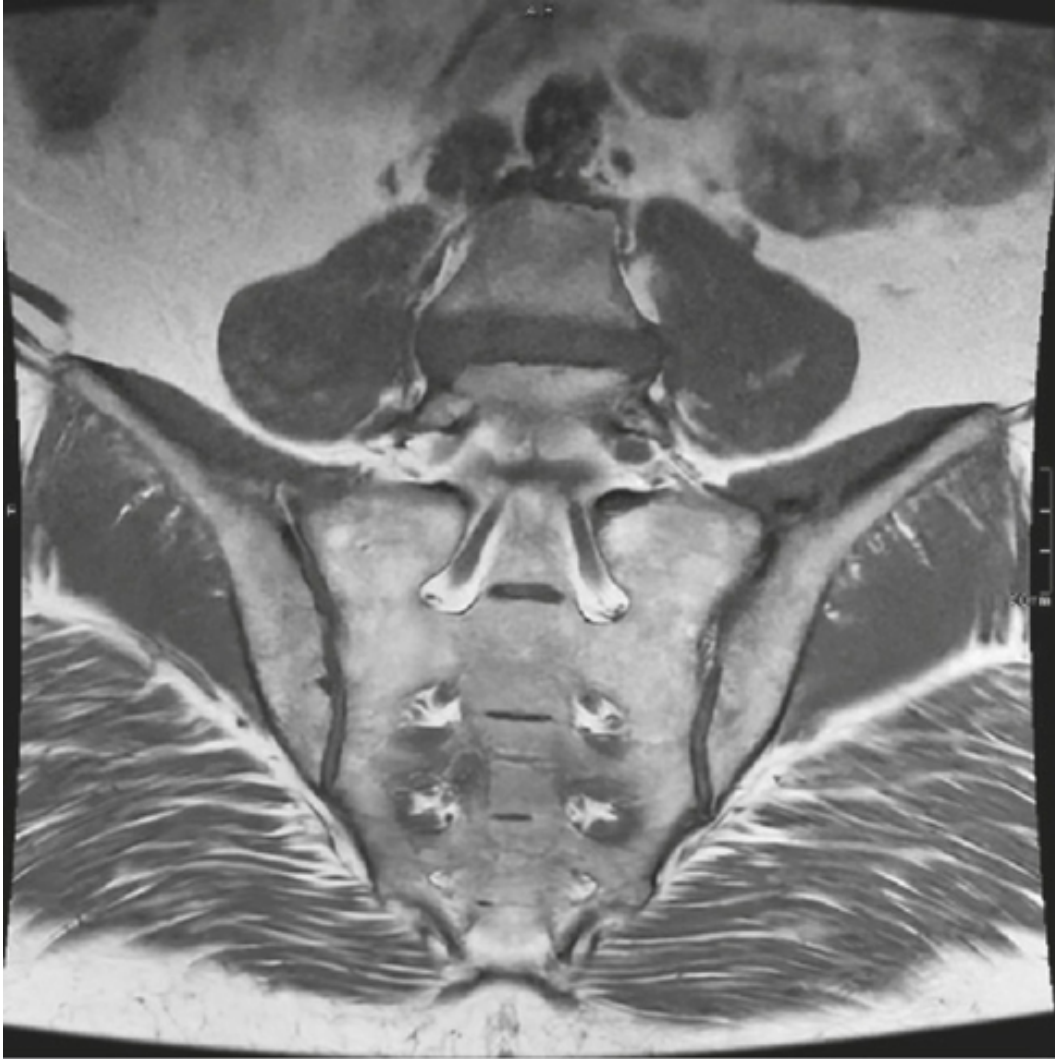


Fig. 2.74b Example T2 coronal oblique image. [🔗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as inflammatory change or osteomyelitis. Hand injection is suitable.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.75a, b](#))



Fig. 2.75a Scan carried out in the left lateral decubitus position in a patient who is unable to lie flat. Body array placed over the level of the sacroiliac joints. Spine coils used also. [↗](#)



Fig. 2.75b Feet-first supine positioning in a patient who has claustrophobia. [🔗](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the sacroiliac joints to acquire a diagnostic image. By positioning the patient feet first in the scanner, the images can still be achieved and the patient is less likely to feel symptoms of claustrophobia. Alternatively, as with other MRI spine examinations if the patient is unable to lie flat on their back they can be positioned in a lateral decubitus (or prone position as per [Fig. 2.79b](#)) with the phased array coil placed over their SIJs.

MUSCULOSKELETAL PELVIS/HIP

MRI is a non-invasive diagnostic method that allows evaluation in patients with musculoskeletal (MSK) pelvis and hip pain to identify and to characterise pathologies ([1](#)). In an ageing population it is valuable in the assessment of osteoarthritis, when clinical examination and X-rays have not demonstrated typical features of osteoarthritis. Current hardware and scanning techniques allow high spatial and contrast resolution imaging that allow the review of normal hip anatomy and common anatomic variants, assessment of acetabular, labral and articular cartilage; and aid in the detection of subtle abnormalities within the joint. MRI is important in the differential diagnosis of inflammatory arthritis (e.g. rheumatoid), femoro-acetabular impingement, septic arthritis and malignancy (bone pain) ([2](#)).

Indications

- Sacroiliac joint pain
- Suspected neoplasm or infection of bone, joint or soft tissue
- Sacroiliac joint inflammation
- Sacroiliac joint dysfunction
- Ankylosing spondylitis
- Suspected osteonecrosis/avascular necrosis
- Suspected periarticular pathology, e.g. abductor tendinopathy
- Bone pain
- Assessment of the extent of osteoarthritis
- When clinical examination, history and X-rays have identified osteoarthritis but more information is needed
- Suspicion of infection: swollen red joint, pyrexia, other risk factors of septic arthritis
- Trauma
- Family history of inflammatory arthropathy

- Mechanical impingement symptoms
- Prolonged morning stiffness
- History of cancer and corresponding factors

NOTE: The sequence selection is dependent upon the locally agreed radiologist protocols.

Imaging Procedure: MSK Pelvis ([Fig. 2.76](#))



Fig. 2.76 Standard positioning. [📄](#)

- Position the patient supine head-first with feet apart and toes turned slightly inwards.
- Place body array coil over the pelvis.

- Use small cushions under the knees. Avoid using large pads that will elevate the thighs.
- Place sandbags next to or across the ankles to encourage the patient to remain still during scans.
- Centre for the localiser with laser light at the level of the femoral heads.
- Position arms comfortably across the chest and upper abdomen; avoid leaving by the side to avoid getting aliasing artefact on images.

Sequence Planning: MSK Pelvis ([Fig. 2.77a](#), [Fig. 2.77b](#) and [Fig. 2.77c](#))

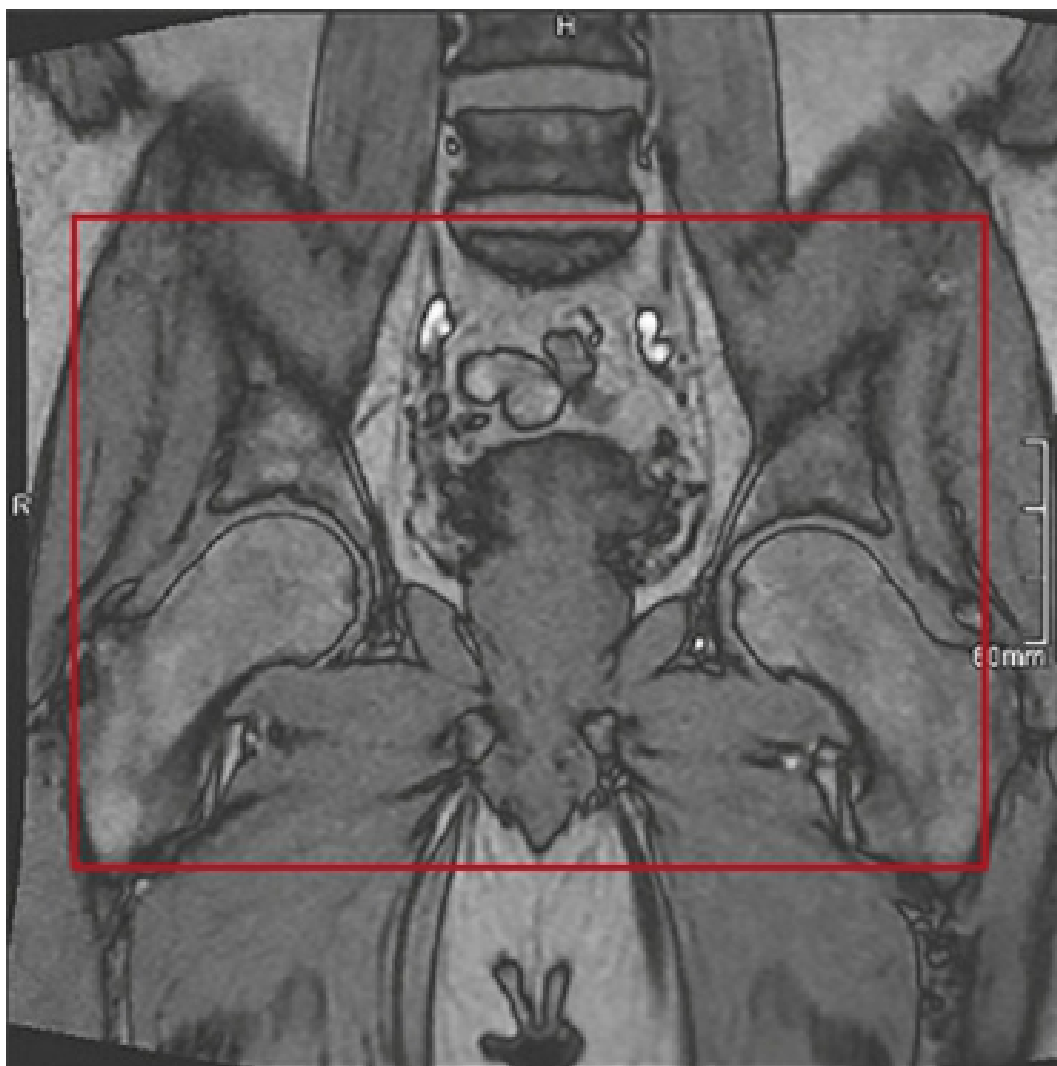


Fig. 2.77a [🔗](#)

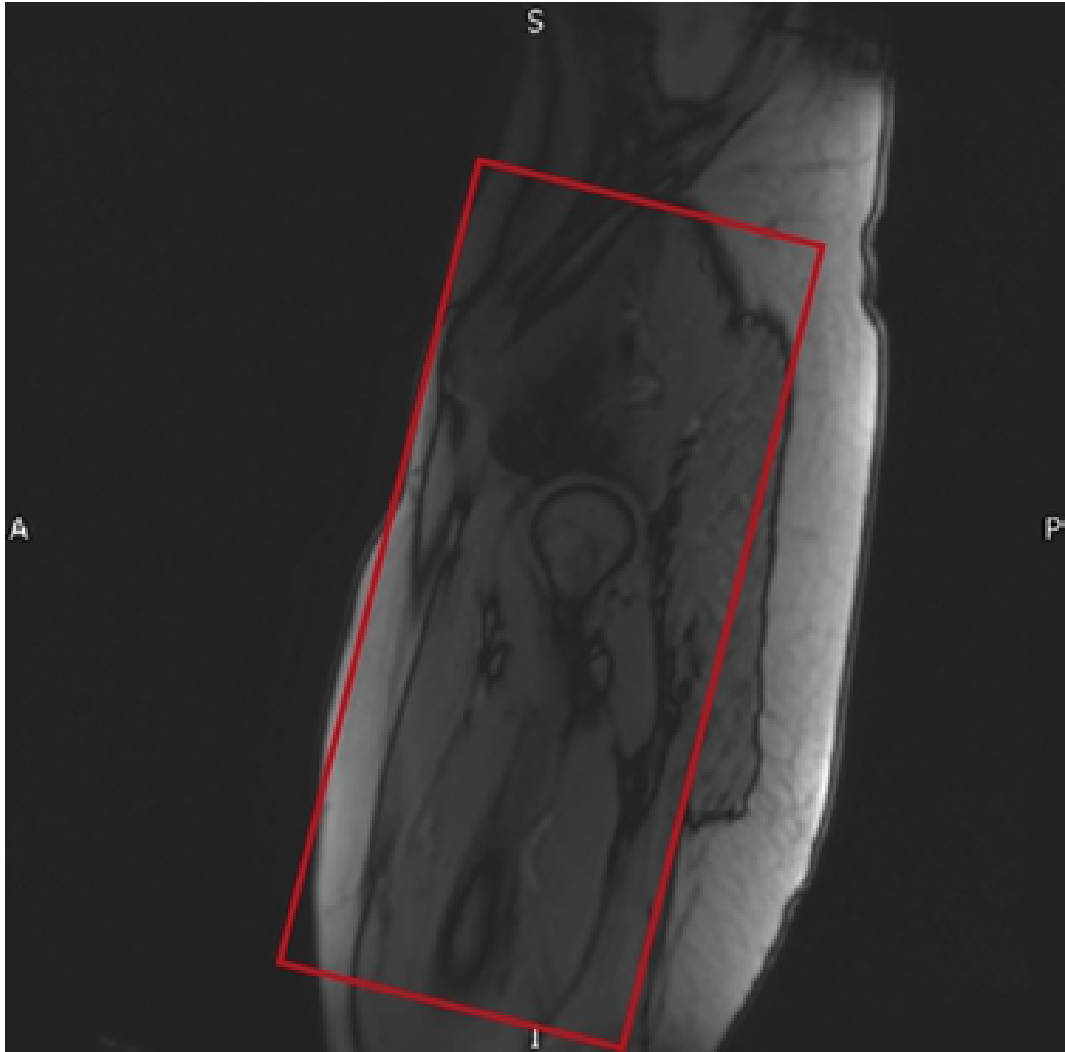


Fig. 2.77b [↗](#)

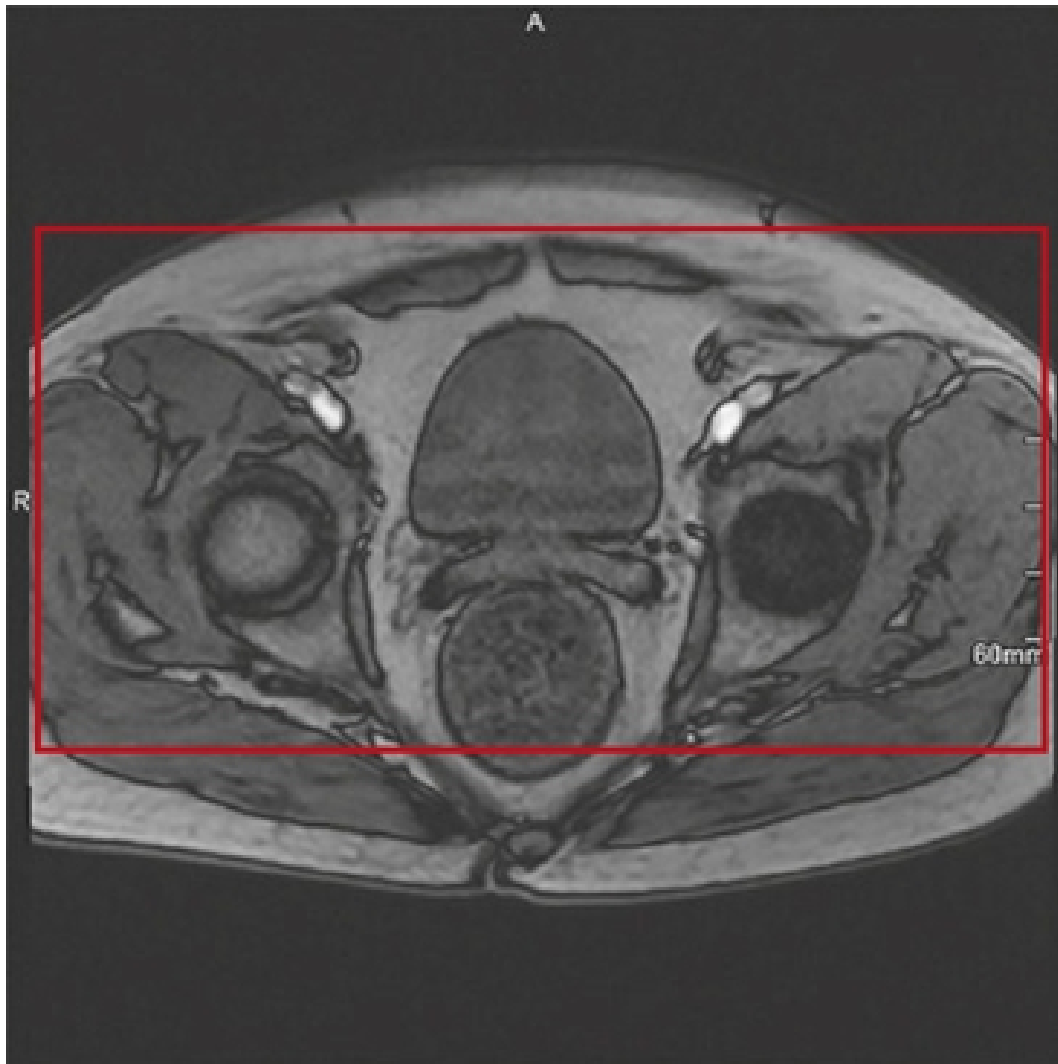


Fig. 2.77c [📄](#)

Planning coronal sequence: plan slices parallel to the femoral heads on an axial image. Check in the other two planes and ensure the block is angled parallel to the femur in the sagittal plane ([Fig. 2.77c](#)). Cover from the top of the iliac crest to below the lesser trochanters.

Planning axial sequence: angle slices parallel to the femoral heads. In the sagittal plane ensure perpendicular to the femur ([Fig. 2.77a](#)). In the sagittal plane ensure perpendicular to the femur ([Fig. 2.77b](#)). Cover from the top of the iliac crest to below the lesser trochanters.

Planning sagittal sequence: plan slices parallel to the femur. In the axial plane ensure perpendicular to the femoral heads ([Fig. 2.77c](#)).

When planning include the sacroiliac joints and all soft tissues of the pelvis.

Example sequences: MSK pelvis						
Routine	3 plane localiser	5 mm Cor T1 STIR	5 mm Cor T1	6 mm Ax T2	6 mm Ax T2 FS	Sag PD FS and Sag T1 of affected hip(s)

Acquired Images: Examples ([Figs. 2.78a,b](#))



Fig. 2.78a Example of T1 coronal image. [📄](#)

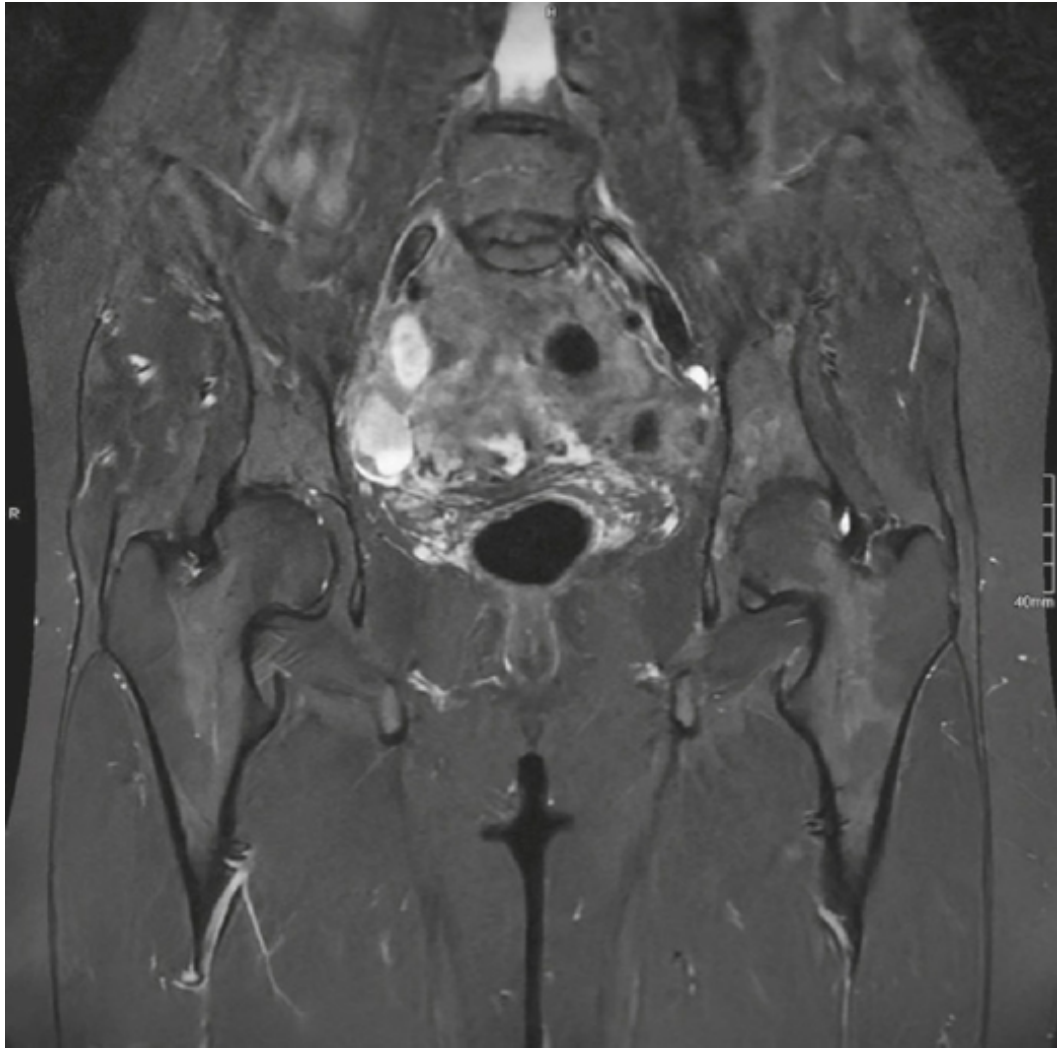


Fig. 2.78b Example of T1 STIR coronal image. [🔗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard MSK pelvic imaging is adequate. Where vascular angiography is indicated, dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.79a,b](#))



Fig. 2.79a Feet-first supine position in a patient who has claustrophobia. [↗](#)



Fig. 2.79b Prone position a patient who is unable to lie flat. [↗](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis, or claustrophobia, adaptive techniques can be used to demonstrate the anatomy of the pelvis to acquire a diagnostic image. By positioning the patient feet first in the scanner, the images can still be achieved and they are less likely to experience feelings of claustrophobia. Alternatively, if the patient is unable to lie flat on their back, then they can lay prone with the phased array coil placed over their back.

Imaging Procedure: MSK Hips

Follow standard positioning technique used for MSK pelvis (see [Fig. 2.76](#)).

Sequence Planning: MSK Hips ([Fig. 2.80a](#), [Fig. 2.80b](#) and [Fig. 2.80c](#))



Fig. 2.80a [🔗](#)

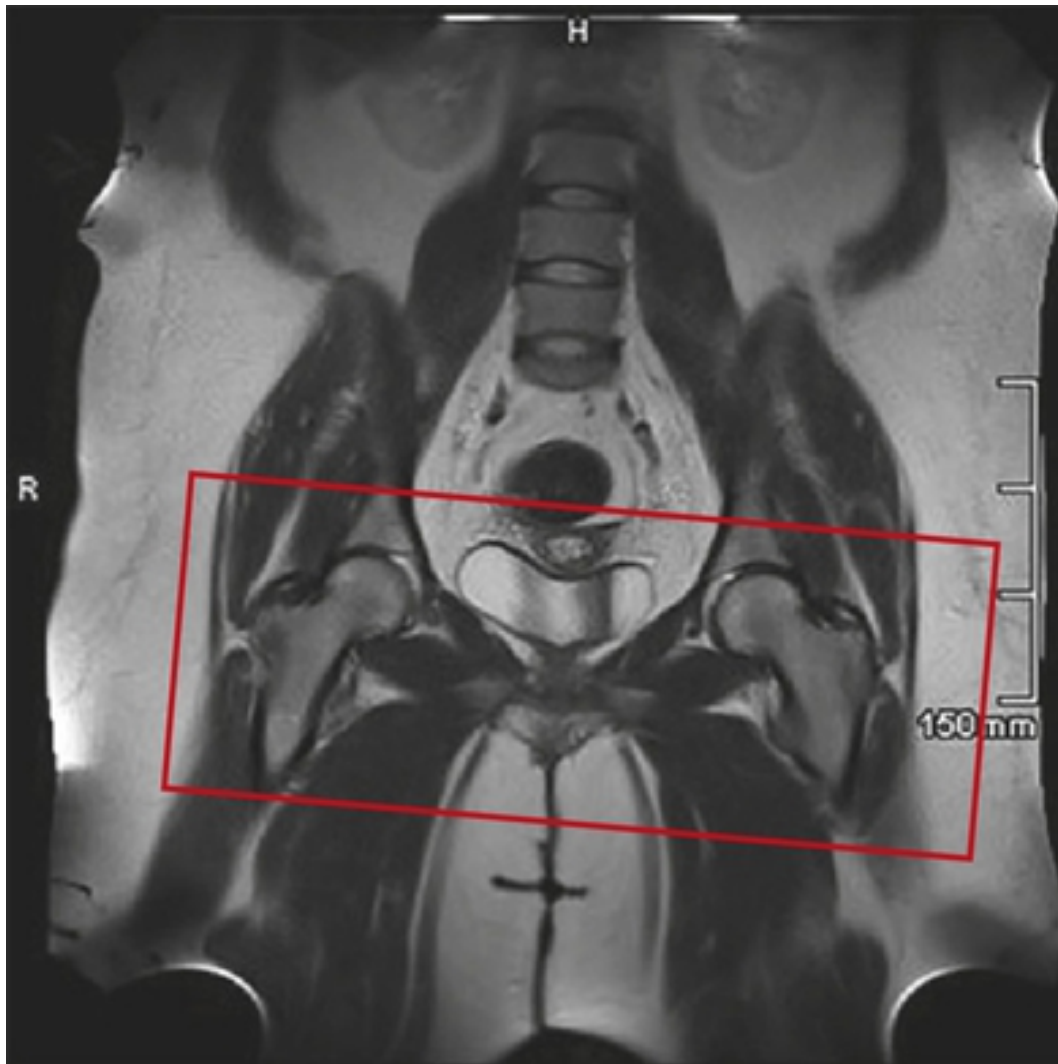


Fig. 2.80b [🔗](#)

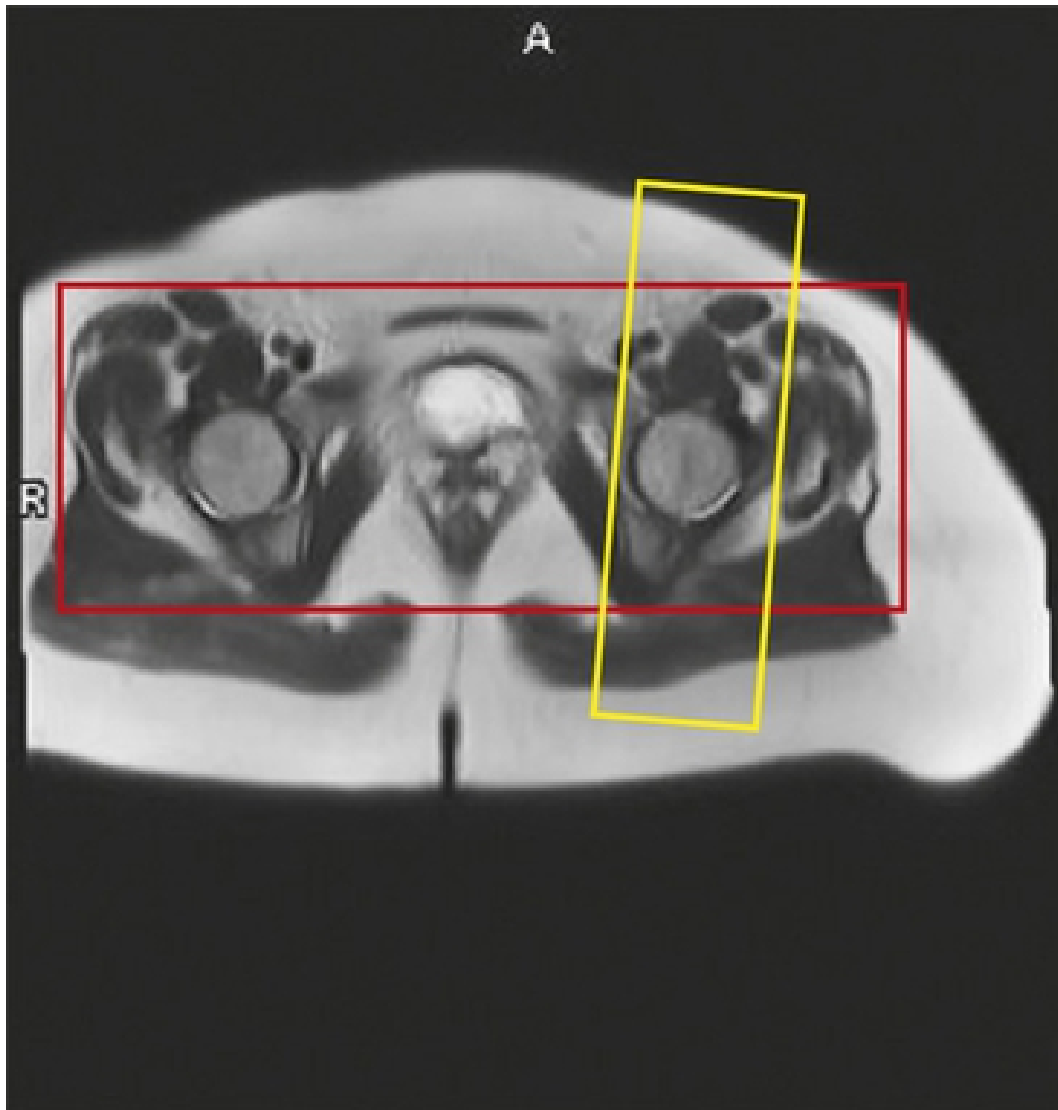


Fig. 2.80c [🔗](#)

Planning coronal sequence: plan on an axial slice – angle from the right and left, parallel to femoral heads. On a sagittal image adjust the angle of slices parallel to the femur and check that, on all three planes of localiser, slices cover from the iliac crest to the upper third of the femur ([Fig. 2.80c](#)).

Planning axial sequence: plan on a coronal sequence – angle slices along right and left femoral heads. On a sagittal image adjust the angle of the slices perpendicular to femur and check that, on all three planes of

localiser, slices cover from above the acetabulum to below the lesser trochanter ([Figs. 2.80a,b](#)).

Planning sagittal sequence: plan using the axial and coronal sequence images. Angle slices parallel to the femur, covering from the outer cortex of the femur to the symphysis pubis (yellow box in [Fig. 2.80c](#)).

Example sequences: MSK hips						
Routine	3 plane	4 mm	4 mm	3.5 mm	3.5 mm	Sag PD FS
	localiser	Cor T1	Cor T1	Ax T2	Ax T2	and Sag
		STIR			FS	T1 of affected hip(s)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard MSK hip imaging is adequate. Where vascular angiography is indicated, dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques

When it is not possible to position the patient in the standard position adaptive techniques can be used (see [Figs. 2.79a,b](#)).

Imaging Procedure: Unilateral Hip ([Fig. 2.81](#))



Fig. 2.81 Standard positioning. [↗](#)

- Position the patient head-first supine with feet apart and toes turned slightly inwards.
- Place a flexible coil off-centre on the patient over the hip that is being imaged. Centre the coil level with the centre of the femoral head.
- Use small cushions under the knees. Avoid using large pads that will elevate the thighs.
- Place sandbags next to or across the ankles to encourage the patient to remain still during scans.

- Centre for localiser with the laser light at the level of the femoral head.
- Position arms comfortably across the chest and upper abdomen; avoid leaving by the side to avoid getting aliasing artefact on images.

Sequence Planning: Unilateral Hip ([Fig. 2.82a](#), [Fig. 2.82b](#) and [Fig. 2.82c](#))



Fig. 2.82a [↗](#)

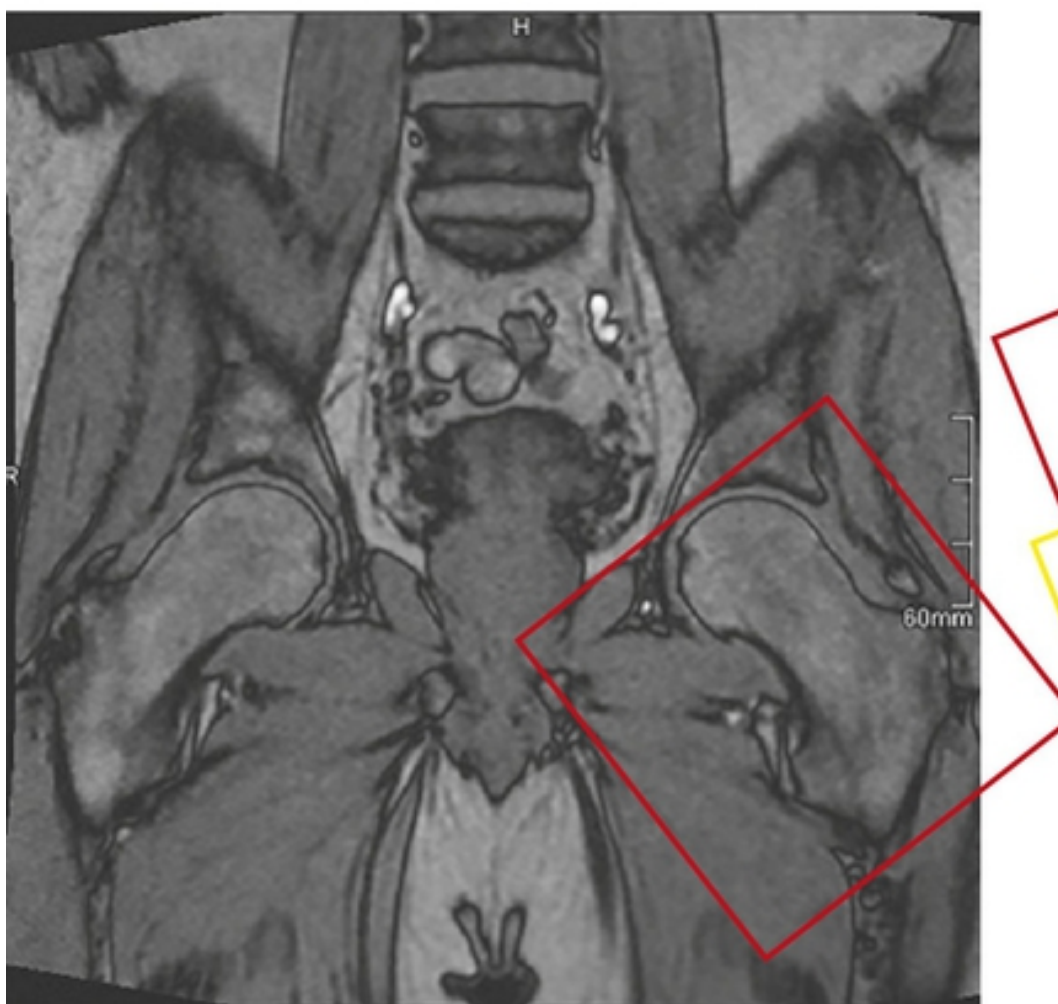


Fig. 2.82b [↗](#)

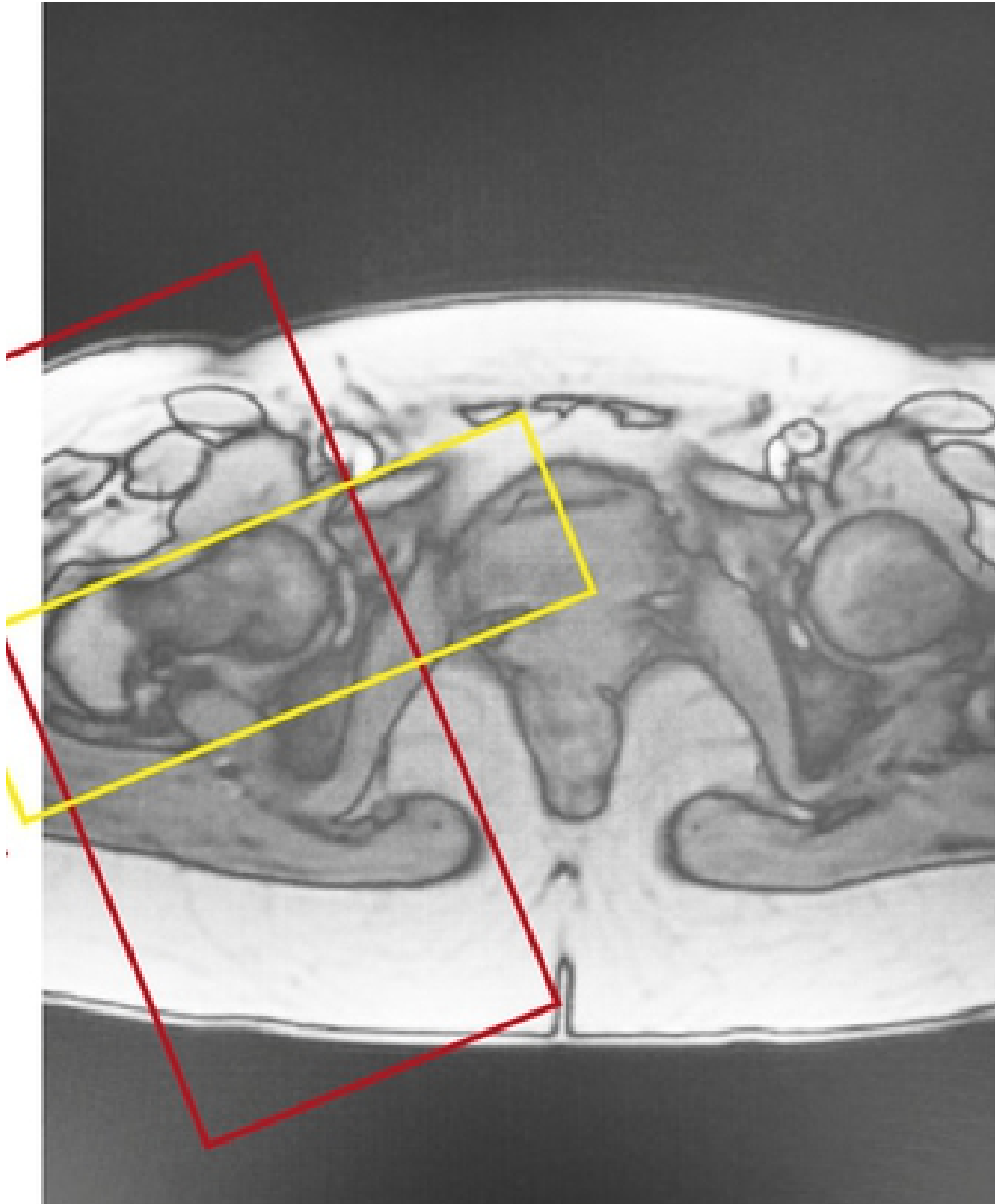


Fig. 2.82c [🔗](#)

Planning axial oblique sequence: angle along the femoral neck on a coronal image. Ensure slices cover from above the acetabulum to the lesser trochanter ([Fig. 2.82b](#)). On an axial image plan slices parallel to the angle of the neck of femur (red box in [Fig. 2.82c](#)).

Planning coronal oblique sequence: angle perpendicular to the femoral neck on an axial image. ([Fig. 2.82a](#)). On an axial image angle parallel to the neck of the femur (yellow box in [Fig. 2.82c](#)).

Example sequences: unilateral hip						
Routine	3 plane localiser	3 mm Cor oblique PD FS	3 mm Cor oblique T2	3 mm Ax TRUFI 3D	3 mm Ax obliqueT1	3 mm Sag oblique PD FS
Additional sequences	Ax and Cor oblique T1 FS pre- and post-contrast					

Contrast Media and Injection Data: Unilateral Hip

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for standard hip imaging is adequate. Where vascular angiography is indicated, dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended. Contrast may also be injected in the form of an arthrogram to evaluate the hip joint, see [Section 3](#).
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Acquired Images: Examples ([Figs. 2.83a,b](#))

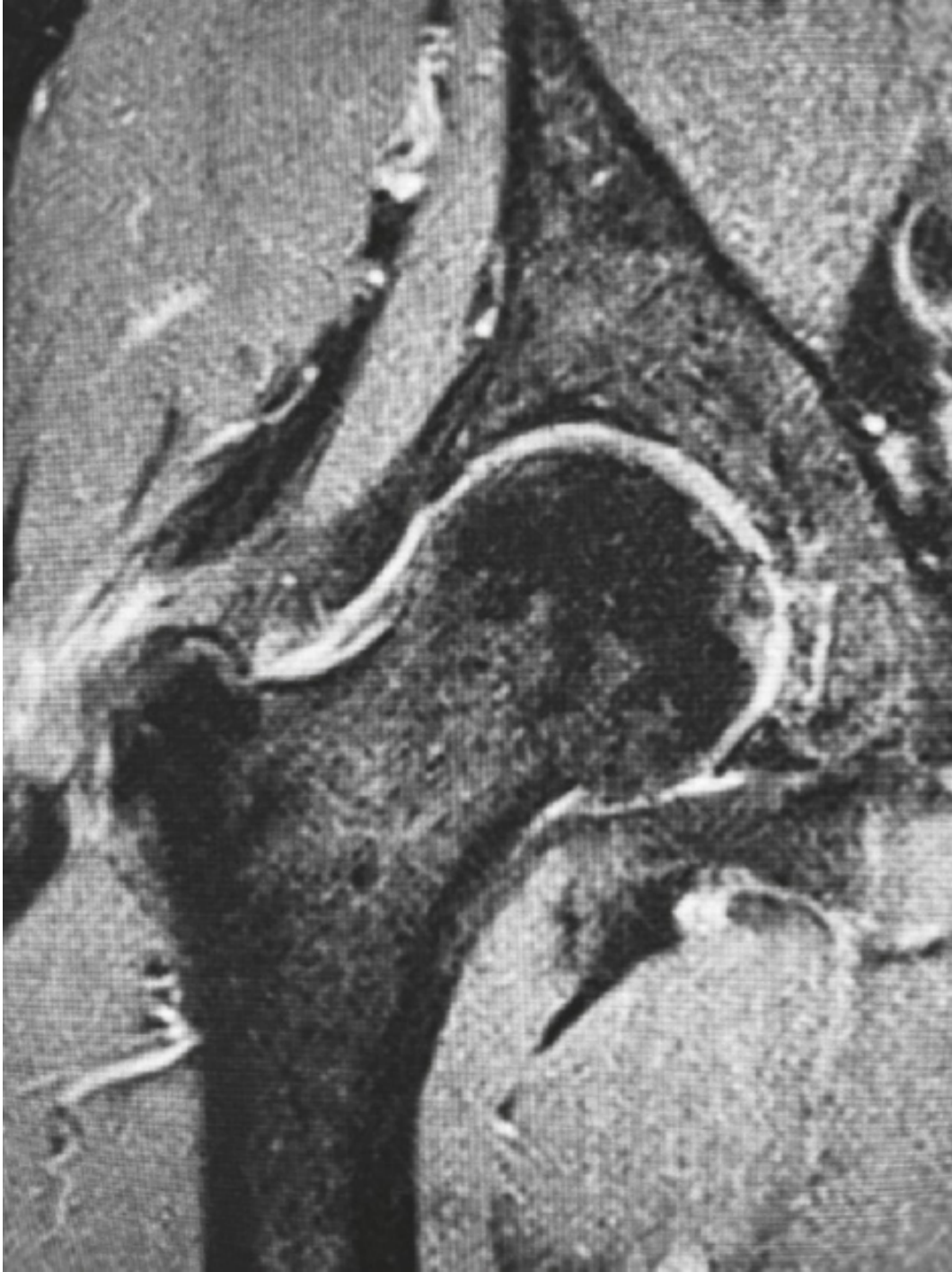


Fig. 2.83a Example of a high-resolution coronal oblique image through the hip joint.[↗](#)

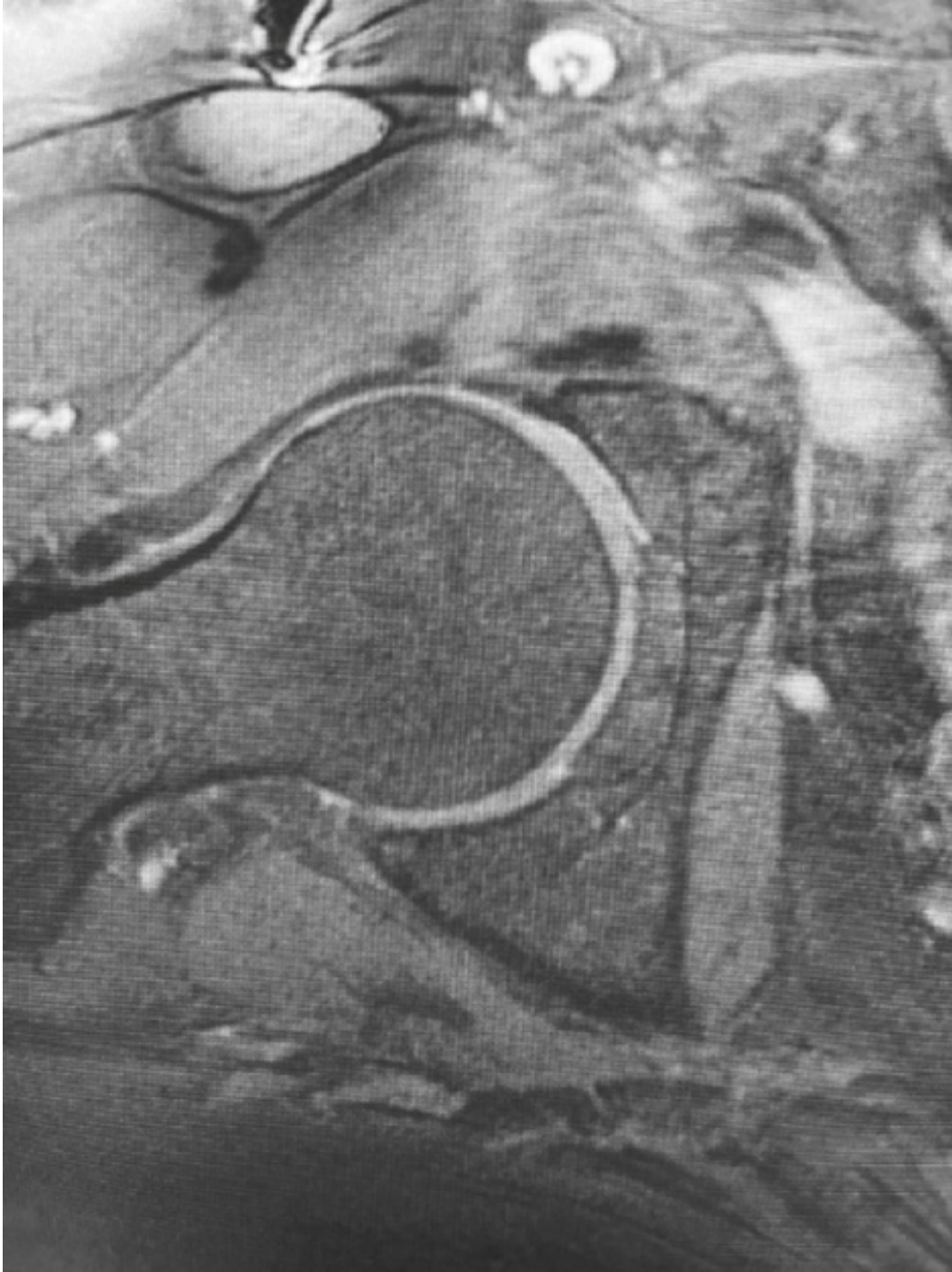


Fig. 2.83b Example of a high-resolution axial oblique image through the hip joint. [📄](#)

Adaptive Techniques ([Fig. 2.84](#))



Fig. 2.84 Feet-first supine in a patient who has claustrophobia, using a small flexible coil for a single high-resolution hip scan.[📄](#)

When it is not possible to position the patient in the standard position adaptive techniques can be used. It is possible to position feet first to alleviate feelings of claustrophobia. Also refer to adaptive technique in the MSK pelvis and hips sections for use of the body array coil as an alternative and altered patient positions (see [Figs. 2.79a,b](#)).

PELVIS GROIN

MRI can be used to diagnose pathology in patients who present with groin pain, allowing visualisation of the tendons of the rectus abdominis and adductor longus, pubic bone pathology and will aid diagnosis of hip or inguinal canal abnormalities ([13](#)).

Imaging Procedure

Refer to standard positioning for MSK pelvis (see [Fig. 2.76](#)).

Indications

- Pain
- Injury
- Labral tears/fractures
- Tumour
- Infection, e.g. osteomyelitis
- Swelling/lump
- Suspected inguinal hernia

Sequence Planning ([Fig. 2.85a](#), [Fig. 2.85b](#) and [Fig. 2.85c](#))

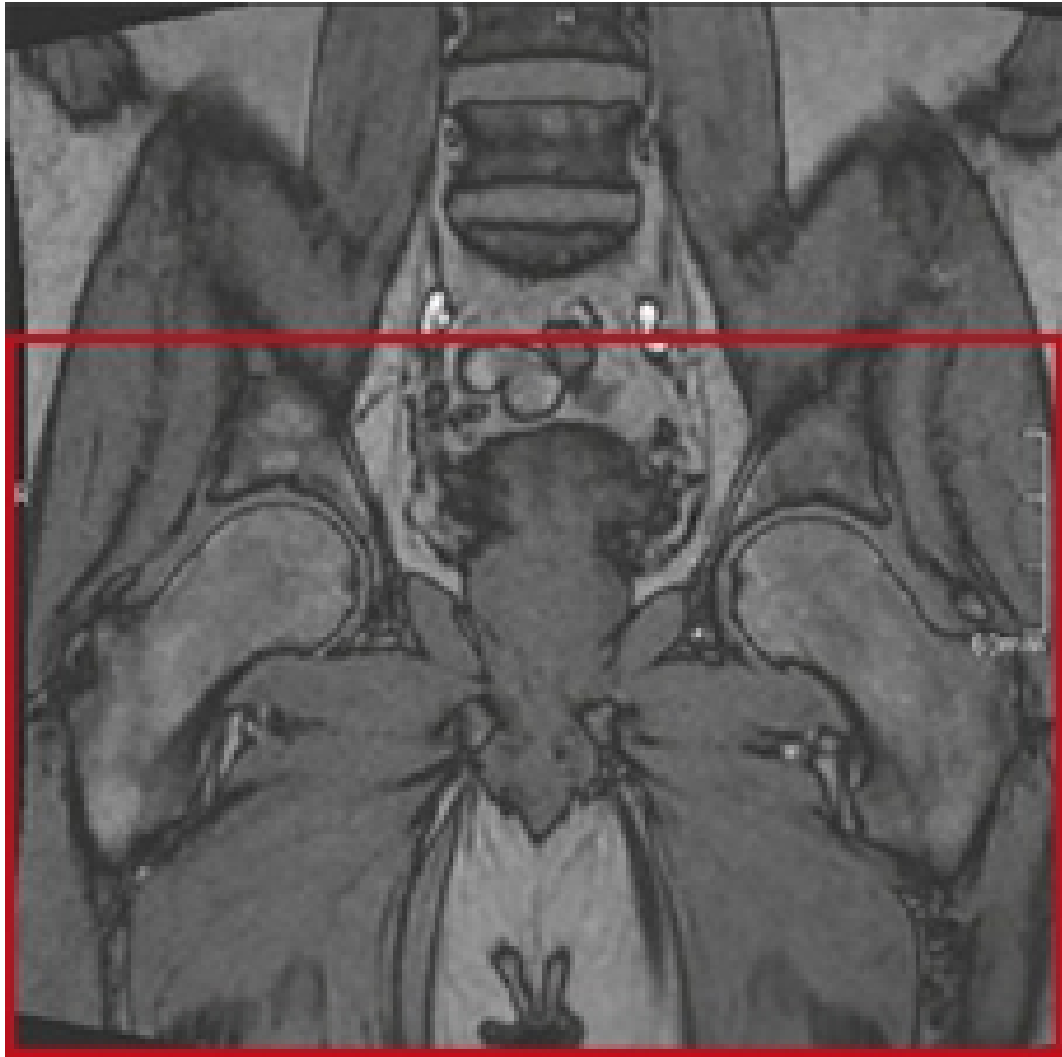


Fig. 2.85a [↗](#)

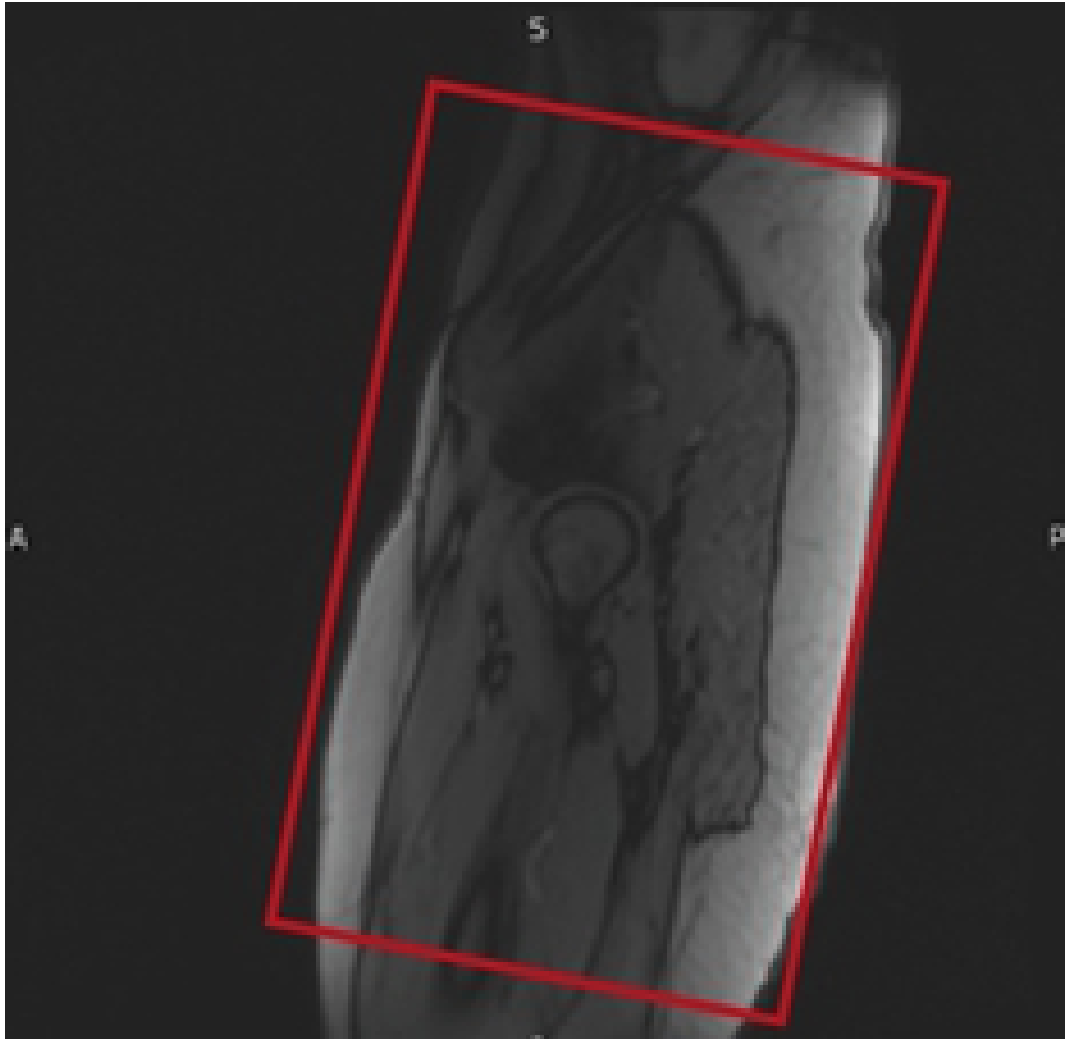


Fig. 2.85b [↗](#)

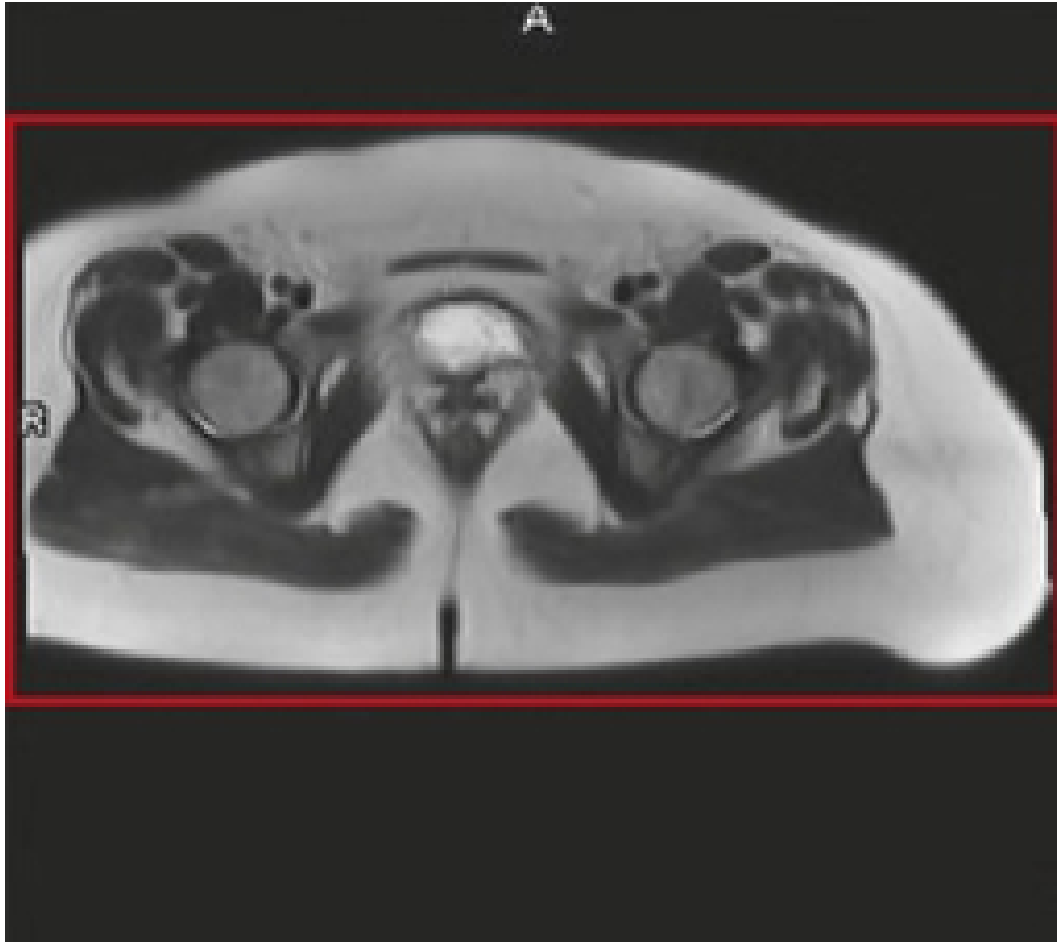


Fig. 2.85c [↗](#)

Planning coronal sequence: angle slices across the femoral heads on an axial image ([Fig. 2.85c](#)). In the sagittal plane angle parallel to the femur.

Planning axial sequence: angle slices parallel to the femoral heads on a coronal image ([Fig. 2.85a](#)). In the sagittal plane ensure the block is perpendicular to the Femur ([Fig. 2.85b](#)).

Planning sagittal sequence: angle slices parallel to the femur on a coronal image ([Fig. 2.85a](#)). In the axial plane ensure the block is perpendicular to the femoral head ([Fig. 2.85c](#)).

Ensure slices cover through to skin edges to include the whole pelvis and soft tissues of the groin areas.

Example sequences: groin						
Routine	3 plane localiser	Cor STIR	Cor T1	Ax T1	Ax T2 FS	Sag PD FS affected side

Acquired Images: Examples ([Figs. 2.86a,b](#))

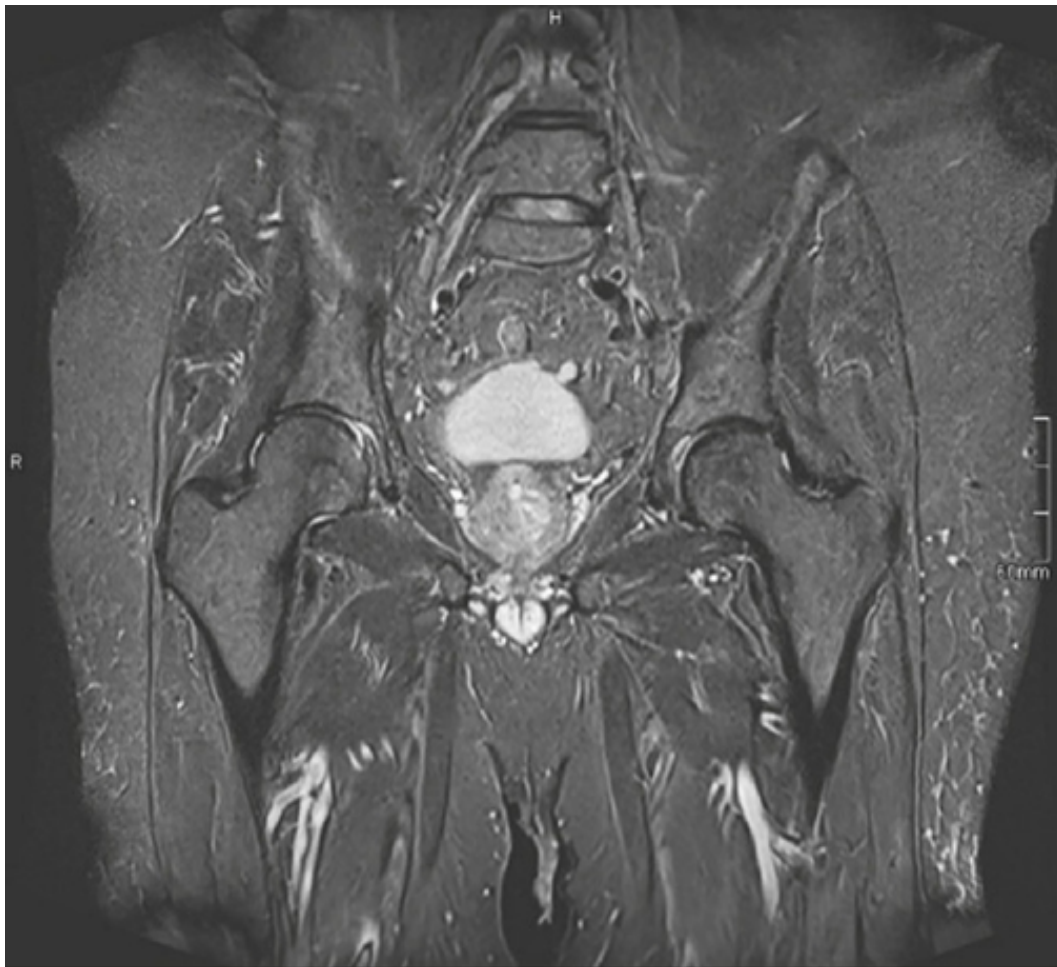


Fig. 2.86a Example of a coronal STIR image. [↗](#)

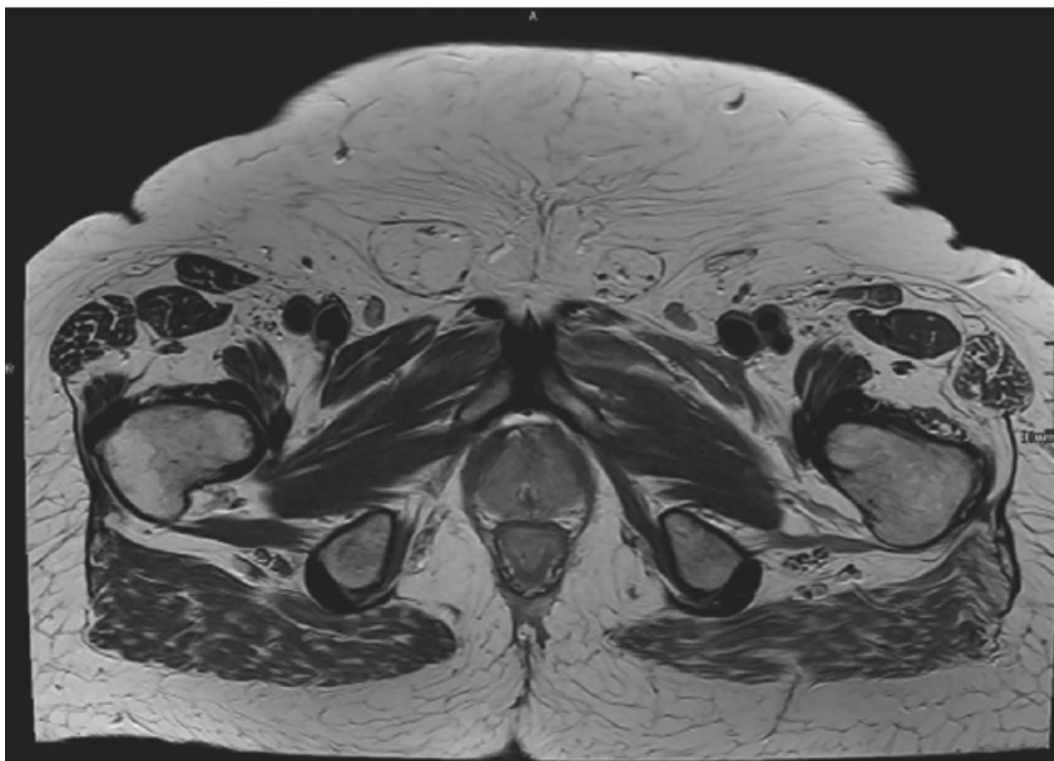


Fig. 2.86b Example of a T1 axial image through the inguinal groin. Ensure the FOV is adequate to cover skin surface. [↗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard pelvic groin imaging is adequate. Where vascular angiography of the pelvis is indicated, dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques

Refer to adaptive technique in the MSK pelvis section for the use of body array as an alternative and altered patient position ([Figs. 2.79a,b](#)).

RECTUM

Colorectal cancer is the third most common cancer in men and the second in women. The prognosis of rectal cancer is indirectly related to the tumour infiltration into the mesorectum and the ability to surgically achieve negative circumferential resection. MR is considered to give the best images of the tissues around the rectum and in identifying the extent of any disease. MR plays a key role in the staging and treatment of patients with rectal cancer. The high resolution of MR can accurately assess tumour infiltration in and beyond the different layers of the bowel wall along with infiltration into surrounding structures. The accuracy of MR helps with the treatment pathways for individuals and can also help to provide the surgical approach to treatment and determine whether radiotherapy or chemotherapy is needed.

Indications

- Patients who are suspected to have rectal carcinoma
- Patients who have undergone post-operative chemotherapy
- Staging for new diagnosis of rectal carcinoma
- Infection
- Pain
- Inflammation
- Abscess

Imaging Procedure ([Fig. 2.87](#))



Fig. 2.87 Standard positioning. [↗](#)

- Position the patient head-first supine.
- Place body array(s) over the pelvis and abdomen.
- Use a support under the knees to help the patient to remain still.
- Centre for the localiser with laser light over the crests of the pelvis.

Sequence Planning ([Fig. 2.88a](#), [Fig. 2.88b](#) and [Fig. 2.88c](#))



Fig. 2.88a [📄](#)

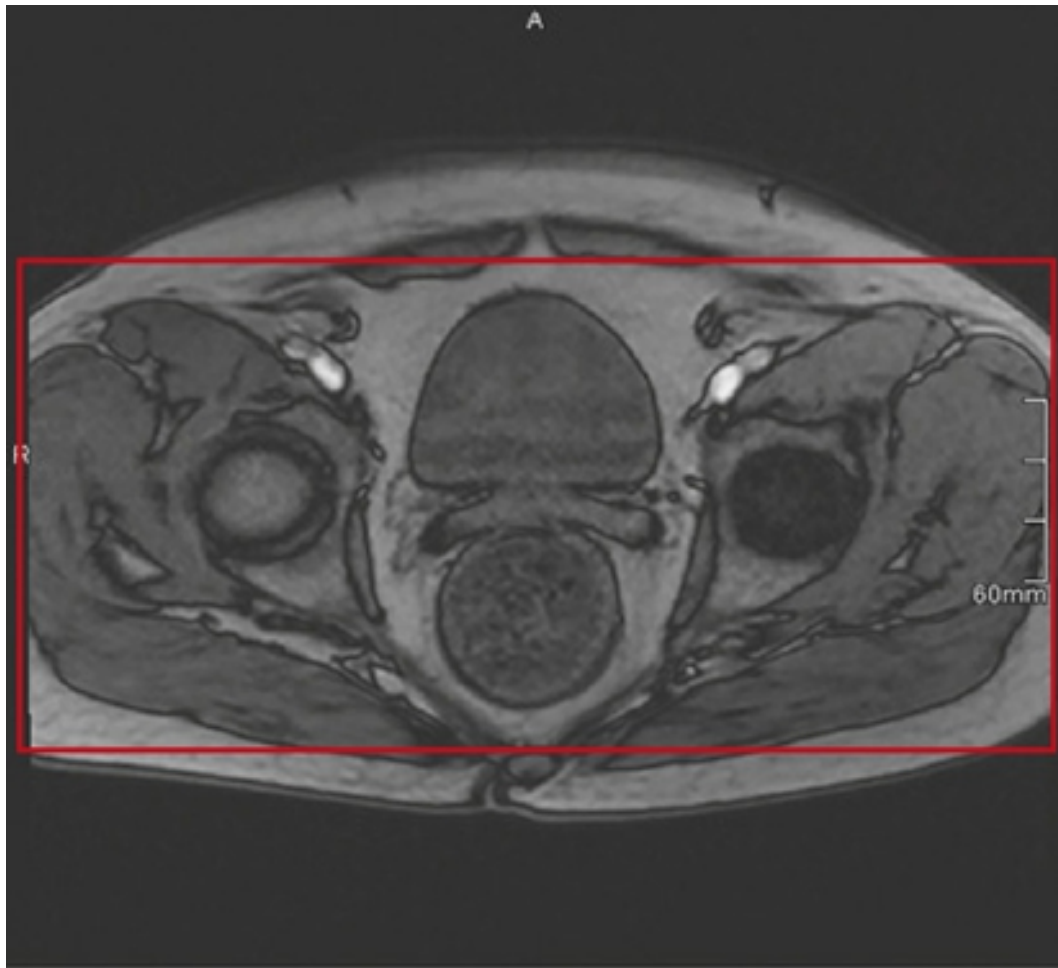


Fig. 2.88b [🔗](#)

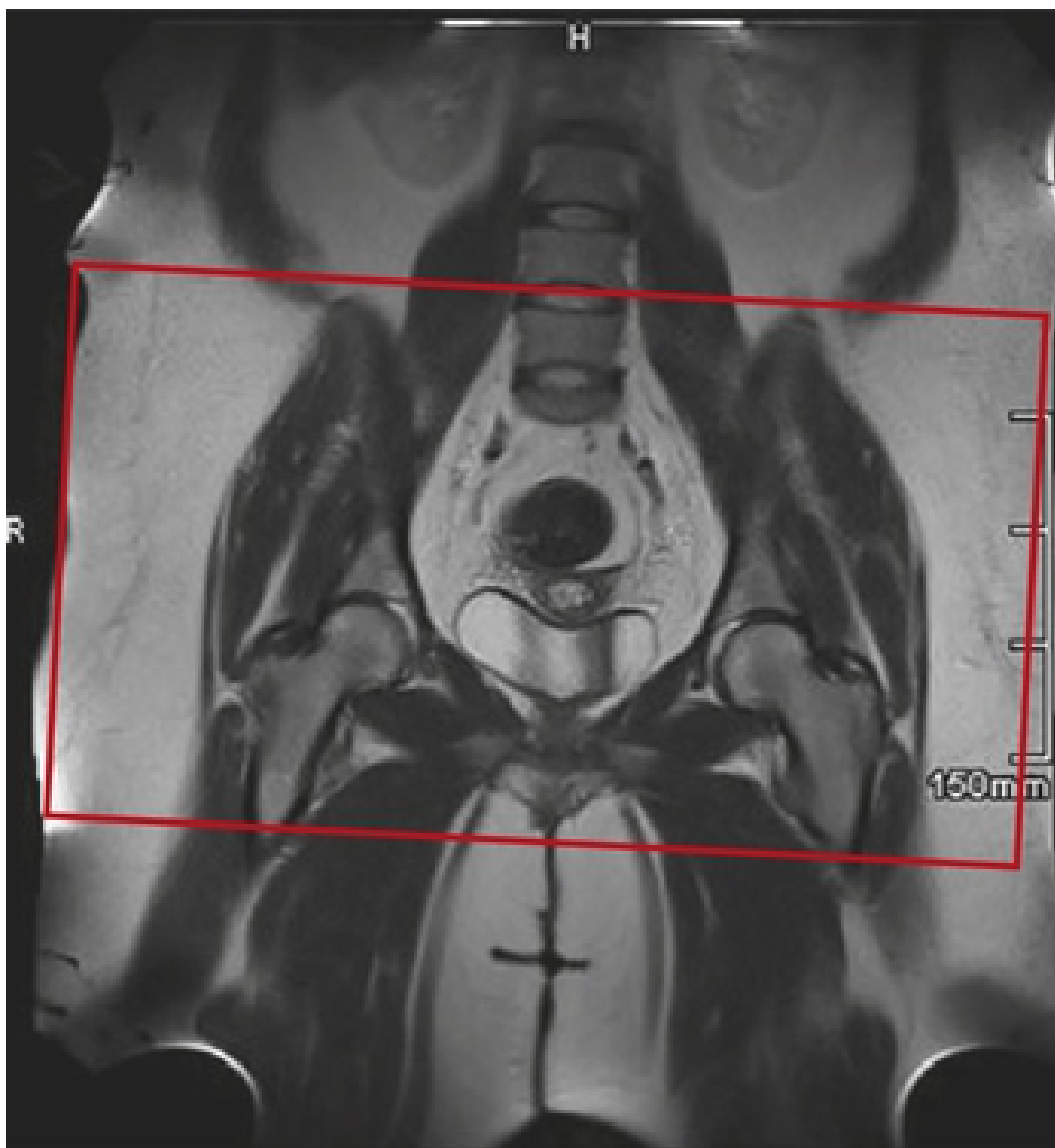


Fig. 2.88c [📄](#)

Planning sagittal sequence: position the block parallel to the interpubic fibrocartilage and the anal canal on an axial image ([Fig. 2.88b](#)). Ensure full coverage ([Fig. 2.88c](#)).

Planning axial oblique sequence: plan on a sagittal image, angling slices perpendicular to the rectum, or any visible cancer in the rectum (red box in [Fig. 2.88a](#)).

Planning coronal oblique sequence: plan on the sagittal sequence. Plan this block 90 degrees to the block that was planned on the axial oblique sequence, angling the slices parallel to the rectum or any visible cancer in the rectum on a sagittal image (yellow box in [Fig. 2.88a](#)).

Planning axial DWI: copy the centre of slices to the axial oblique sequence.

Planning axial T2 inner pelvic sequence: angle the block perpendicular to the rectum on a sagittal image, ensuring slices cover the entire rectum. Check positioning in the other two planes.

Planning axial T1 pelvic sequence: angle the slices across the abdomen on a sagittal image. To ensure coverage of the para-aortic and pre-sacral lymph nodes use a large FOV and cover from the level of the mid-abdomen to the bottom of the pelvis.

Planning coronal abdomen: plan on a sagittal image and angle the block parallel to the vertebral bodies of the spine. Using an axial image align the block across the level of both hip joints. To ensure coverage of the para-aortic and pre-sacral lymph nodes use a large FOV and cover from the level of the mid-abdomen to the bottom of the pelvis.

Planning axial T1 upper abdomen: angle on the coronal image so that the slices are perpendicular to the thoracic vertebra. In the sagittal plane angle the block perpendicular to the long axis of the kidney. Ensure slices cover from the top of the liver to ensure coverage of the para-aortic lymph nodes.

Example sequences: rectum							
Routine	3 plane	Sag	Ax T1	Ax T2	T2	T2	DWI
	localiser	T2	pelvis	inner pelvis	long axis	short axis	
Additional	Ax T2 HASTE upper abdomen Cor T1 abdomen						

Acquired Images: Examples ([Figs. 2.89a,b](#))

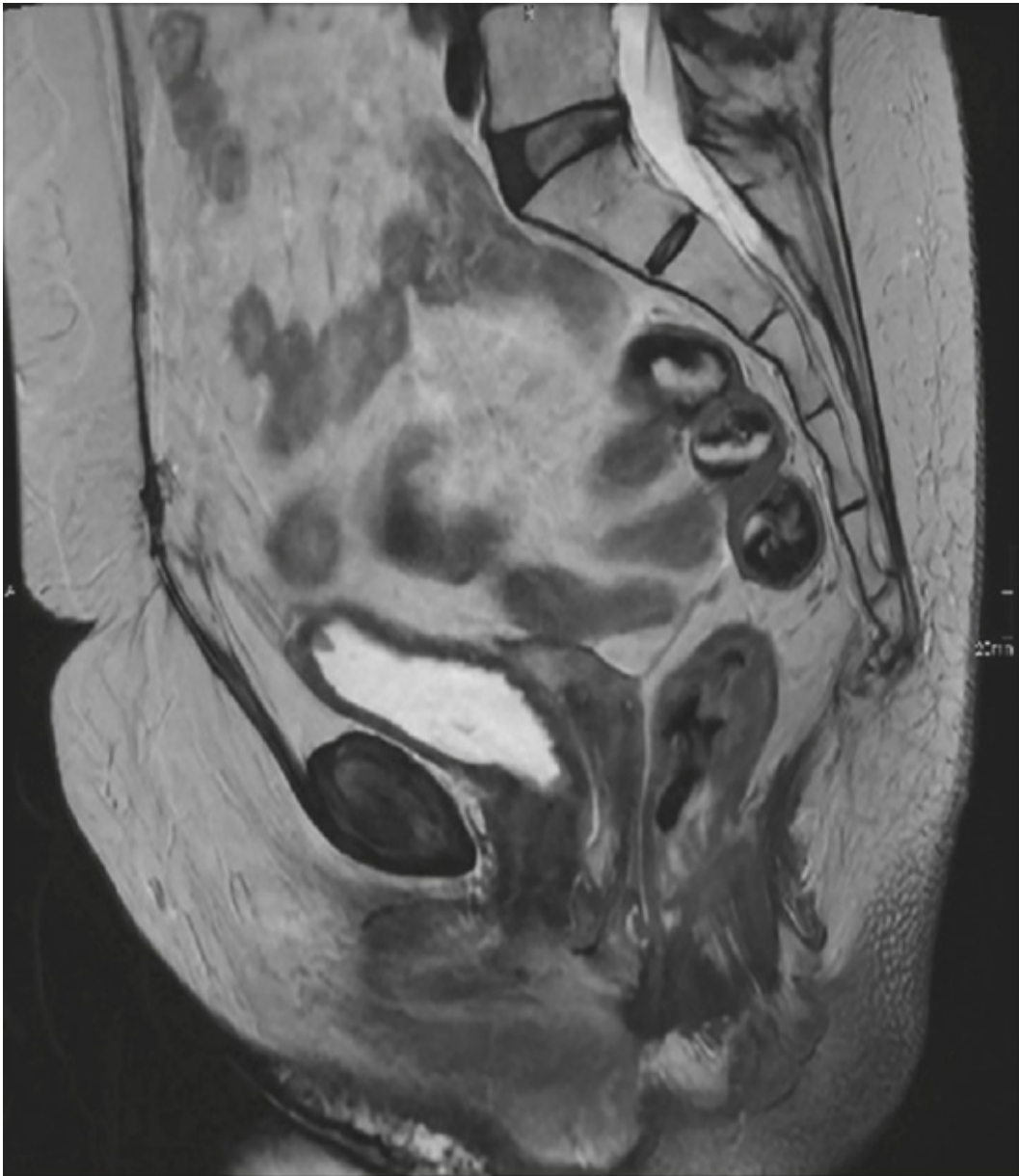


Fig. 2.89a Example of a sagittal T2 image through the midline. This sequence can be used to plan the high-resolution slices through the rectum. [↗](#)

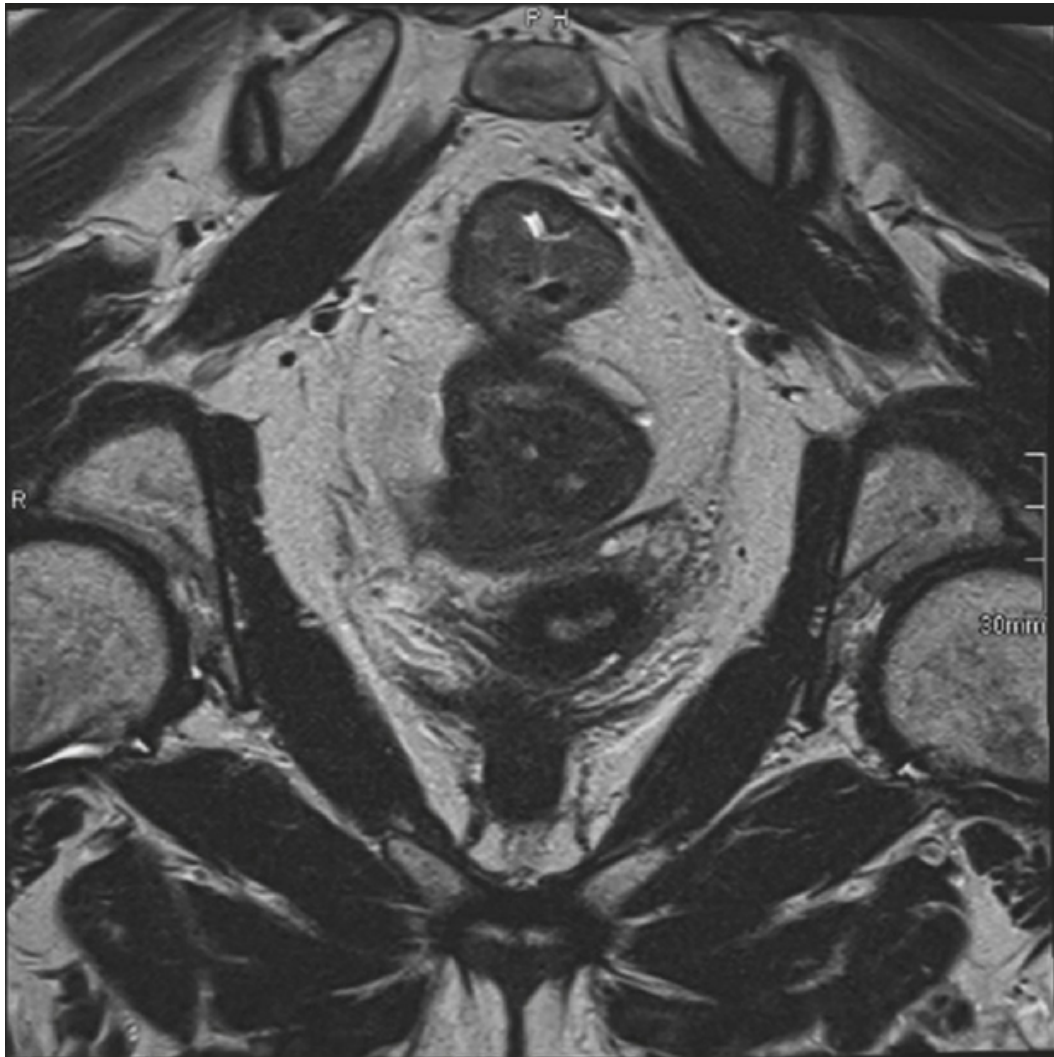


Fig. 2.89b Example of a high-resolution T2 long axis image through the rectum. [↗](#)

Contrast Medium and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Contrast is not generally necessary for the imaging of the rectum when looking for tumour. If contrast is indicated, a hand injection is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.
- An antispasmodic can be administered to limit peristalsis from the bowel creating artefact on the resultant imaging.

Adaptive Techniques ([Figs. 2.90a,b](#))



Fig. 2.90a Patient positioned feet-first supine due to claustrophobia, using the spine coils and body array coils. [↗](#)



Fig. 2.90b Patient who is unable to lie supine is positioned head-first prone. Spine coils and body array coils are used. [↗](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or severe claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the rectum to acquire a diagnostic image. By positioning the patient feet first in the scanner the images can still be achieved, and patients are less likely to feel symptoms of claustrophobia.

PERINEUM

MRI is the most sensitive, non-invasive imaging modality used for looking at soft tissues and structures of the perineum along with the surrounding organs. Imaging of the perineum can depict the complex sphincteric and muscle anatomy of the anal canal, which enables reference of anatomical description of fistulas and abscess location.

Indications

- Neoplasm
- Infection
- Inflammation
- Anal cramps/pain
- For the assessment of activity of perianal fistula in the course of Crohn's disease
- For pre-operative evaluation of perineal fistula or abscess
- To check the anatomy of the anal region
- To investigate the causes and extent of fistulas

Imaging Procedure ([Fig. 2.91](#))



Fig. 2.91 Standard positioning. [🔗](#)

- Position the patient head-first supine.
- Position the patient with their head on a pillow.
- Place their legs over a support device for comfort.
- Use cushions and pads as appropriate to ensure they remain still throughout the scan.
- Centre for the localiser with laser light over the centre of the pelvis.

Sequence Planning ([Fig. 2.92a](#), [Fig. 2.92b](#) and [Fig. 2.92c](#))

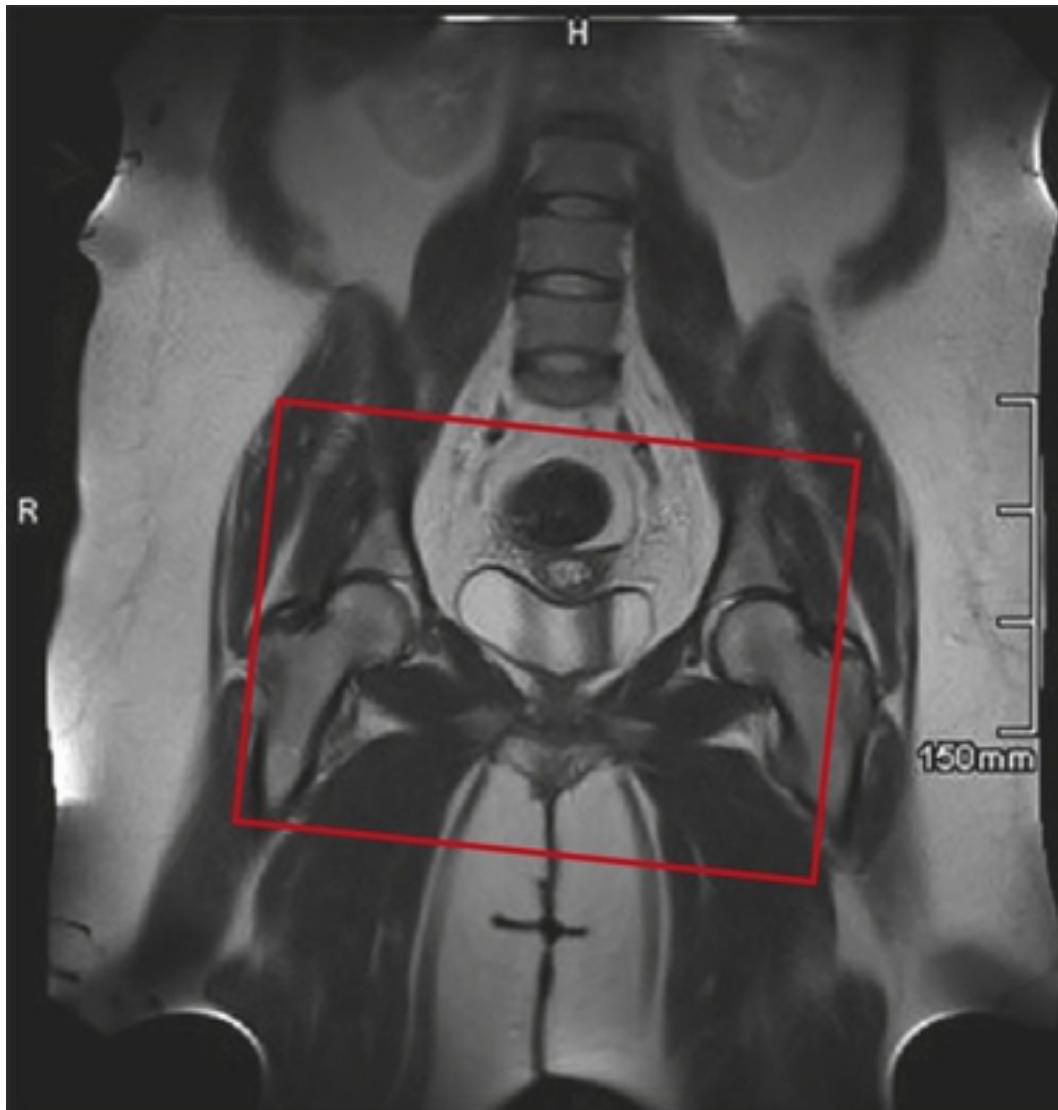


Fig. 2.92a [📄](#)

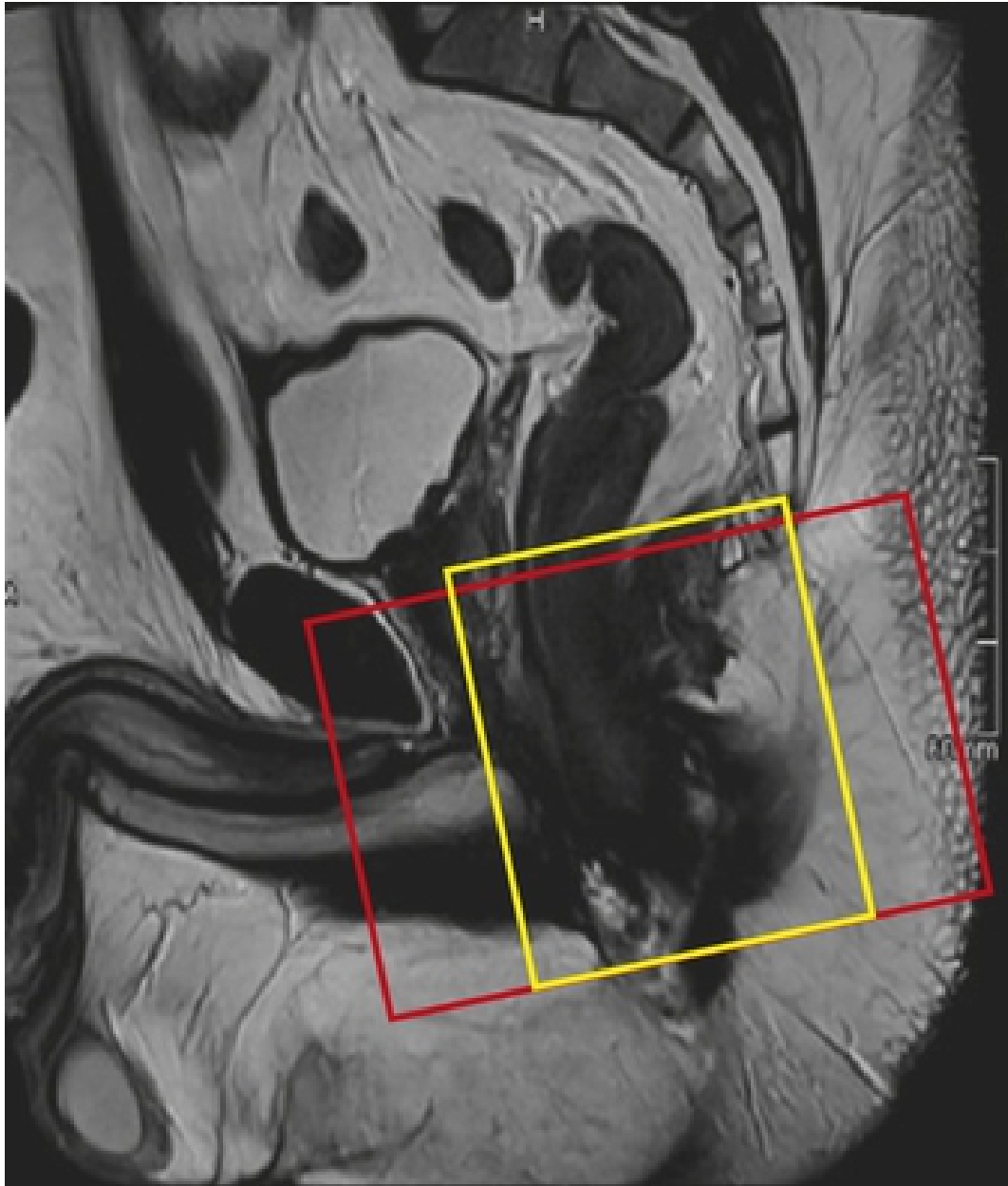


Fig. 2.92b [↗](#)



Fig. 2.92c [📄](#)

Planning sagittal sequence: position the block parallel to the interpubic fibrocartilage and the anal canal on a coronal image ([Fig. 2.92a](#)).

Planning axial oblique sequence: angle perpendicular to the anal canal. Plan on a sagittal image (red box in [Fig. 2.92b](#)).

Planning coronal oblique sequence: angle parallel to the anal canal on a sagittal image (yellow box in [Fig. 2.92b](#)). Ensure full coverage of area of interest ([Fig. 2.92c](#)).

When planning axial and coronal oblique sequences ensure coverage extends down to the lower edges of the buttocks. The reason for this is

because, as well as tracking inside, anal fistulas can track between the skin on the outside of the buttock area.

Example sequences: fistula							
Routine	3 plane	Sag	Cor T1	T2	T2	Ax T1	Ax T1
	localiser	T2	STIR	short	long	short	whole
		FS	pelvis	axis	axis	axis	pelvis

Acquired Images: Examples ([Figs. 2.93a,b](#))

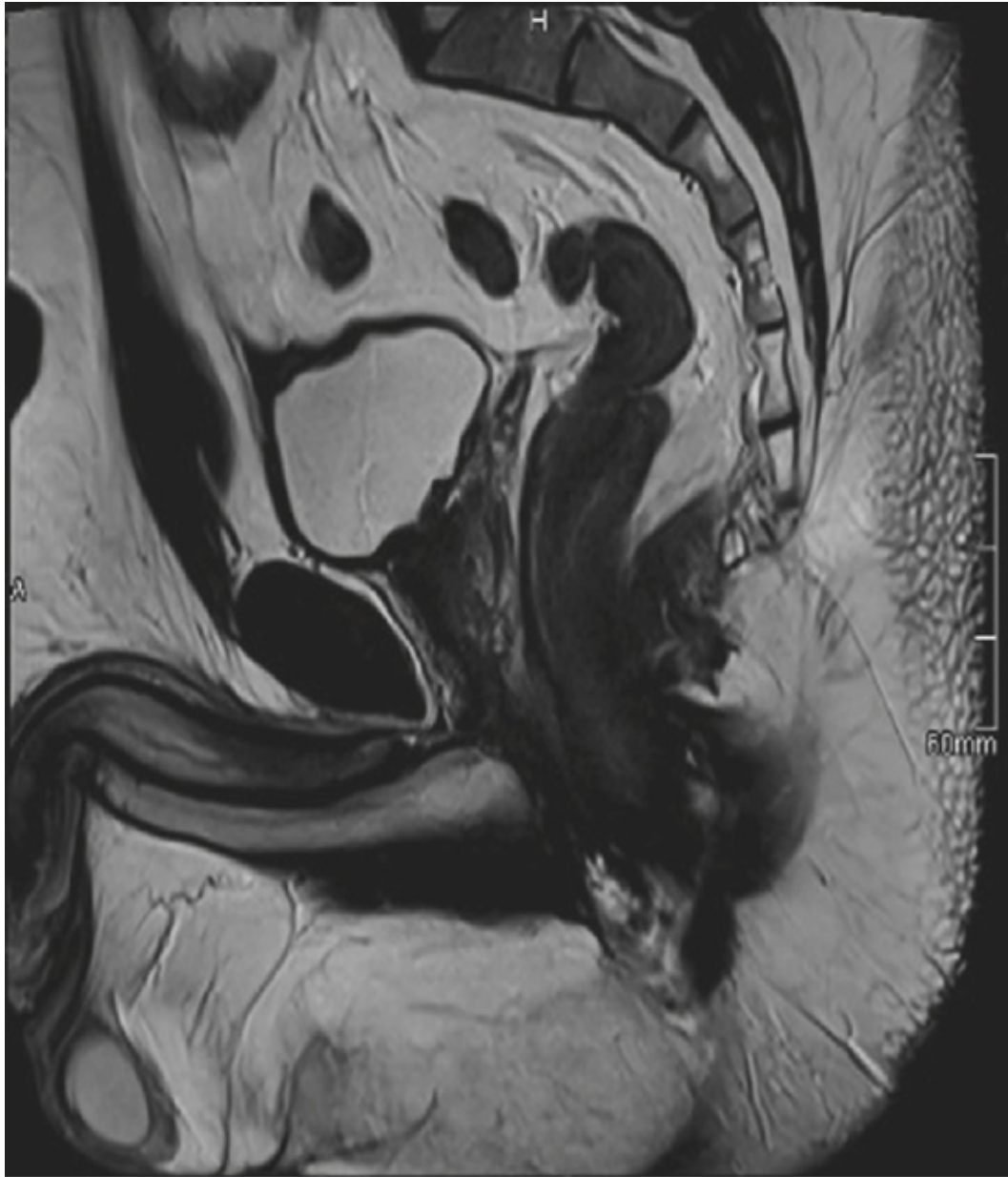


Fig. 2.93a Example of a T2 sagittal image through the midline. This sequence allows accurate planning of the high-resolution images through the anal canal. [↗](#)



Fig. 2.93b Example of a high-resolution T2 axial image through the lower end of the anal canal and buttocks. It is important to scan beyond the anal canal as fistulas can track down to the perineum. [↗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement is not routinely given as part of a routine perineum MRI examination. However, if indicated, a hand injection is suitable.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.94](#))



Fig. 2.94 Patient positioned feet-first supine with a body array.[🔗](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the perineum to acquire a diagnostic image. By positioning the patient feet first in the scanner the images can still be achieved, and they are less likely to feel symptoms of claustrophobia.

PROSTATE

The prostate is a part of the male reproductive system, and it sits in front of the rectum above the base of the penis and below the bladder. It surrounds the first part of the urethra and plays an important role in the production of

semen. MRI is the most sensitive, non-invasive imaging modality used for looking at the prostate gland and its surrounding soft tissue structures. Multiparametric imaging of the prostate can be used to demonstrate anatomical features and information to show the functionality of the prostate.

Indications

- Prostate cancer
- Infection (prostatitis) or prostate abscess
- Enlarged prostate called benign hyperplasia
- Abnormal conditions present at birth
- Complications after prostate surgery
- Post-radiotherapy and chemotherapy assessment
- Newly diagnosed prostate cancer staging
- Diagnosis of recurrent prostate cancer
- Post-prostatectomy assessment
- Pre-surgical assessment
- Tumour detection and staging
- Enlarged prostate
- Rising prostate-specific antigen (PSA)

Imaging Procedure ([Fig. 2.95](#))



Fig. 2.95 Standard positioning. [↗](#)

- Position the patient head-first supine.
- Place body array coil(s) over the pelvis and the abdomen.
- Use a support under the knees to help the patient to remain still.
- Centre for the localiser with laser light over the centre of the iliac crests.
- The bladder should be two-thirds full for scanning. To achieve this, prior to the scan ask the patient to empty their bladder and then drink two cups of water prior to entering the scan room.

Sequence Planning ([Fig. 2.96a](#), [Fig. 2.96b](#) and [Fig. 2.96c](#))

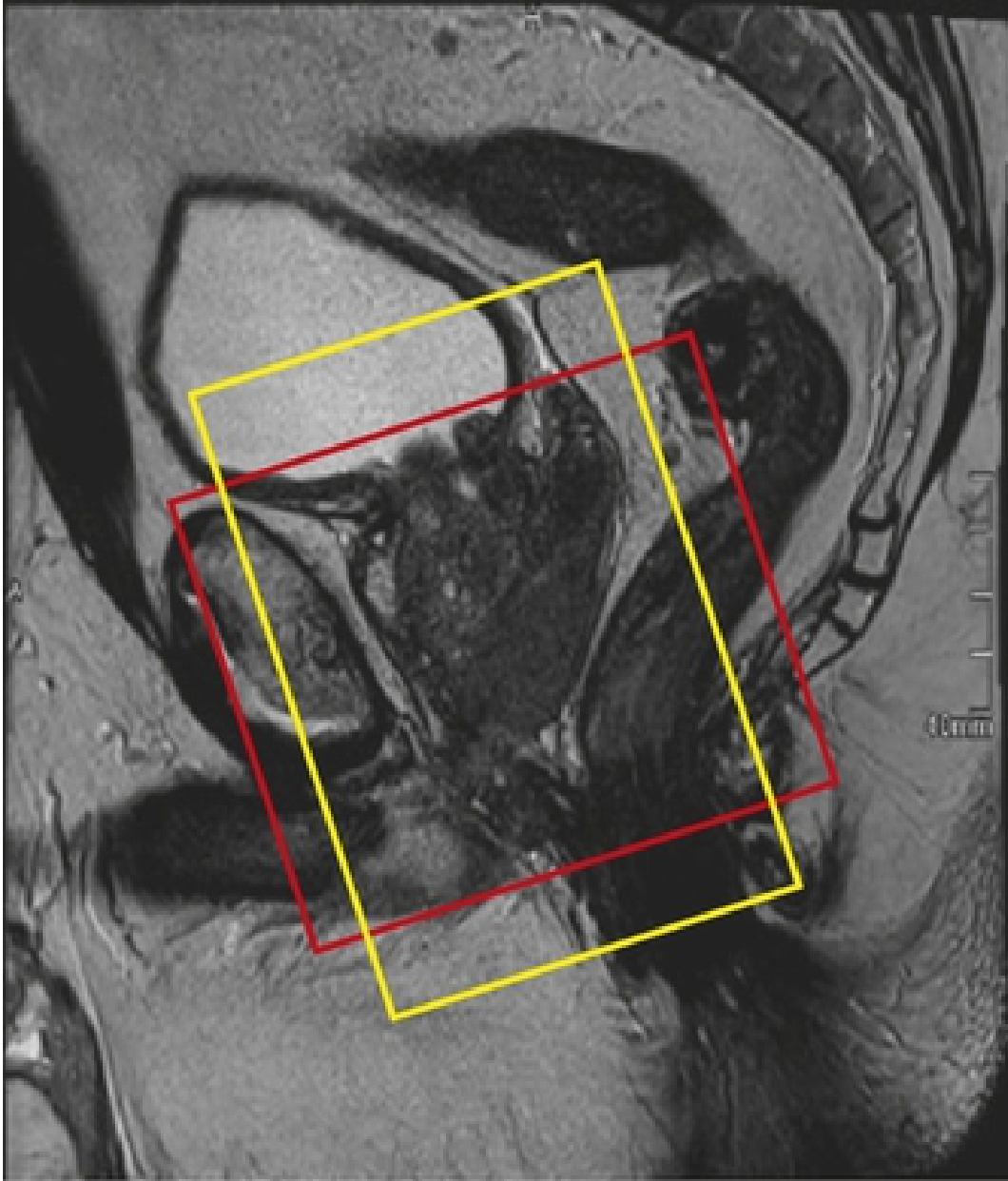


Fig. 2.96a [↗](#)

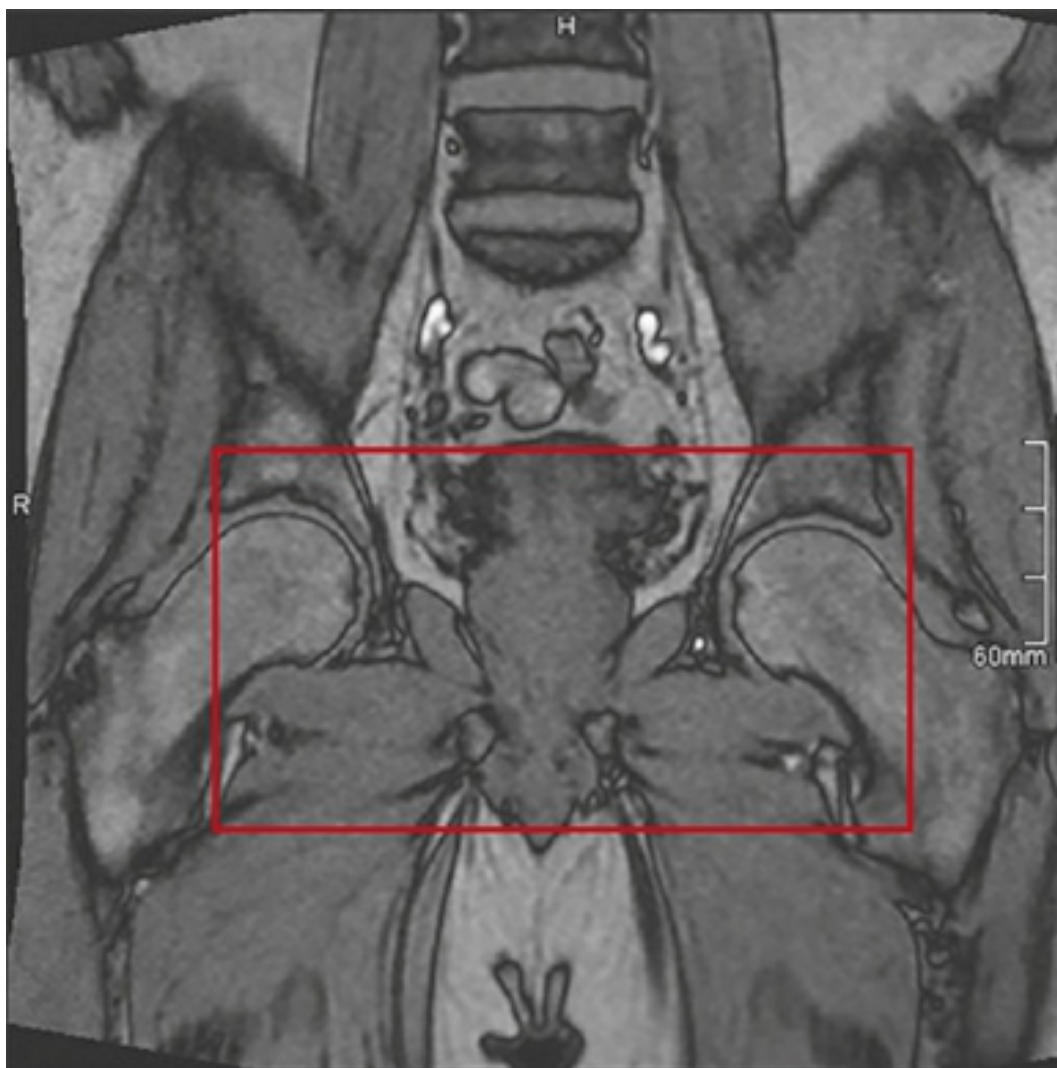


Fig. 2.96b [↗](#)

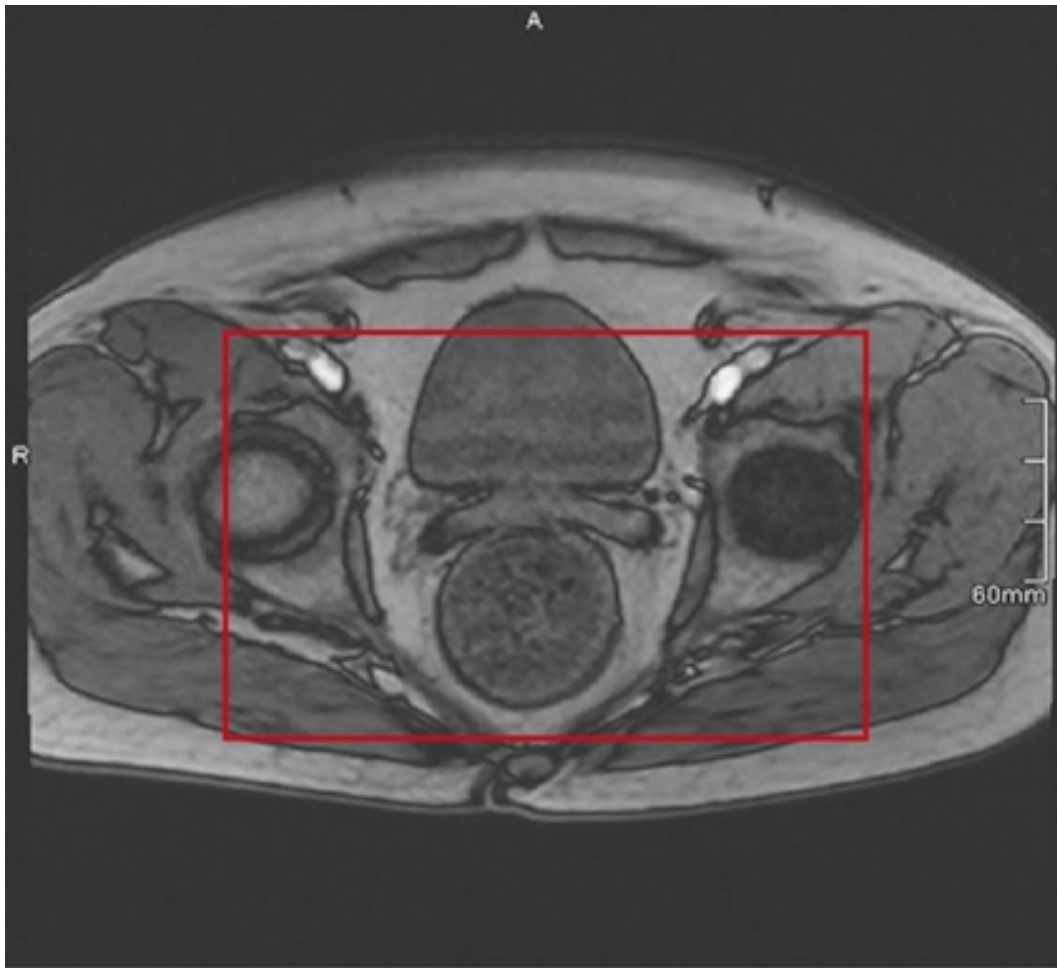


Fig. 2.96c [📄](#)

Planning sagittal sequence: plan in a true sagittal plane on the axial and coronal images ([Figs. 2.96b, c](#)). Ensure slices cover from the right to the left acetabulum, with a sufficient FOV to cover the entire prostate and seminal vesicles.

Planning short axis: plan on a sagittal image and angle the block horizontally across the prostate. Use a small FOV but ensure it is sufficient to cover the entire prostate and seminal vesicles (red box in [Fig. 2.96a](#)).

Planning long axis: plan on a sagittal image and angle the block vertically across the prostate. Use a small FOV but ensure it is sufficient to cover the entire prostate and seminal vesicles (yellow box in [Fig. 2.96b](#)).

Planning DWI: copy the centre of slices to short axis T2 sequence. Ensure the entire prostate and seminal vesicles are covered.

Planning axial pelvis sequence: angle the slices across the abdomen on a sagittal image. To ensure coverage of the para-aortic and presacral lymph nodes use a large FOV and cover from the level of the mid-abdomen to the bottom of the pelvis.

Planning coronal abdomen: plan on a sagittal image and angle the block parallel to the vertebral bodies of the spine. Using an axial image align the block across the level of both hip joints. To ensure coverage of the para-aortic and pre-sacral lymph nodes use a large FOV and cover from the level of the mid-abdomen to the bottom of the pelvis.

The addition of a saturation band may be beneficial in reducing movement artefact caused by peristalsis, arterial blood flow and breathing.

Example sequences: prostate							
Routine	3 plane localiser	Sag T2	Ax T1 pelvis	T2 short axis	T2 long axis	DWI	Cor T1 abdomen
Additional	Ax T2 HASTE upper abdomen Dynamic post-contrast scan subtraction sequences: T1 VIBE SPAIR pre- and post-contrast						

Acquired Images: Examples ([Figs. 2.97a, b](#))



Fig. 2.97a Example of a T2 sagittal image through the midline. This image can be used to accurately locate the prostate and plan the high-resolution sequences. [↗](#)



Fig. 2.97b Example of a high-resolution T2 axial image through the prostate. [↗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended for prostate imaging.
- An antispasmodic can be administered to limit peristalsis from the bowel creating artefact on the resultant imaging.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the prostate to acquire a diagnostic image. By positioning the patient feet first in the scanner the images can still be achieved and they are less likely to feel symptoms of claustrophobia.

Refer to the adaptive technique in the rectum section ([Figs. 2.90a, b](#)).

PENIS/TESTES

MRI is the most sensitive imaging modality used for looking at the penis as it shows many of the important structures within the penis. It is used when clinical evaluation and ultrasound are not conclusive. It is probably most useful in the investigation of a painful penile implant and acute low flow priapism and can sometimes be useful for the local staging of penile cancer, for the localisation of penile fracture and for imaging complex cases of fibrosis. The penis is predominantly a superficial organ and for the most part is easily examined by palpation or with ultrasound. Although MRI can be used to assess most penile pathologies, it needs to demonstrate clinical utility to justify its expense.

Indications

- Local staging in penile cancer
- Penile fracture
- Fibrosis
- Painful penile implants
- Metastatic tumours of the urethra or penis
- Benign tumours of the urethra or penis

- Tuberculosis of the urethra or penis
- Blunt penile or urethral trauma
- Penetrating penile injury
- Condyloma acuminata
- Peyronie's disease
- Post-irradiation injuries

Imaging Procedure ([Fig. 2.98](#))

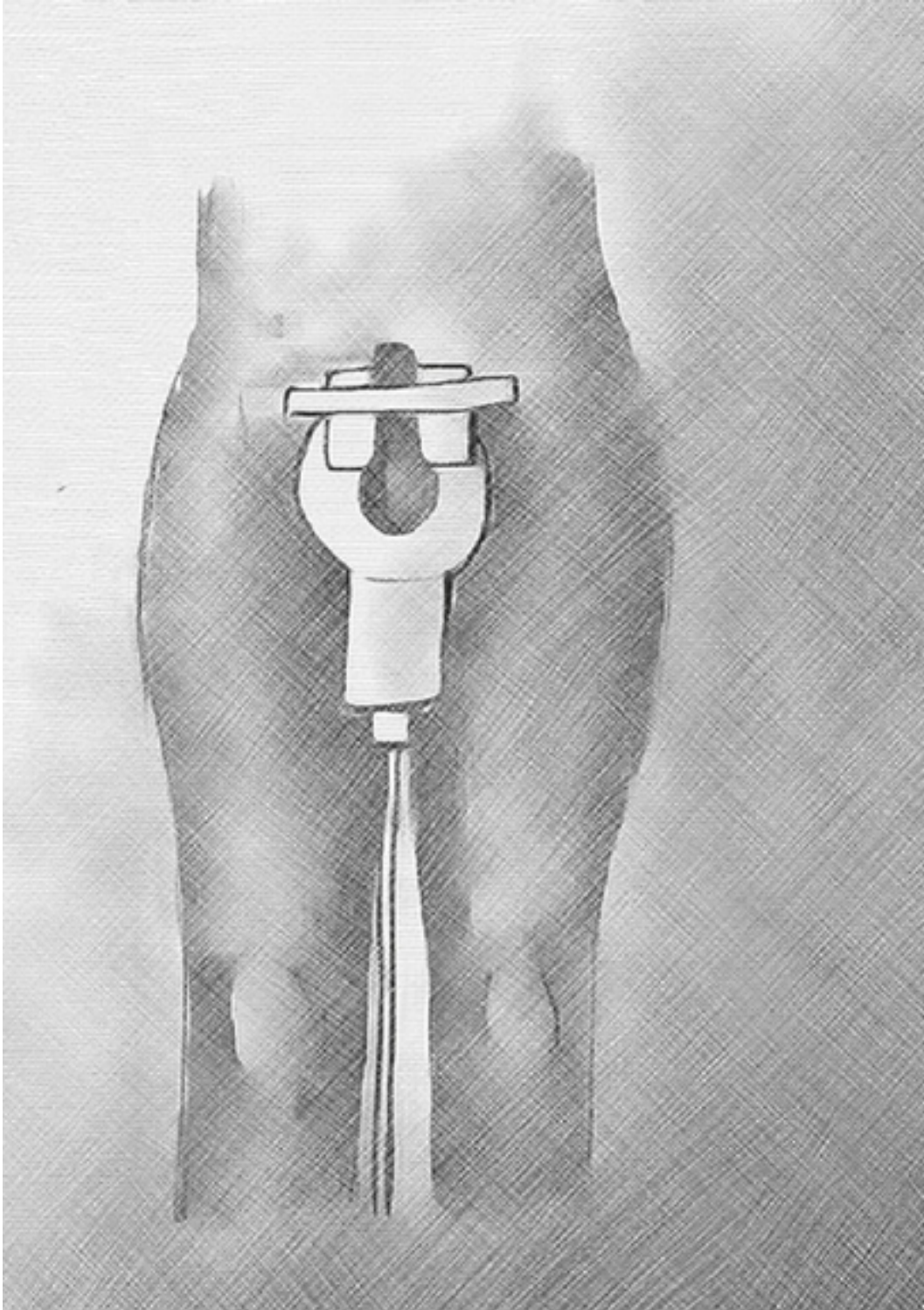


Fig. 2.98 Illustration of standard positioning using a dedicated coil. [↗](#)

- Position the patient head-first supine.

- Position a dedicated penis coil over the penis. Ensure the penis is aligned in the centre of the coil.
- Ask the patient to adjust their anatomy so that the penis is central and straight.
- Adhesive tape can be used to immobilise the penis and avoid motion and artefact on images. Cover the patient once positioned in the coil to maintain dignity and ensure comfort.
- Use cushions and pads as appropriate to immobilise.
- Centre for the localiser with laser light over the level of the penis.

Sequence Planning ([Figs. 2.99a, b](#))



Fig. 2.99a [📄](#)

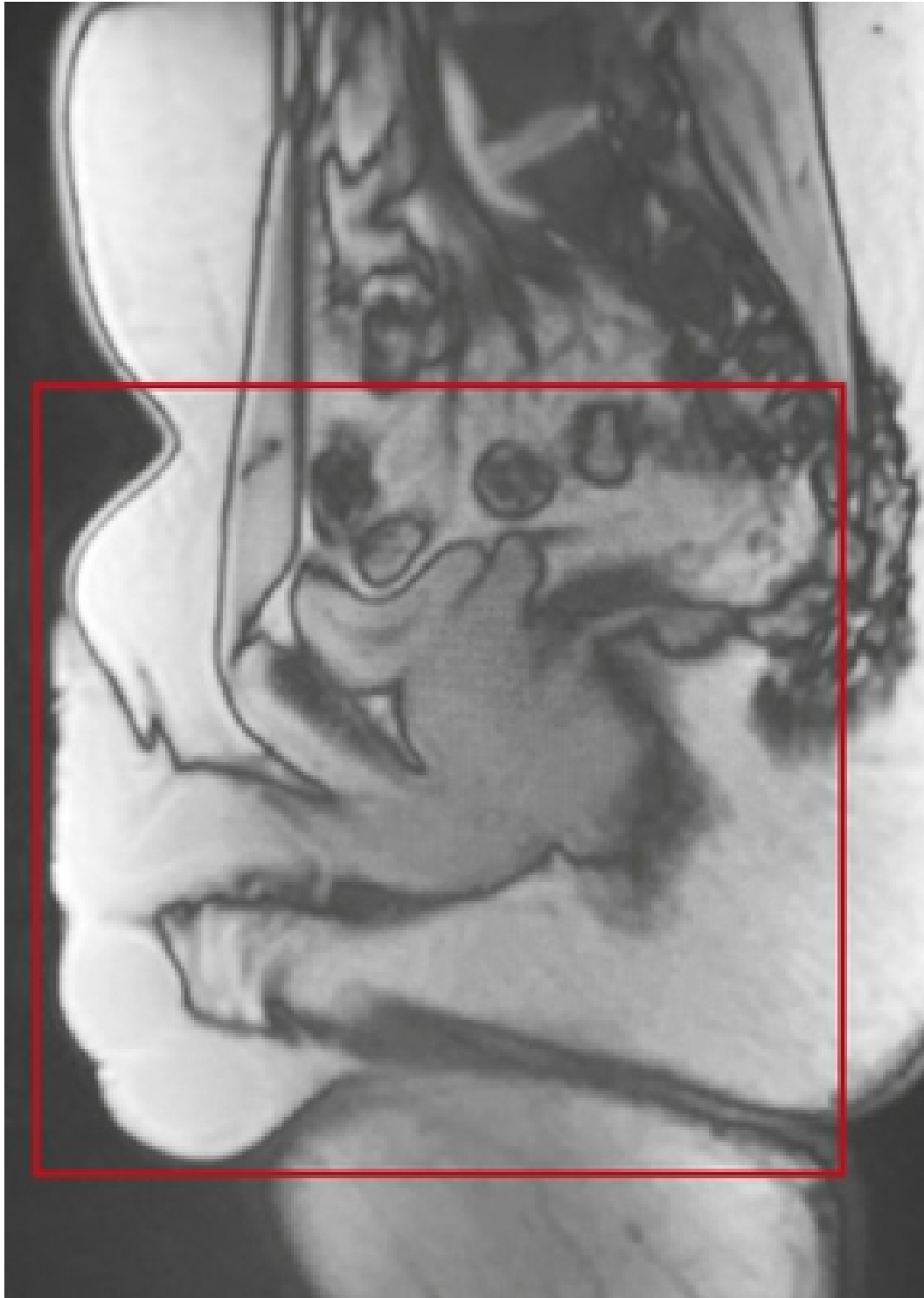


Fig. 2.99b [↗](#)

Planning sagittal sequence: angle the positioning block parallel to the penile base on an axial image ([Fig. 2.99a](#)). Coverage must be sufficient to

cover the whole penis ([Fig. 2.99b](#)).

Planning coronal sequence: use a large FOV and angle parallel to the right and left hip joint on a coronal image. An appropriate angle must be given in the sagittal plane (vertically across the abdomen).

Planning axial sequence: angle the positioning block parallel to the penile base on a sagittal image. The slices must be sufficient to cover the entire penis from 1 cm above the tip of the penis and cover the entire prostate.

Example sequences: penis	
Routine	3 plane localiser Sag T2 localiser Ax T2 Ax T2 SPAIR Sag T2 Sag T2 SPAIR Cor T2 Cor PD FS Sag T1 Ax PD
Additional	Cor T1 FS and Ax T1 FS post-contrast

Acquired Images: Examples ([Figs. 2.100a, b](#))

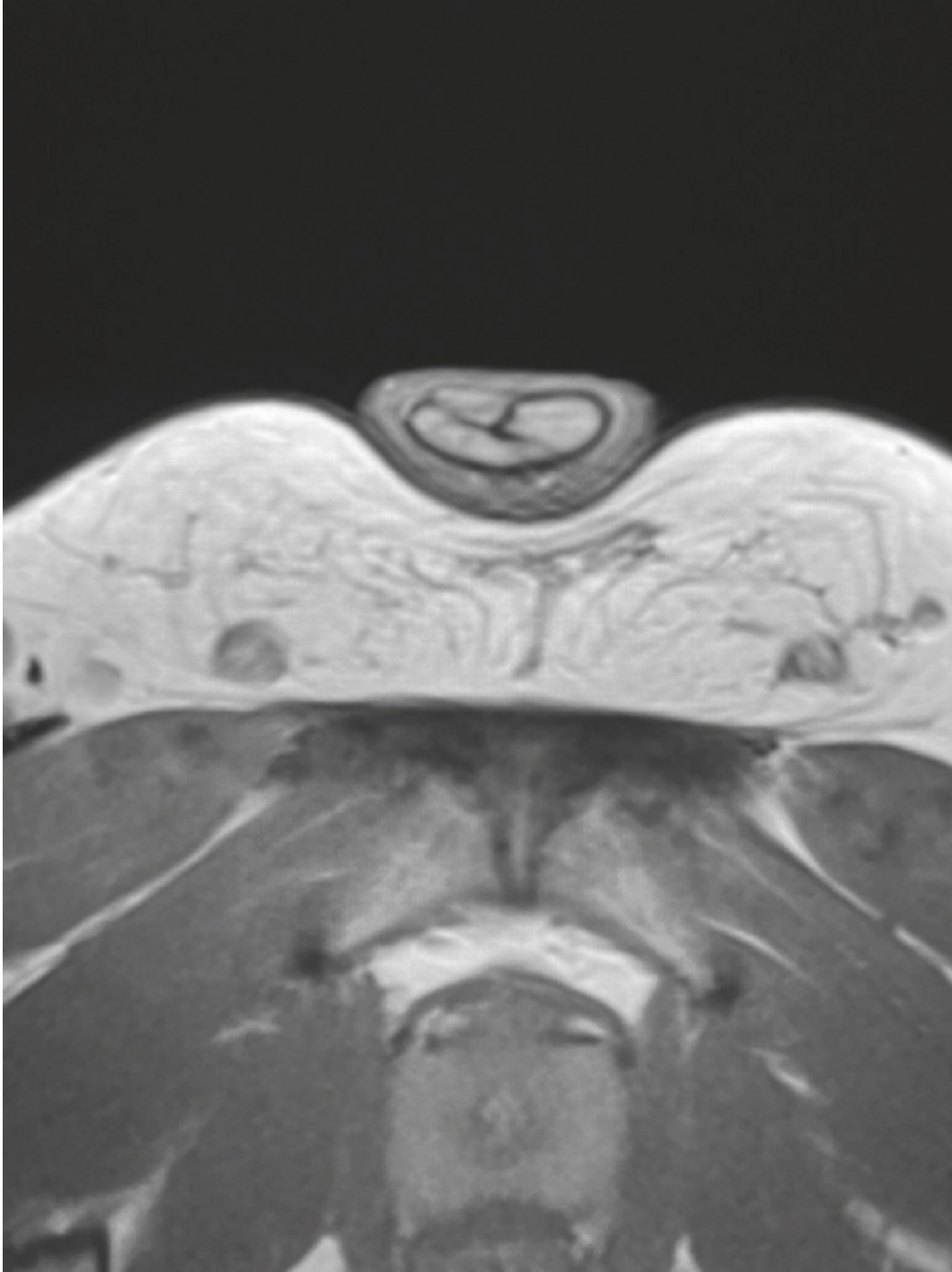


Fig. 2.100a Example of a T1 small FOV image of the penis in the axial plane. [📄](#)

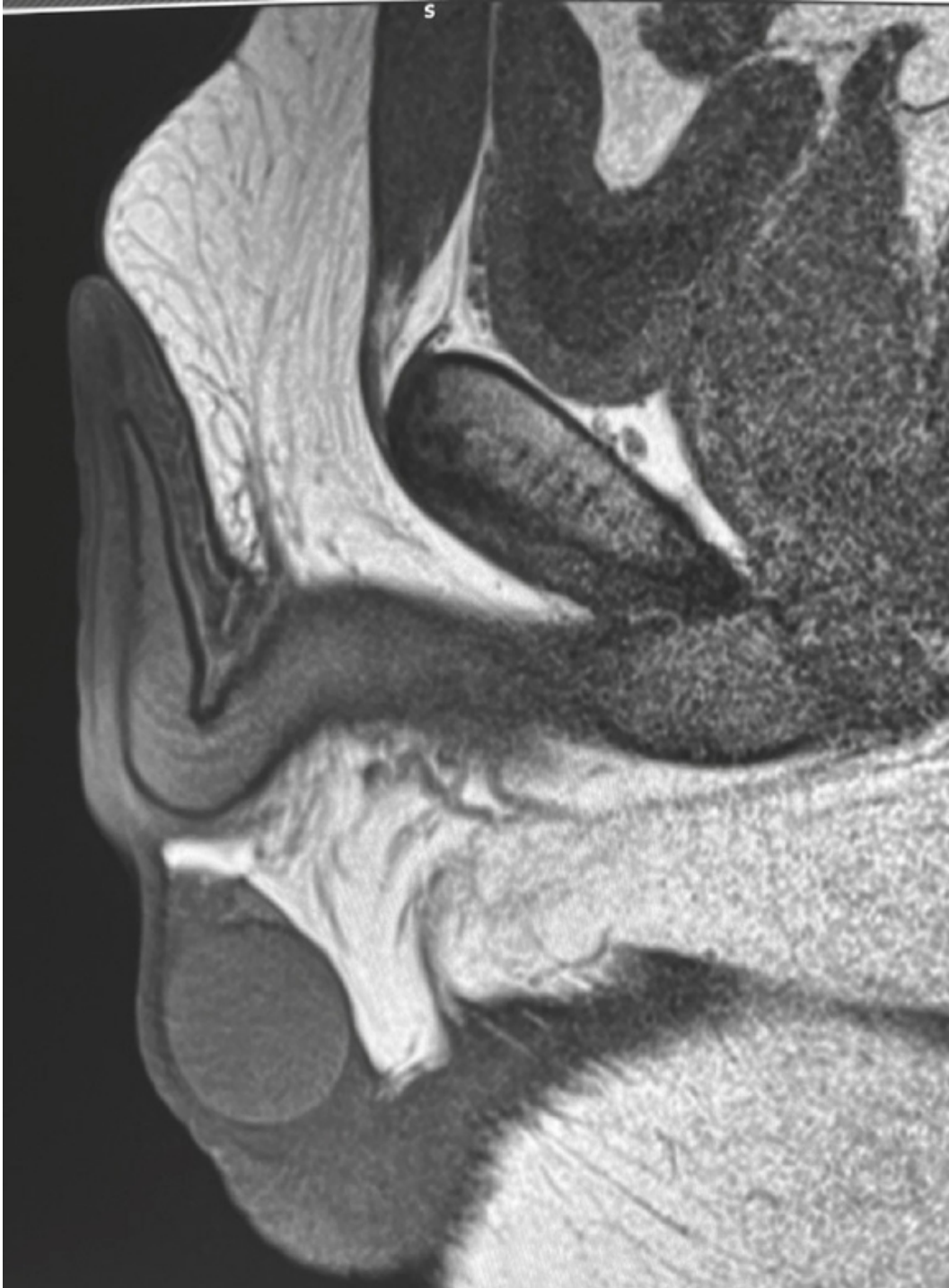


Fig. 2.100b Example of a T1 sagittal image through the midline of the penis. [📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard penis imaging is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.101a, b](#))



Fig. 2.101a Use of standard abdomen coil. [📄](#)



Fig. 2.101b Use of large flexible coil. [🔗](#)

Not all MR departments have the luxury of a dedicated penis coil; however, they are available. This is due to the limited number of referrals for this type of imaging. Most departments therefore adapt their techniques by using the methods shown in [Figs. 2.101a, b](#) to acquire images.

BLADDER

The bladder is a triangle-shaped, hollow organ. In men, it is bordered by the pubic bone at the front of the pelvis and the rectum at the back of the pelvis in the lower abdomen. In women, the bladder is bordered posteriorly by the uterus and vagina. The bladder is supported by ligaments and connects at the top to two ureters and at the bottom to the urethra. The organ itself is divided into four sections: the apex (top part), fundus (the base), the body that allows for contraction and the neck. MRI is a useful modality for evaluating diseases of the bladder. MRI can detect and stage bladder cancer

by determining the presence and depth of muscle invasion. Direct multiplanar imaging and superb soft tissue contrast make MRI an ideal modality for evaluating less common neoplastic diseases of the bladder. It is usually used alongside CT and cystoscopy to confirm diagnosis.

Indications

- To check the invasion of the bladder wall by cancer or other lesions
- To characterise masses or atypical structures seen on ultrasound or CT
- Staging of urinary bladder cancer diagnosis
- Malformation
- Cystocele
- Fistula

Imaging Procedure ([Fig. 2.102](#))



Fig. 2.102 Standard positioning. 

- Position the patient head-first supine.
- Position the patient's head on a pillow.
- Place one body coil over the pelvis and abdomen.
- Use a support under the knees to help the patient to remain still.
- Centre for the localiser with the laser light over the centre of the iliac crests.
- The bladder should be two-thirds full for scanning. To achieve this, prior to the scan ask the patient to empty their bladder and then drink two cups of water prior to entering the scan room.

Sequence Planning ([Fig. 2.103a](#), [Fig. 2.103b](#) and [Fig. 2.103c](#))

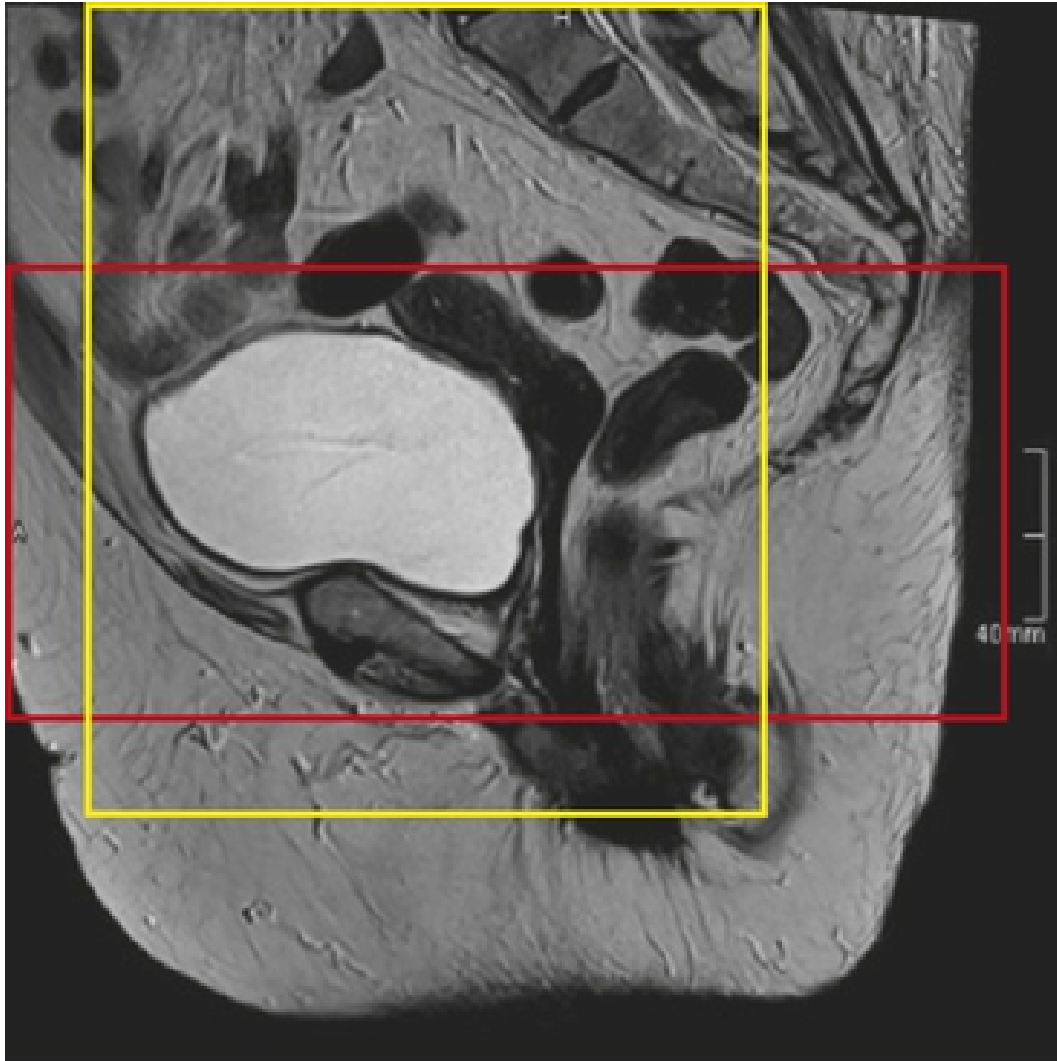


Fig. 2.103a [🔗](#)

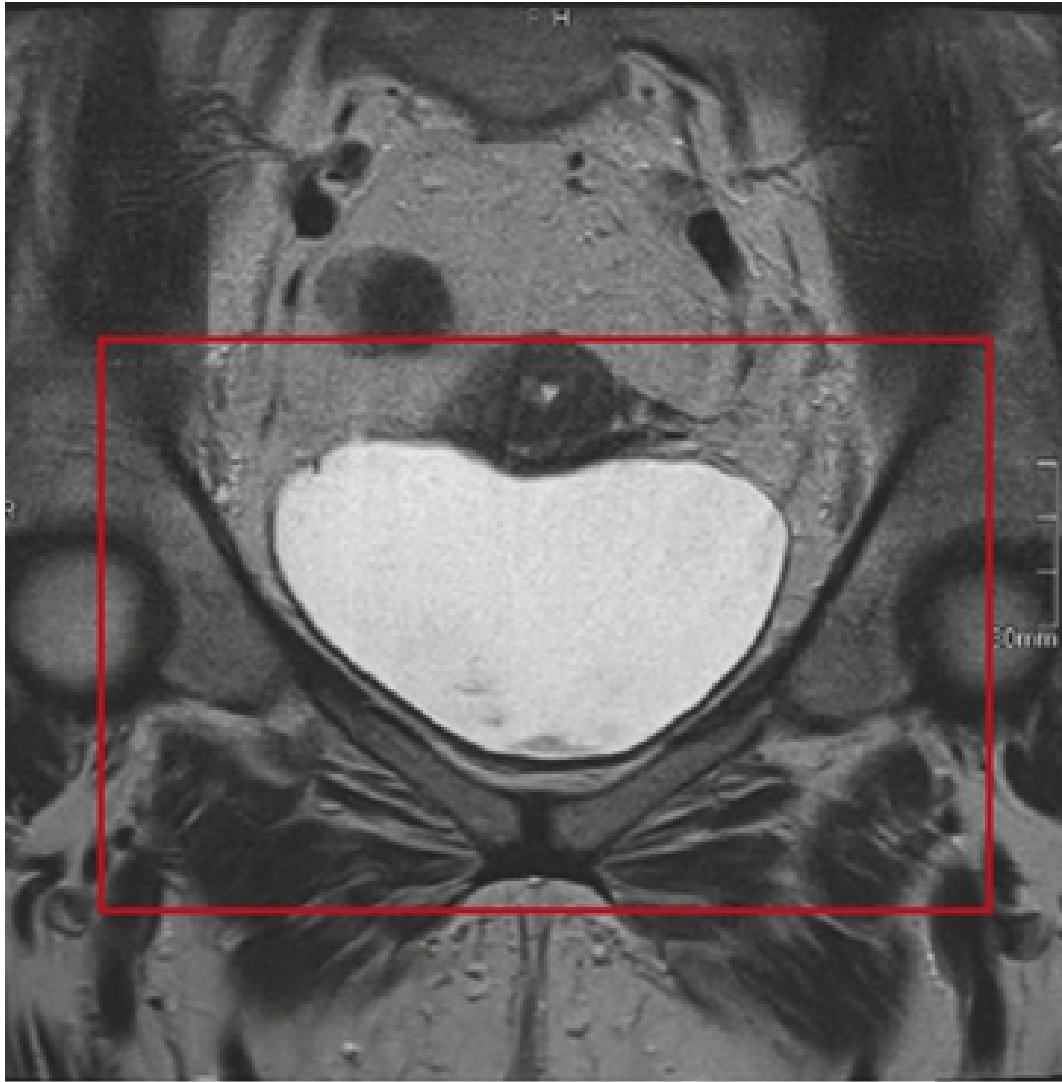


Fig. 2.103b [🔗](#)

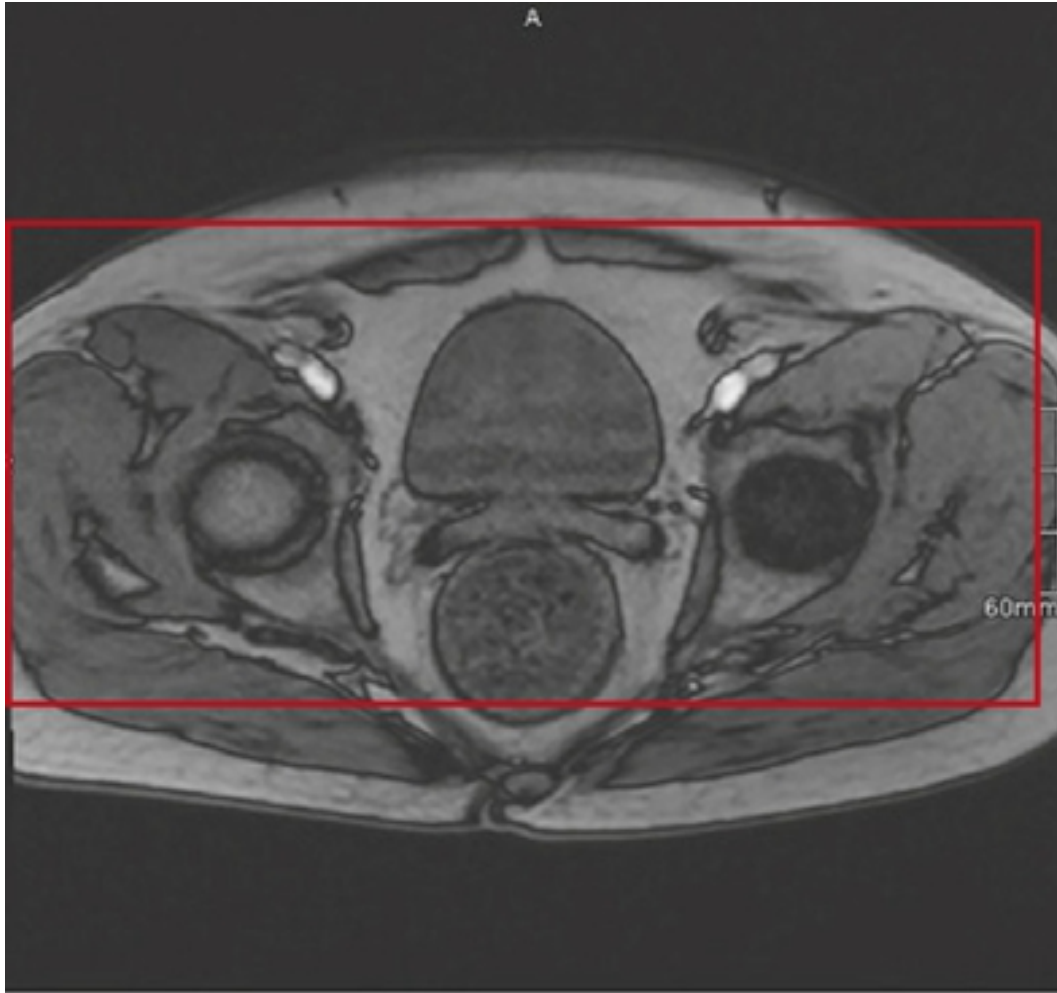


Fig. 2.103c [🔗](#)

Planning sagittal sequence: plan on a coronal image, angling the block parallel to the bladder ([Fig. 2.103b](#)). Ensure slices cover the entire bladder from the acetabular rims ([Fig. 2.103c](#)).

Planning short axis sequence and DWI: plan on a sagittal image, angling the block horizontally across the bladder. Use a small FOV and ensure slices cover the entire bladder (red box in [Fig. 2.103a](#)).

Planning long axis sequence: plan on a sagittal image, angling the block vertically through the bladder. Use a small FOV and ensure slices cover the entire bladder from the anterior abdominal wall to the rectum (yellow box in [Fig. 2.103a](#)).

The addition of a saturation band may be beneficial in reducing movement artefact caused by peristalsis and breathing.

Example sequences: bladder							
Routine	3 plane localiser	Sag T2	Ax T2 pelvis	T2 short axis	T2 long axis	Ax T1 pelvis	Cor T1 abdomen
Additional	Ax T2 HASTE upper abdomen Dynamic post-contrast scan subtraction sequences: T1 VIBE SPAIR pre- and post-contrast						

Acquired Images: Examples ([Figs. 2.104a, b](#))



Fig. 2.104a Sagittal T2 image of the bladder. [↗](#)



Fig. 2.104b Coronal T2 image of the bladder. [📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection is suitable for standard bladder imaging.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.
- An antispasmodic can be administered to limit peristalsis from the bowel creating artefact on the resultant imaging.

Adaptive Techniques

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the bladder to acquire a diagnostic image. By positioning the patient feet first in the scanner the images can still be achieved, and they are less likely to feel symptoms of claustrophobia.

Refer to the adaptive technique in the rectum section ([Figs. 2.90a, b](#)).

GYNAECOLOGICAL PELVIS

Female gynaecological pelvis imaging is a non-invasive way of imaging the female pelvis. It allows an in-depth look at the cervix, the uterus, the ovaries and the vagina. These all make up the female reproductive system situated within the pelvis. Whilst ultrasound is still the first line test for gynaecological imaging, MRI's high contrast resolution allows for good tissue characterisation and along with its multiplanar capabilities this means that MRI is fast becoming the modality to establish the diagnosis and guide the management of patients with gynaecological diseases. Currently, in oncology, MRI is being incorporated into various clinical guidelines to aid in the diagnosis of tumour extent.

Indications

- Cervical cancer
- Endometrial cancer/post-menopausal bleeding
- Evaluation of pelvic floor defects
- Ovarian cancer/adnexal masses/cysts
- Infection
- Endometriosis

- Vaginal anomalies/bleeding
- Evaluation of congenital anomalies
- Pelvic pain
- Fibroid

Imaging Procedure ([Fig. 2.105](#))



Fig. 2.105 Standard positioning. [📄](#)

- Position the patient head-first supine.
- Position the patient's head on a pillow.
- Place one body coil over the pelvis and another over the abdomen.
- Use a support under the knees to help the patient to remain still.
- Centre for the localiser with the laser light over the iliac crests.

Sequence Planning ([Fig. 2.106a](#), [Fig. 2.106b](#) and [Fig. 2.106c](#))

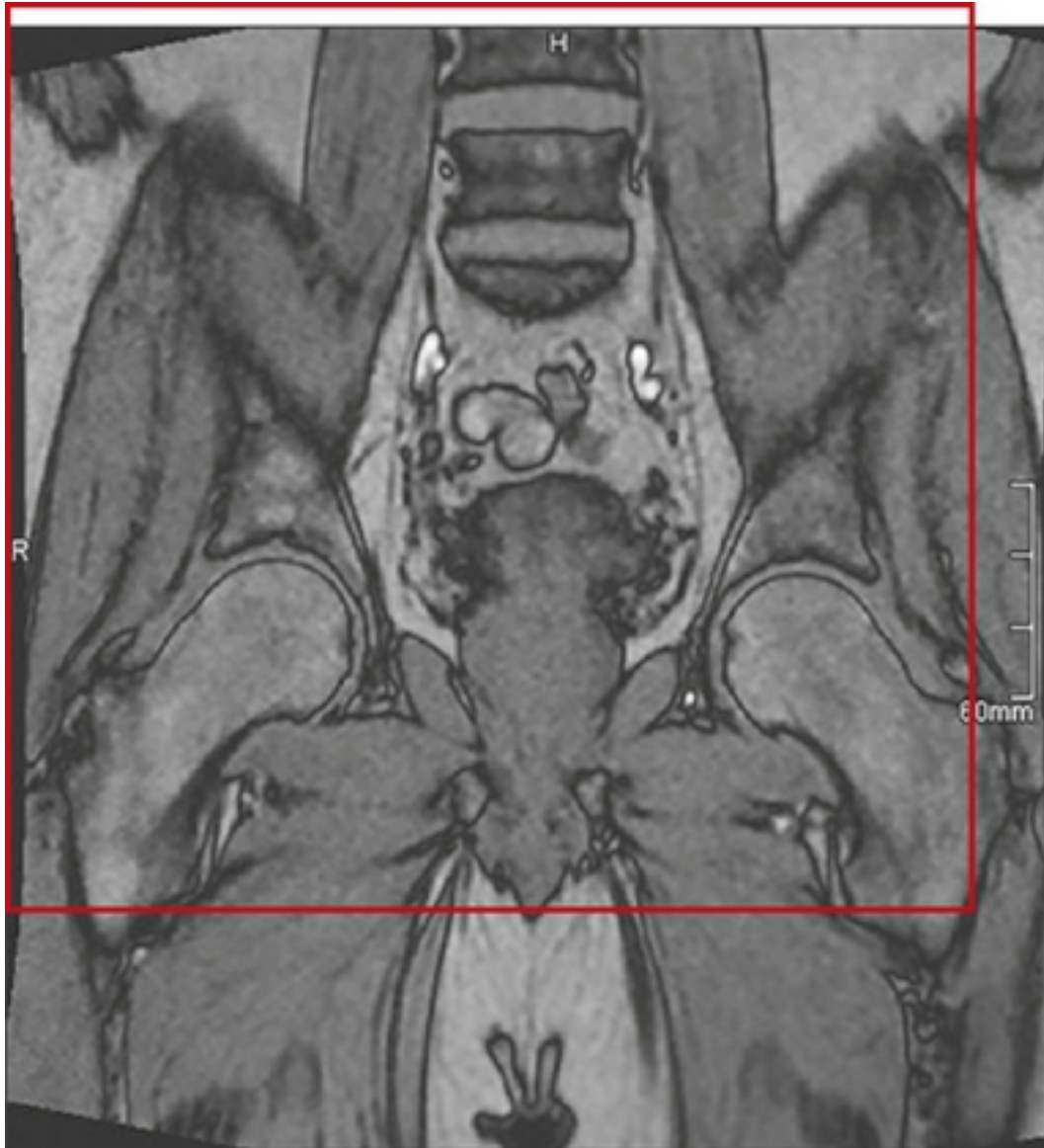


Fig. 2.106a [↗](#)

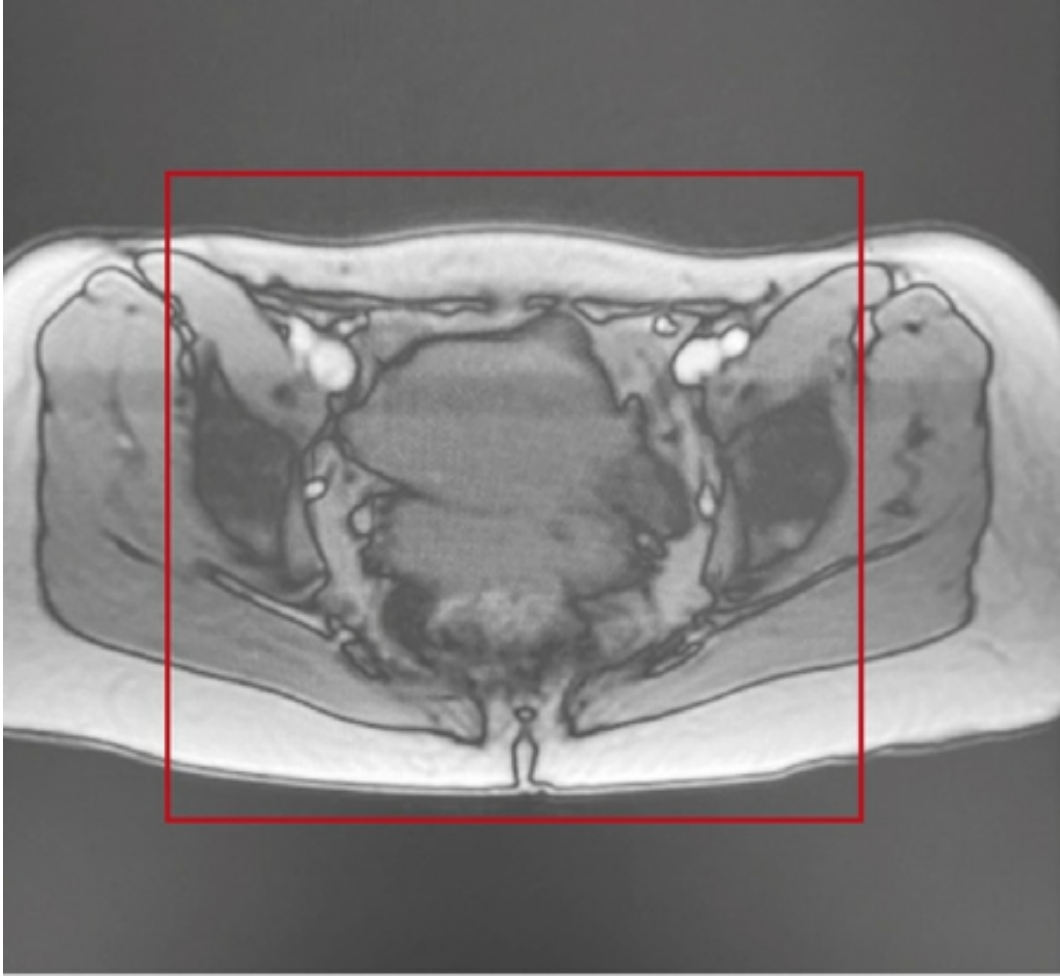


Fig. 2.106b [↗](#)

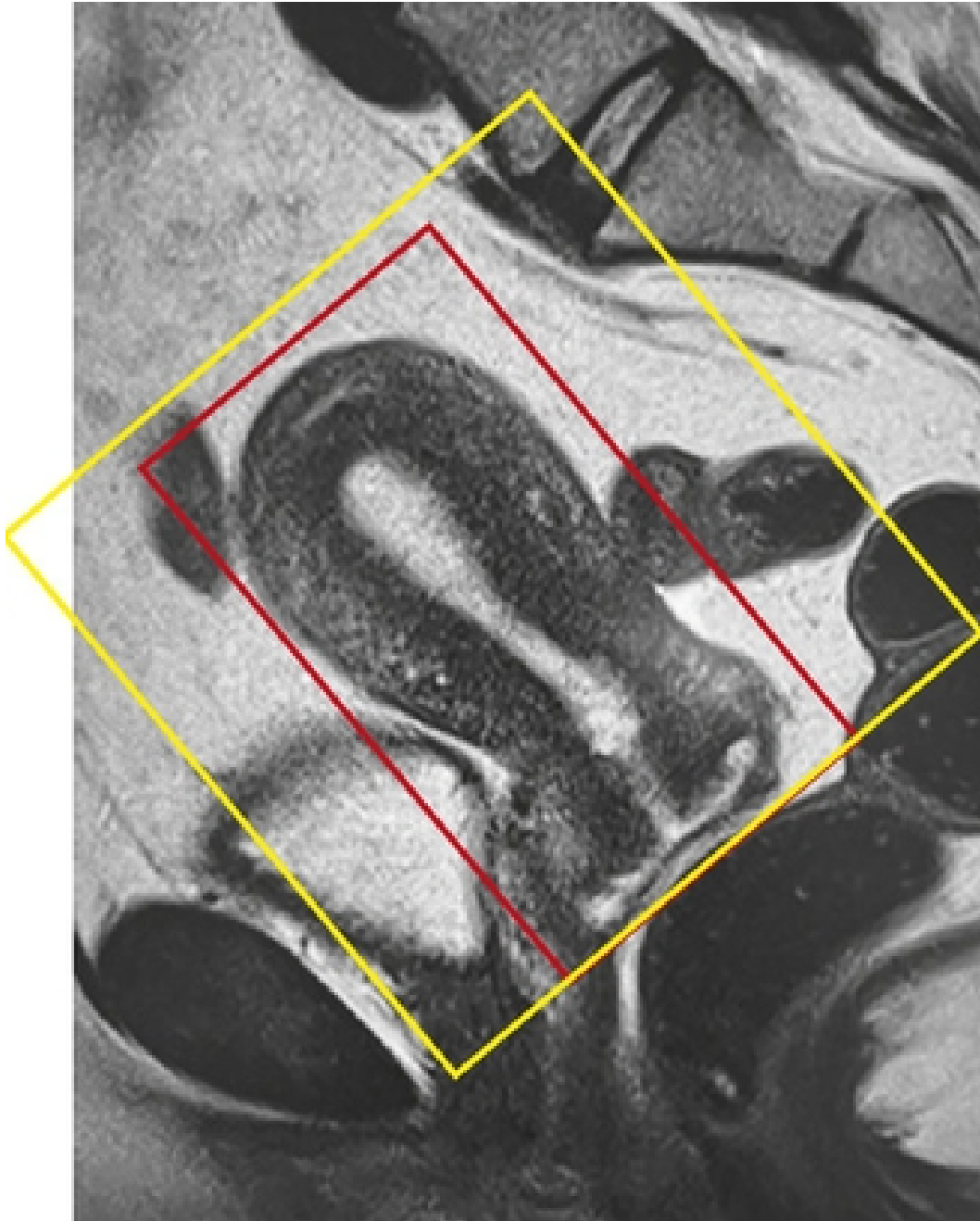


Fig. 2.106c [↗](#)

Planning sagittal sequence: plan on an axial image, angling the block parallel along the linear alba and median sacral crest ([Fig. 2.106b](#)). On the coronal image angle the block parallel to the lumbar vertebrae ([Fig.](#)

[2.106a](#)). Use a large FOV and ensure slices cover the entire pelvis from the right to the left acetabulum.

Planning axial pelvis sequence: plan on a coronal image, angling the block parallel along the right and left iliac crest. On the sagittal image angle the block perpendicular to the lumbar vertebrae. Use a large FOV and ensure slices cover the lower abdomen and pelvis, from the middle of the kidneys to the symphysis pubis.

Planning short axis: plan on a sagittal image and angle the block perpendicular to the endometrium. On an axial image angle the block across the uterus. Use a small FOV but ensure it is sufficient to cover the entire uterus and ovaries (yellow box in [Fig. 2.106c](#)).

Planning long axis: plan on a sagittal image and angle the block parallel to the endometrium. Use a small FOV but ensure it is sufficient to cover the entire uterus and ovaries (red box in [Fig. 2.106c](#)).

Planning DWI: copy the centre of slices to the short axis T2 sequence and ensure the entire uterus and ovaries are covered.

Planning coronal abdomen: plan on a sagittal image and angle the block parallel to the vertebral bodies of the spine. Using an axial image align the block across the level of both hip joints. To ensure coverage of the para-aortic and pre-sacral lymph nodes use a large FOV and cover from the level of the mid-abdomen to the bottom of the pelvis.

The addition of a saturation band may be beneficial in reducing movement artefact caused by peristalsis and breathing.

Example sequences: gynaecological pelvis							
Routine	3 plane localier	Sag T2	Ax T2 pelvis	T2 short axis	T2 long axis	DWI	Cor T1 abdomen
Additional (oncology)	Ax T2 HASTE upper abdomen Ax T1 SPAIR short axis and Sag T1 FS post-contrast scans						
Additional (adnexal mass)	Ax GRE whole pelvis Ax SPAIR whole pelvis Ax T1 SPAIR short axis and Sag T1 FS post-contrast scans						

Acquired Images: Examples ([Figs. 2.107a, b](#))

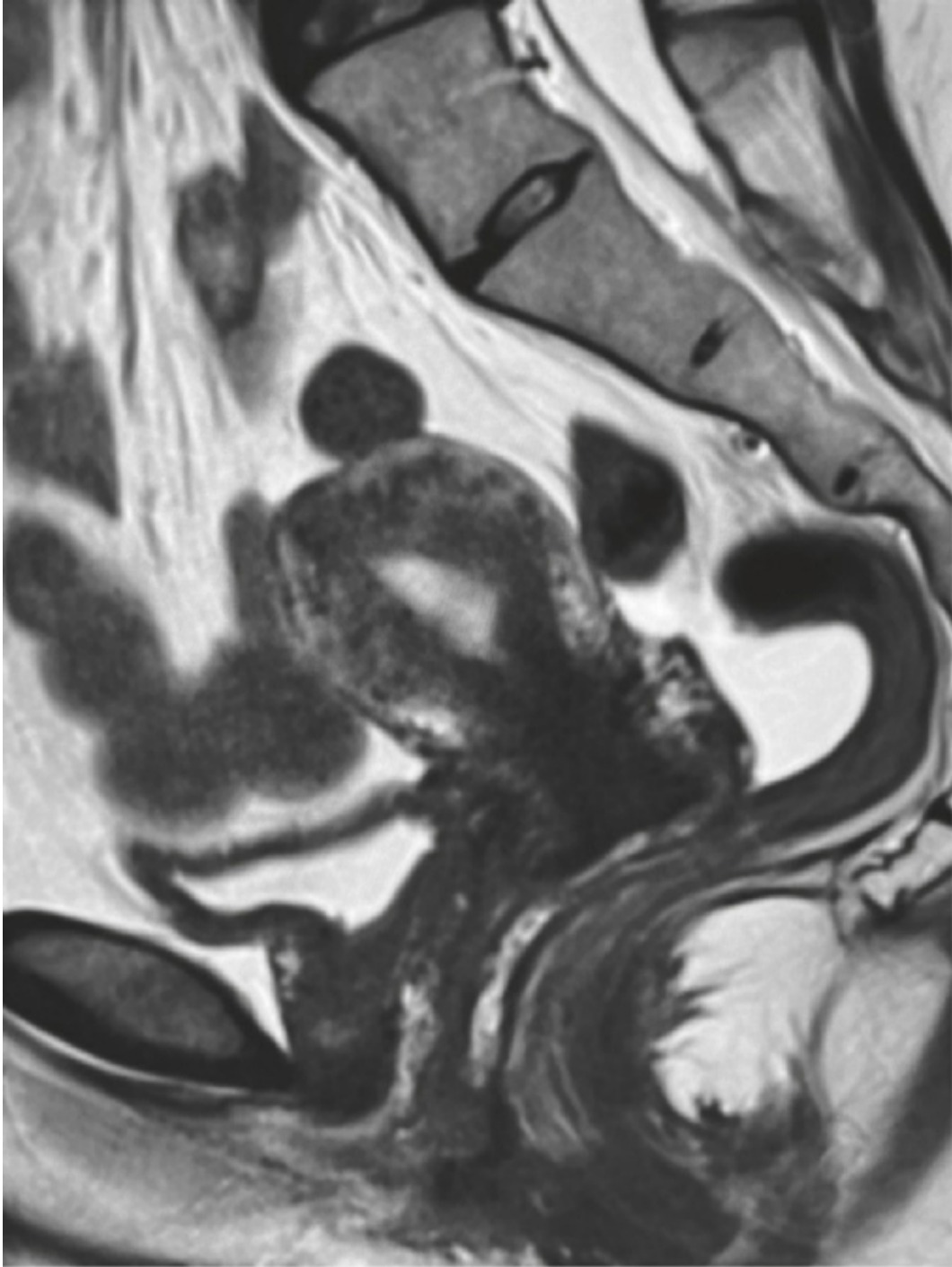


Fig. 2.107a Sagittal T2 image of the gynaecological pelvis. [↗](#)

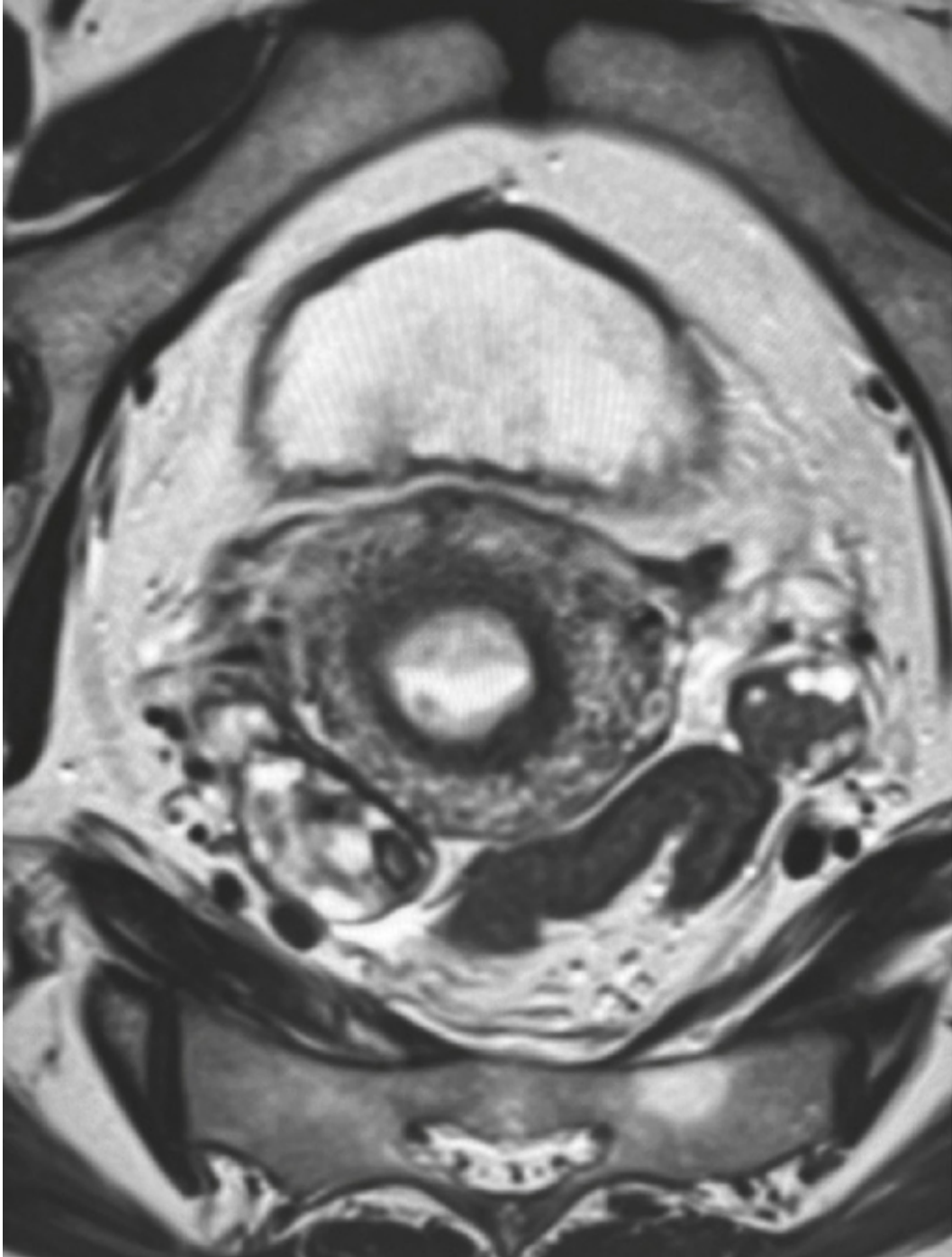


Fig. 2.107b Example of T2 short axis image. [📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard gynaecological pelvis imaging is adequate. Where vascular angiography is indicated, a dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.
- An antispasmodic can be administered to limit peristalsis from the bowel creating artefact on the resultant imaging.

Adaptive Techniques ([Fig. 2.108](#))



Fig. 2.108 Patient positioned feet-first supine. [↗](#)

When it is not possible to position the patient in the standard position due to large body habitus, reduced mobility, kyphosis, scoliosis or claustrophobia then adaptive techniques can be used to demonstrate the anatomy of the gynaecological pelvis to acquire a diagnostic image. By positioning the patient feet first in the scanner the images can still be achieved, and they are less likely to feel symptoms of claustrophobia.

FEMUR/THIGH

MRI is the gold standard in diagnostic imaging of the soft tissue of the thigh and femur. For patients who have sustained injury, an accurate diagnosis of oedema, haematoma, tendinous avulsion or partial or complete muscle tear is important in making decisions about surgical intervention ([14,15](#)). It is especially valuable in sports imaging ([16](#)). MRI allows accurate detection and classification of muscle injuries. It is valuable in detecting occult fractures and in the investigation of osteo-arthritis, swelling and suspected infection such as osteomyelitis.

Indications

- Injury, fractures, tumour or infection, e.g. osteomyelitis
- Swelling/lump
- Pain

Imaging Procedure ([Fig. 2.109](#))



Fig. 2.109 Standard positioning. [📄](#)

- Position the patient head-first supine.
- Position the patient's head on a pillow.
- Place the body coil over the femurs.
- Use a small support under the knee to help the patient to remain still and avoid bending the knee.
- Centre for the localiser with the laser light over the middle of the femur.

Sequence Planning ([Fig. 2.110a](#), [Fig. 2.110b](#) and [Fig. 2.110c](#))

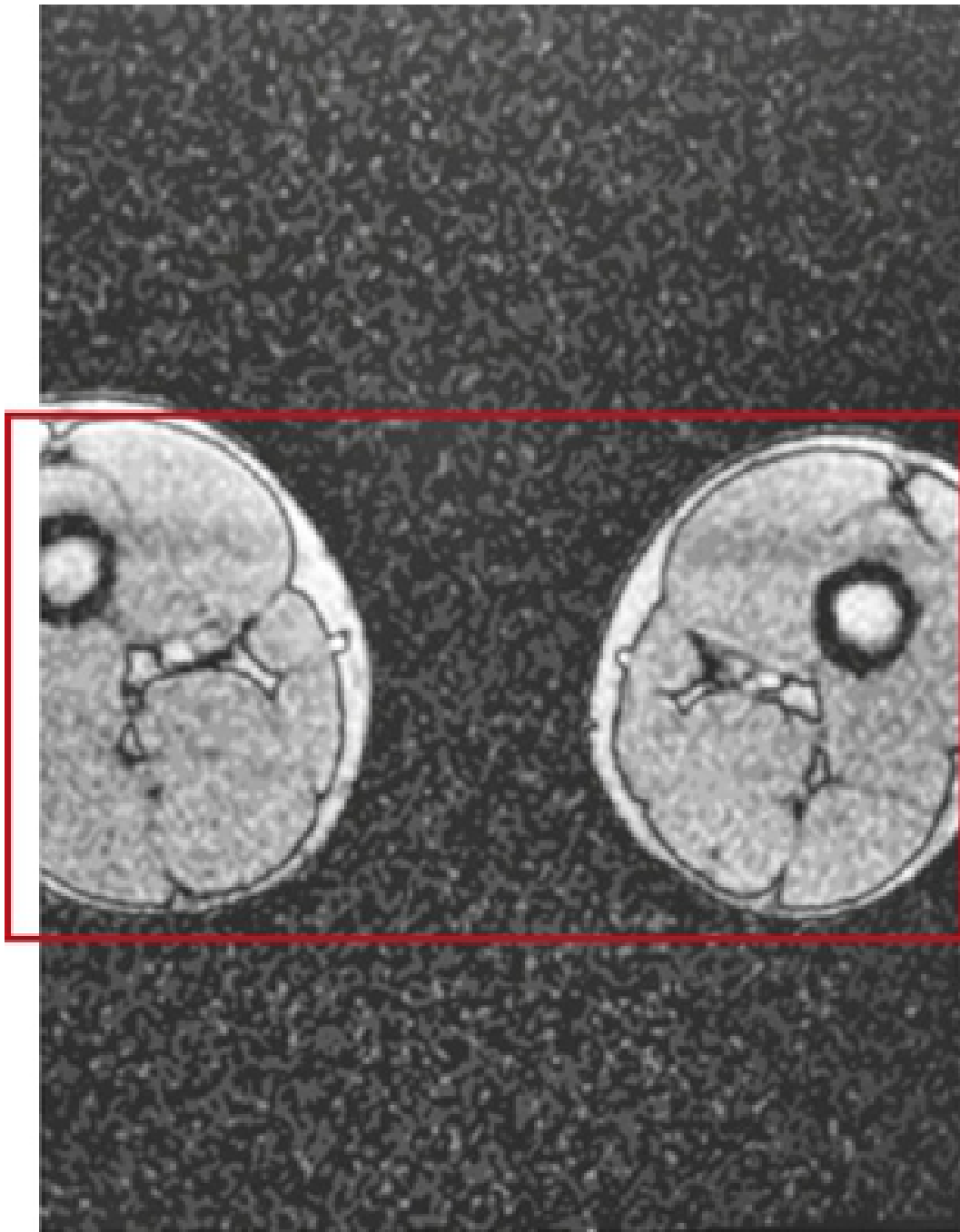


Fig. 2.110a [↗](#)

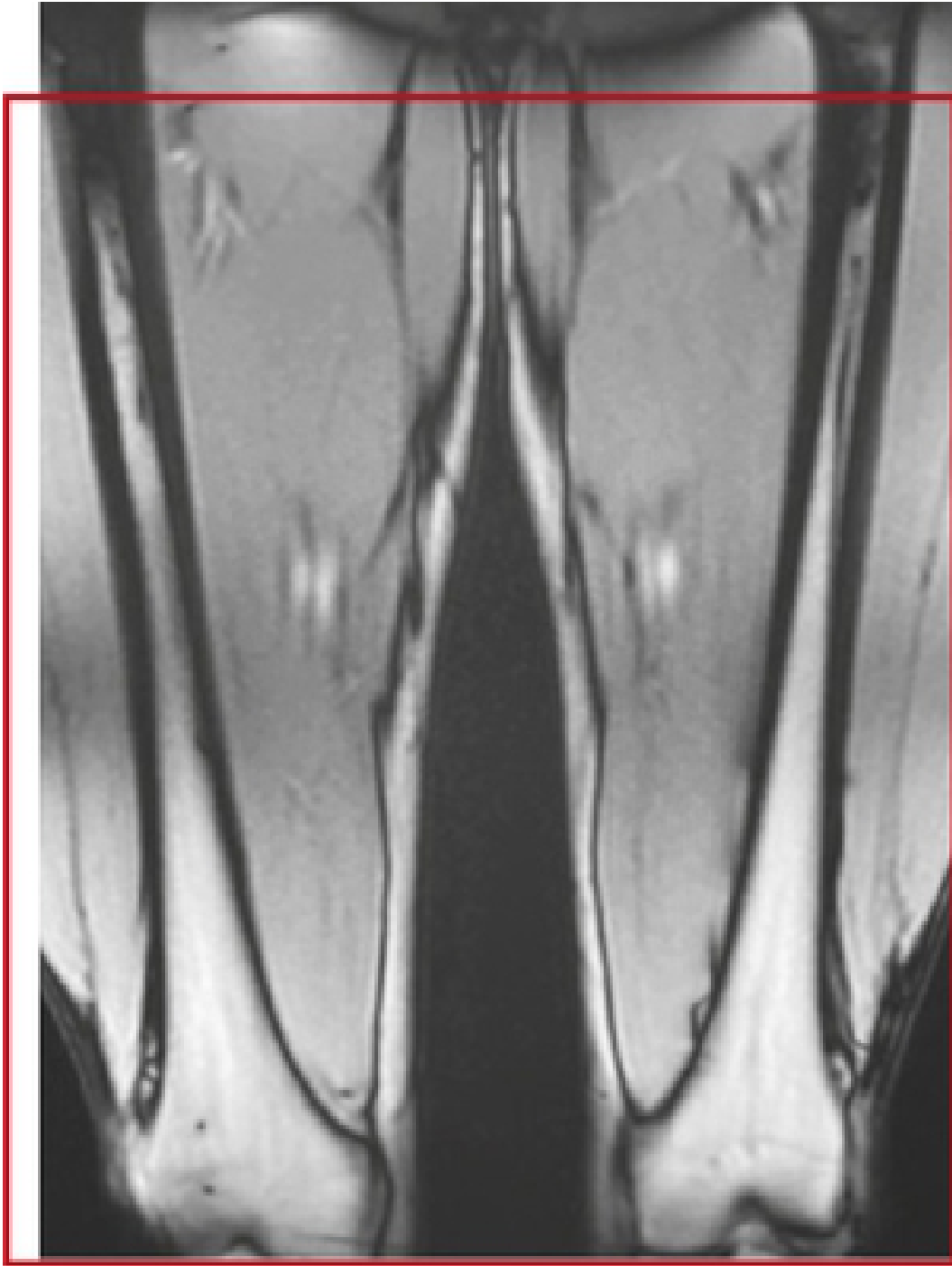


Fig. 2.110b [↗](#)



Fig. 2.110c [📄](#)

Planning coronal sequence: angle along the right and left parallel to the femoral heads on an axial image ([Fig. 2.110a](#)). On a sagittal image adjust

the angle of slices parallel to the femur and check on all three planes of the localiser that slices cover from the iliac crest to the distal femur.

Planning axial sequence: angle slices along the right and left femoral heads on a coronal image ([Fig. 2.110b](#)). Ensure full coverage of femur ([Fig. 2.110c](#)). On a sagittal image adjust the angle of slices perpendicular to the femur and check on all three planes of the localiser that slices cover from above the acetabulum to the lesser trochanter.

Planning sagittal sequence: angle slices parallel to the femur on an axial and coronal image, covering from the outer cortex of the femur to the symphysis pubis ([Figs. 2.110a, b](#)).

Example sequences: femur						
Routine	3 plane localiser	Cor T1	Cor STIR or TIRM	Ax T2 FS upper and lower	Ax T2 upper and lower	Sag PD FS affected side
Additional sequences	Ax and Cor T1 FS pre- and post-contrast					

TIRM, turbo inversion recovery magnitude.

Acquired Images: Examples ([Figs. 2.111a, b](#))

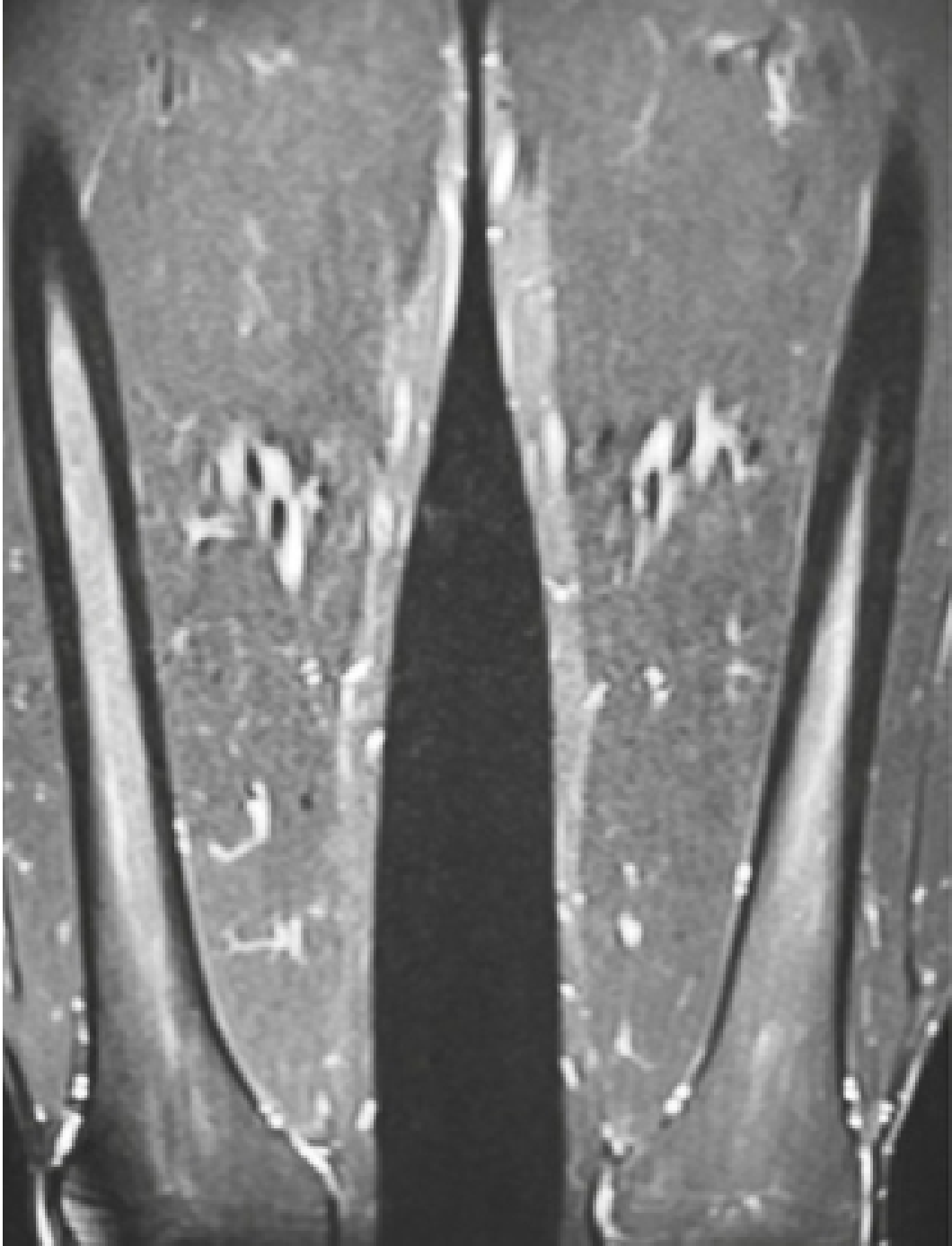


Fig. 2.111a Coronal STIR images of bilateral femurs. [↗](#)

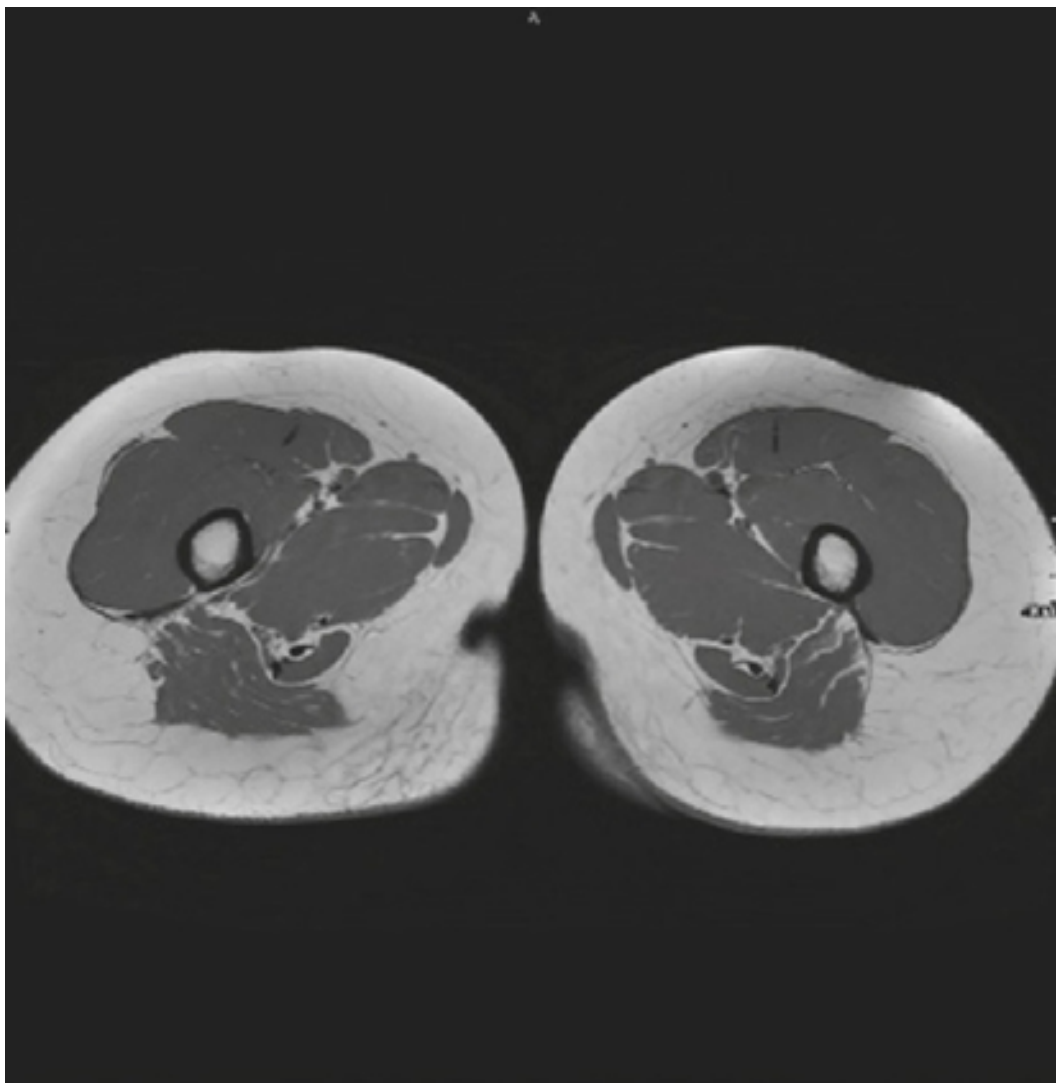


Fig. 2.111b T1 axial image of bilateral femurs. [📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard femur imaging is adequate. Where vascular angiography is indicated, a dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Technique ([Fig. 2.112](#))



Fig. 2.112 Patient who is unable to lie flat is positioned feet-first supine with a large cushion under the knees to elevate the legs. [📄](#)

In patients who are unable to lie flat due to severe pain, who have severe claustrophobia, or cannot put their arms up onto their chest due to pain adaptive techniques can be used. In patients who need to elevate legs due to pain a large cushion can be placed underneath.

KNEE

Whilst plain X-ray imaging is the standard initial imaging modality to diagnose knee derangement, MRI is useful in the detection and characterisation of acute and chronic internal derangement injuries of the knee meniscal, cruciate ligament, collateral ligament and extensor mechanism, as well as articular cartilage, synovial and tendon disorders.

MRI allows improved evaluation of the bones and soft tissues and it helps to guide patient management ([17](#)).

Indications

- When plain X-ray has excluded fracture
- Post-traumatic injury
- Where there is a clinical suspicion of damaged cartilage, torn tendons or ligaments, fracture, osteoarthritis, osteochondral defects, infections and tumour

Imaging Procedure ([Fig. 2.113](#))



Fig. 2.113 Standard positioning. [🔗](#)

- Position the patient feet-first supine.

- Position in the dedicated knee coil with the lower border of the patella at the centre of the coil. External rotation of approximately 15 degrees will allow better visualisation of the anterior cruciate ligament.
- Immobilise with pads and cushions, ensure support is placed under the ankle and place a small sandbag over the patient's ankle if they can tolerate it.
- Centre for the localiser with the laser light over the lower border of the patella.

Sequence Planning ([Fig. 2.114a](#), [Fig. 2.114b](#) and [Fig. 2.114c](#))

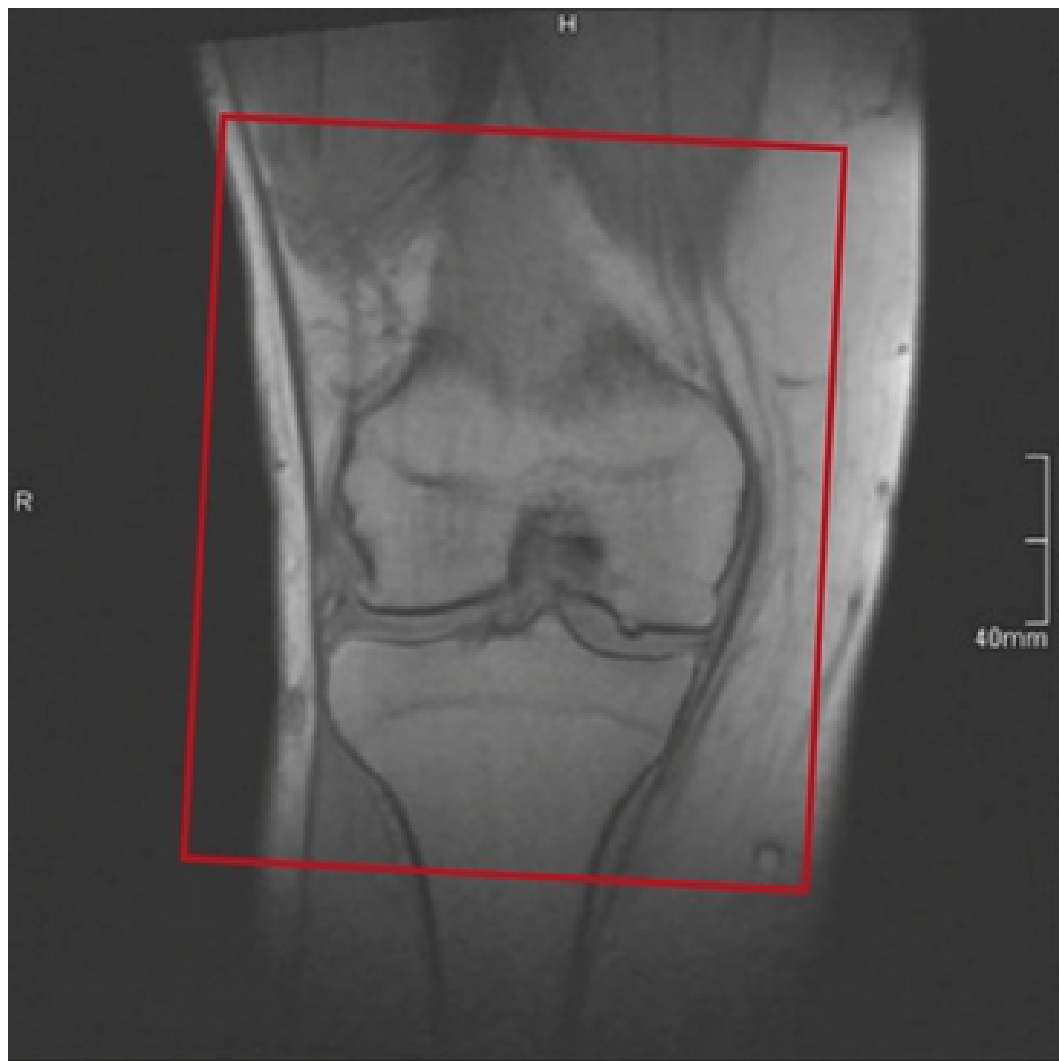


Fig. 2.114a [↗](#)

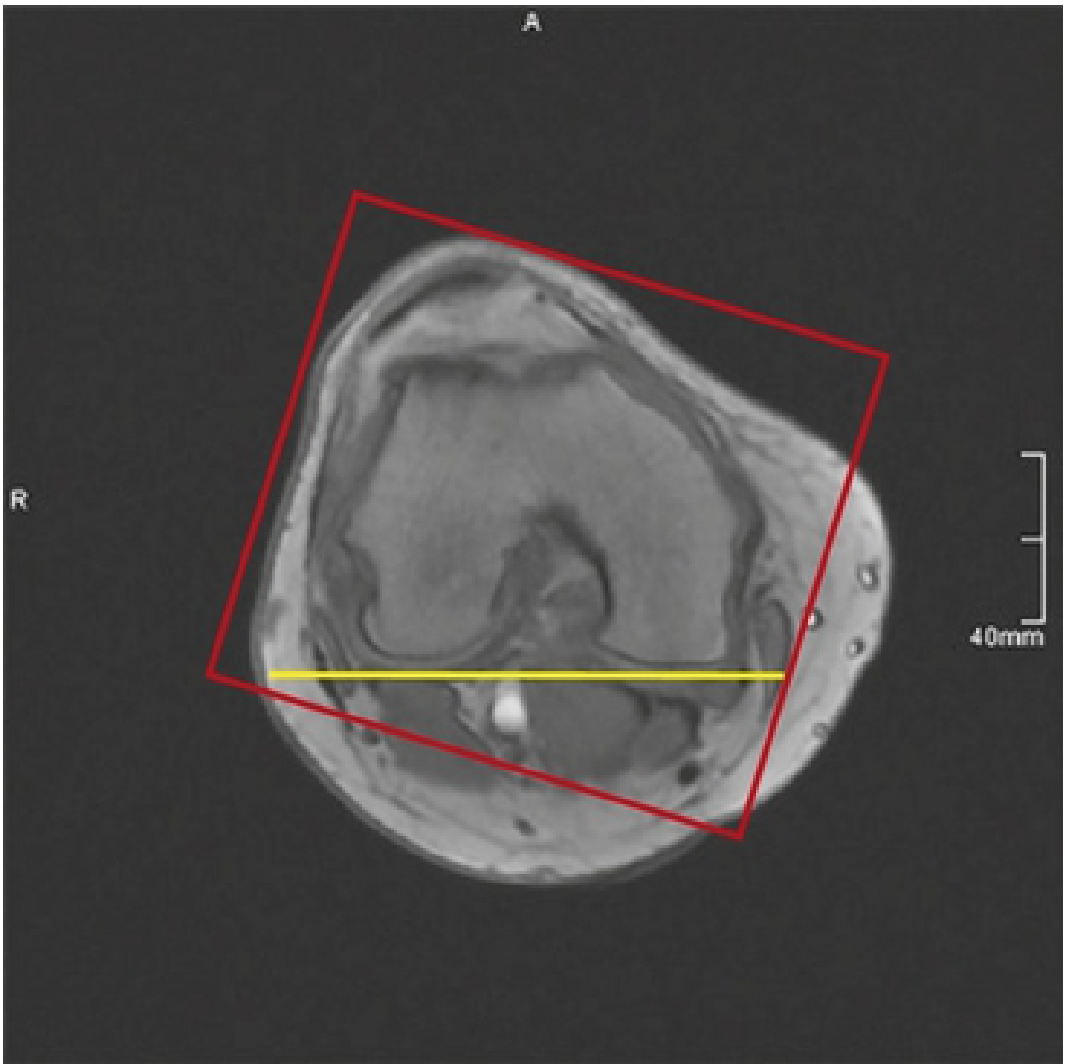


Fig. 2.114b [↗](#)

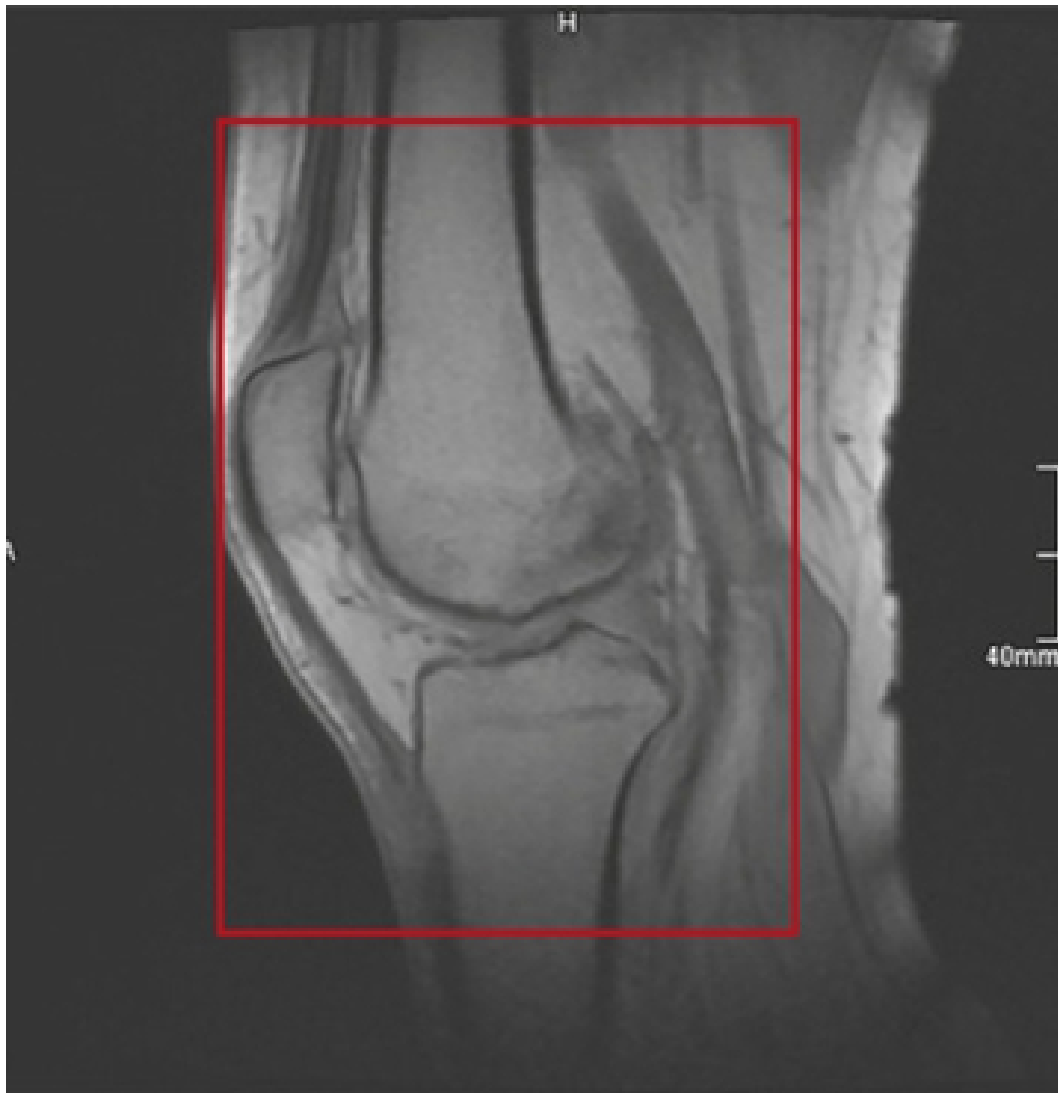


Fig. 2.114c [↗](#)

Planning coronal sequence: angle the block parallel to the posterior borders of the medial and lateral condyles of the femur on an axial image (yellow line in [Fig. 2.114b](#)).

Planning axial sequence: angle the block parallel to the medial and lateral condyle of the femur on a coronal image ([Fig. 2.114a](#)). Ensure full coverage of the knee joint ([Fig. 2.114c](#)).

Planning sagittal sequence: angle the block parallel to the lateral condyle on an axial image (red box in [Fig. 2.114b](#)).

Example sequence: knee						
Routine	3 plane localiser	Ax T2 or PD FS	Cor T1 STIR	Sag PD FS	Sag T2 GRE	Sag or Cor T1
Additional	Ax/Cor/Sag T1 FS pre- and post-contrast					

Acquired Images: Examples ([Figs. 2.115a, b](#))

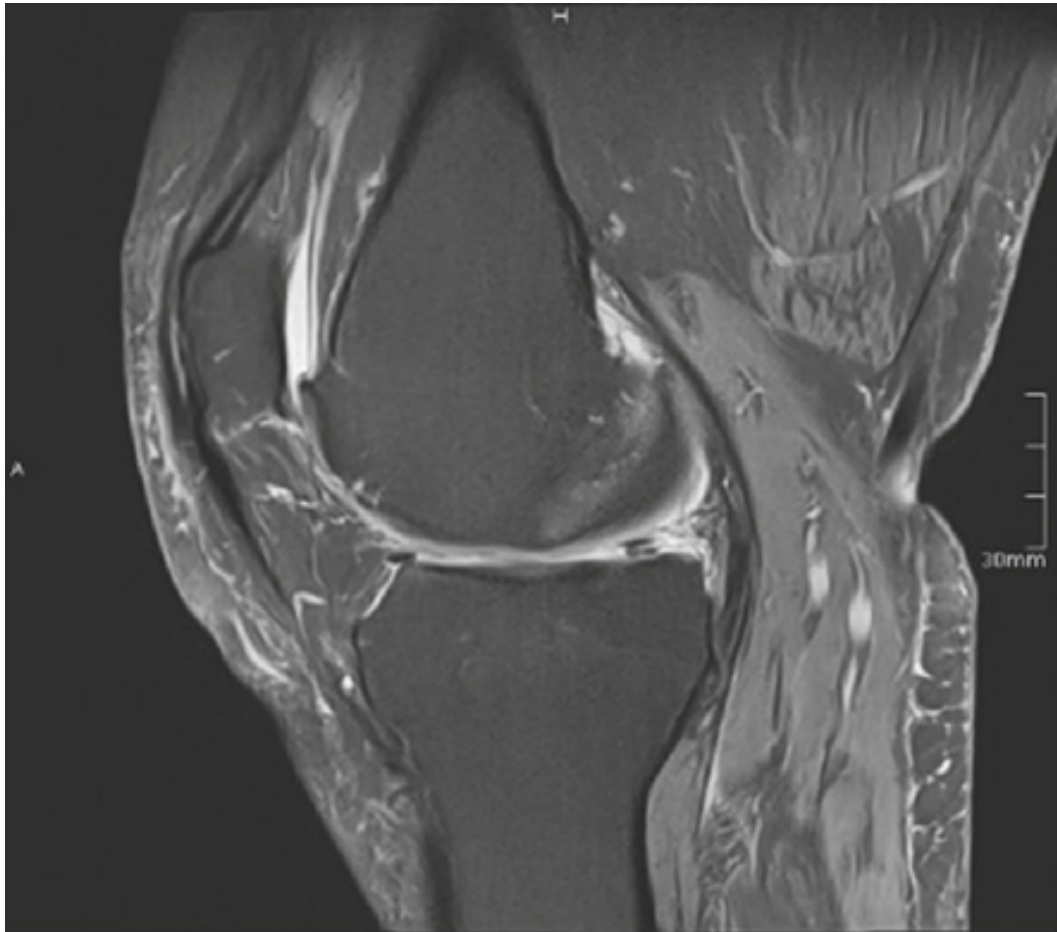


Fig. 2.115a Example of a T2 FS sagittal image of the knee. [↗](#)

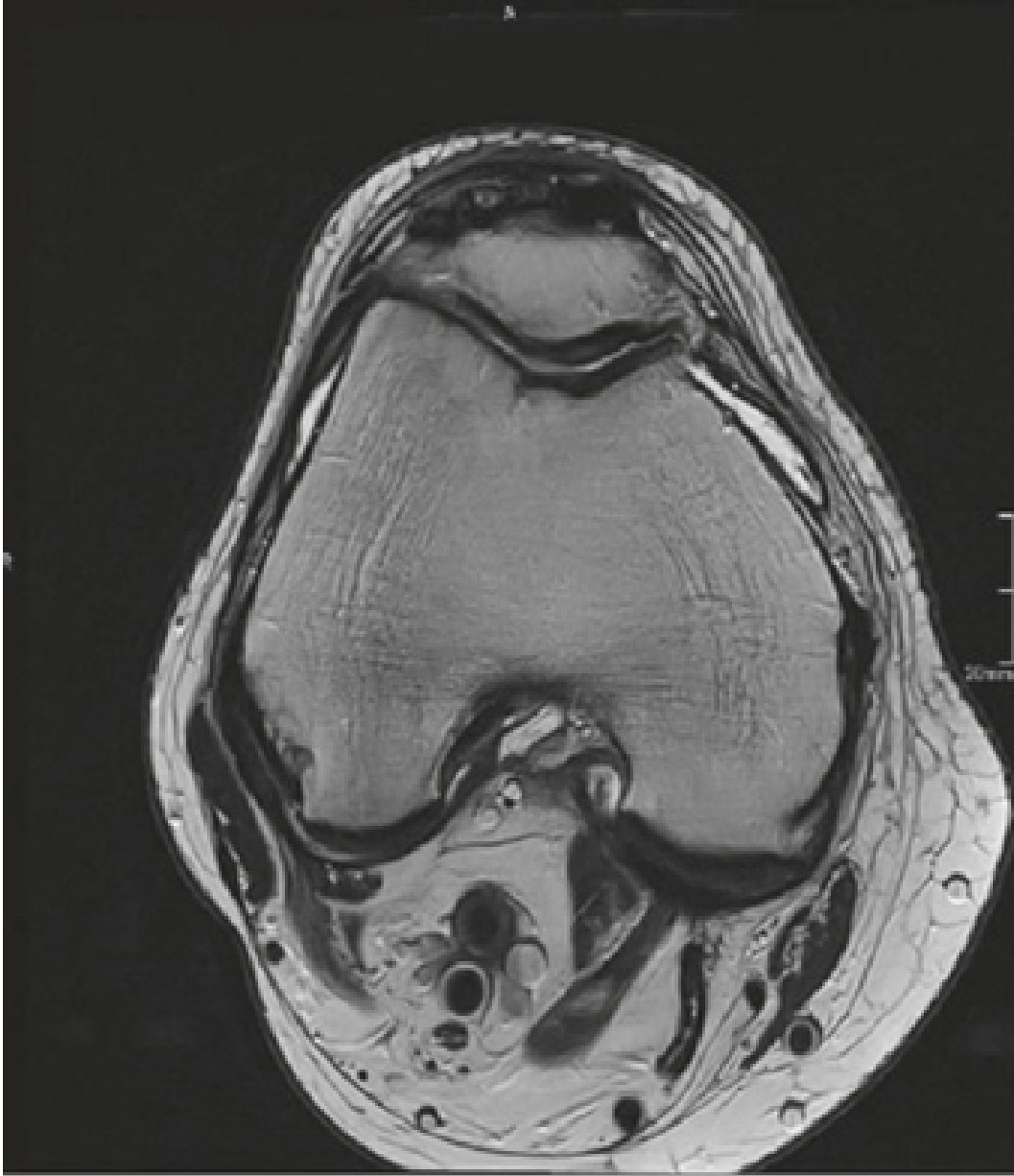


Fig. 2.115b Example of a T2 axial image of the knee. [🔗](#)

Contrast Media and Injection Data

Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as synovitis.

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard knee imaging is adequate.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.116a, b](#))

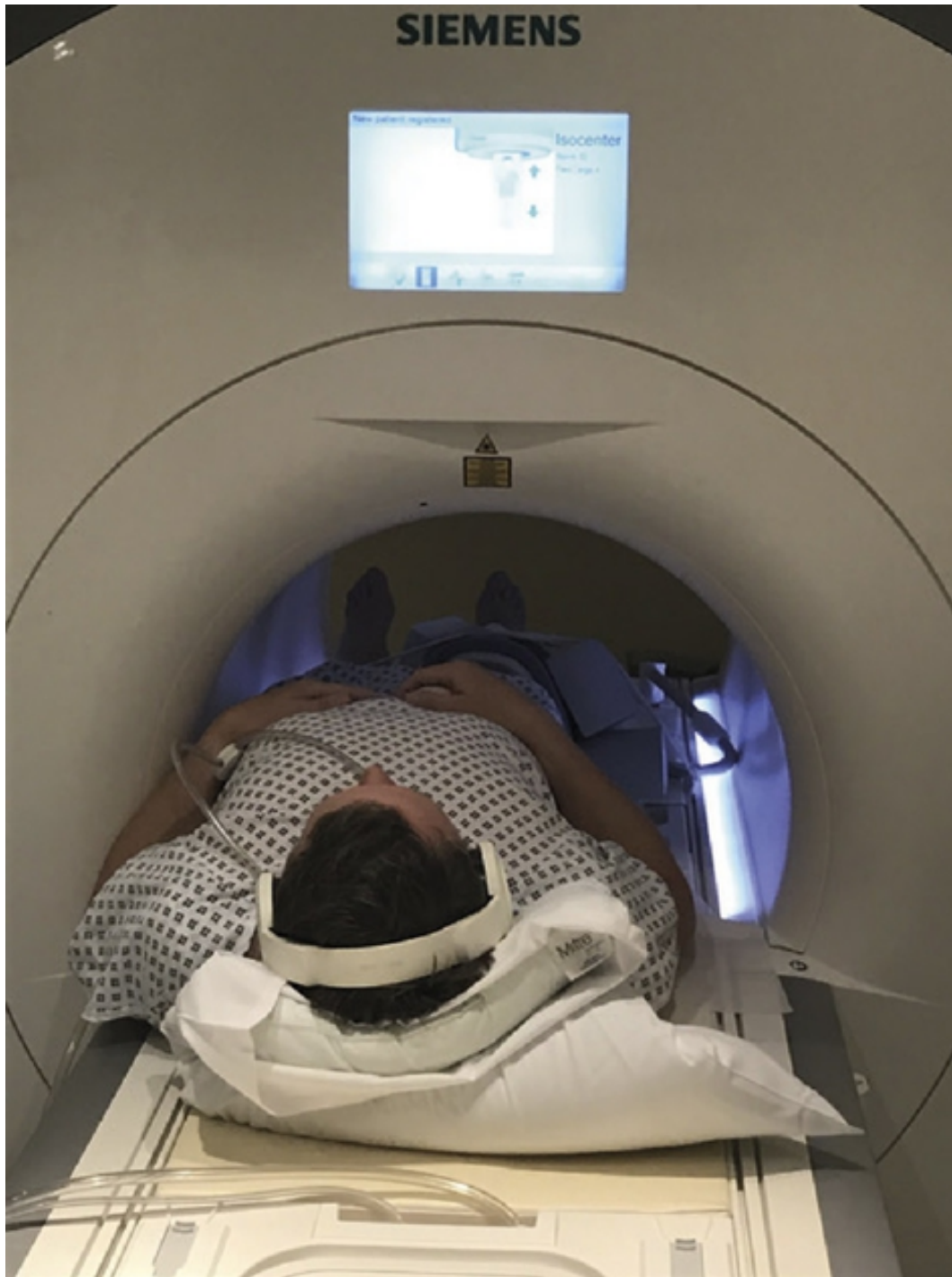


Fig. 2.116a Large flex coil wrapped around the knee. When adapting technique, avoid positioning the knee close to the side of the magnet, as this affects fat saturation. [🔗](#)

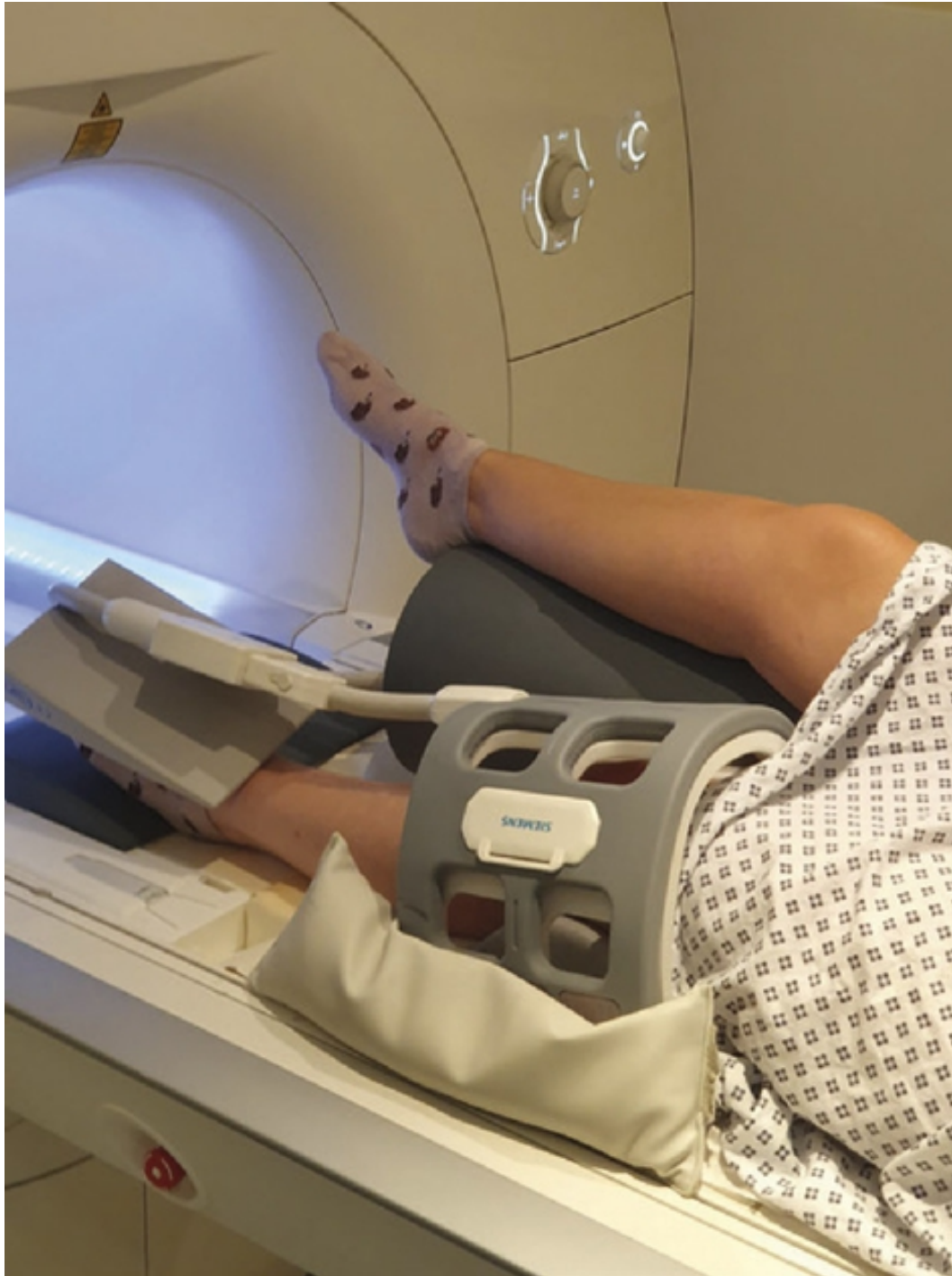


Fig. 2.116b Small flexible coil wrapped around the knee. Ensure adequate immobilisation devices are used. [↗](#)

When it is not possible to position in the dedicated knee coil due to large body habitus or swollen knee, or if the patient is unable to straighten their

leg, it is possible to use adaptive techniques to obtain diagnostic images. Either a body array or a flex coil can be wrapped around the patient's knee or a body array coil, whichever is the best fit on assessment. Ensure that when using the flex coil the knee is not too close to the edge of the magnet bore as this will result in reduction in fat saturation and signal loss.

LOWER LEG: TIBIA AND FIBULA

Whilst plain X-ray imaging is often used in the first instance to investigate problems of the lower leg, both CT and MRI are used to better evaluate abnormalities that have been identified. Both cross-sectional modalities provide better evaluation of cortical abnormalities, but MRI gives excellent soft tissue contrast resulting in high sensitivity and specificity in the differential diagnosis of lower leg pain ([18](#)). Other advantages include the fact that it does not use ionising radiation and therefore makes it an ideal diagnostic tool in evaluating abnormalities that have been identified in young people.

Indications

- Injury or lump
- Lower leg pain, suspicion of ruptured tendon at insertion point
- Shin splints or compartment syndrome
- Bone tumours, stress fractures or soft tissue calcification
- Demonstrates oedema in conditions like periostitis and infection
- Peripheral vascular disease

Imaging Procedure ([Fig. 2.117](#))



Fig. 2.117 Standard positioning. [🔗](#)

- Position the patient supine.
- Place a large flexible coil over both tibias/fibulas.
- Use small cushions to support under the knees. Avoid using large pads that will elevate the lower leg.

- Place sandbags next to or across the ankles to encourage the patient to stay still during scans.
- Centre for the localiser with the laser light at the middle of the tibia/fibula.
- Position arms comfortably by the side.

Sequence Planning ([Fig. 2.118a](#), [Fig. 2.118b](#) and [Fig. 2.118c](#))

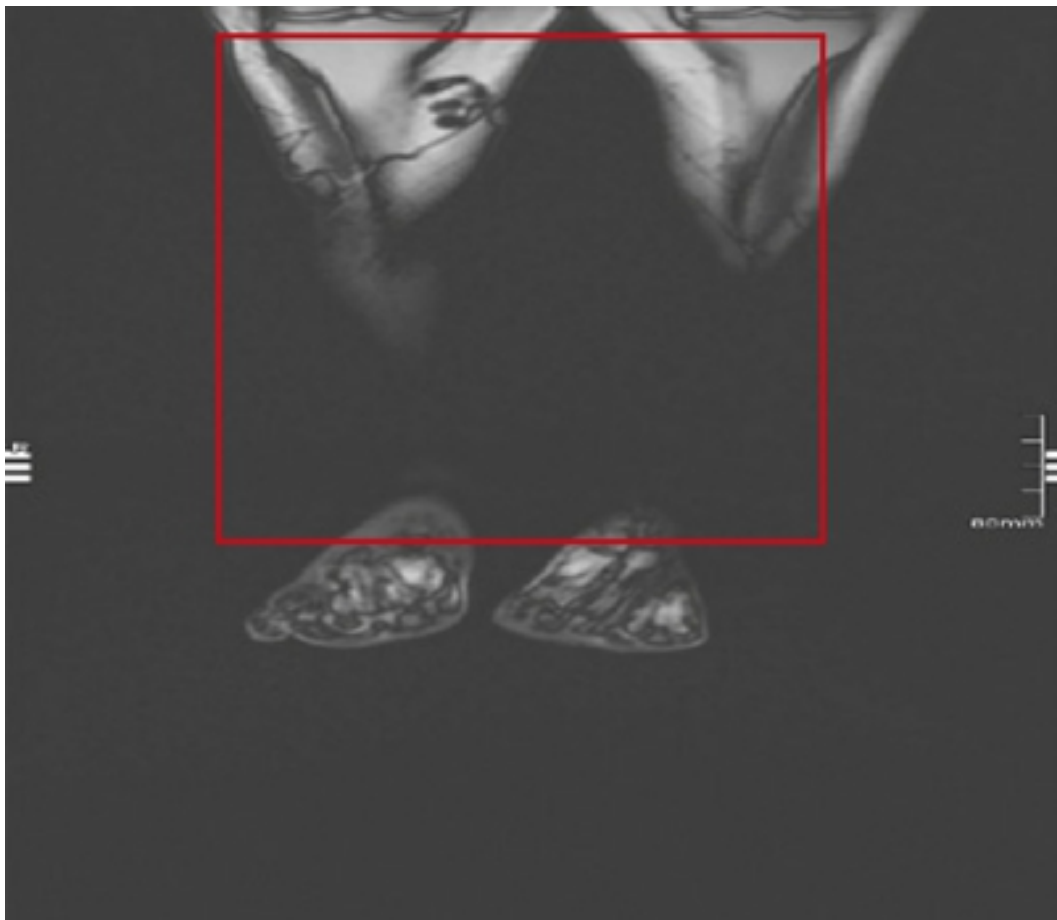


Fig. 2.118a [↗](#)

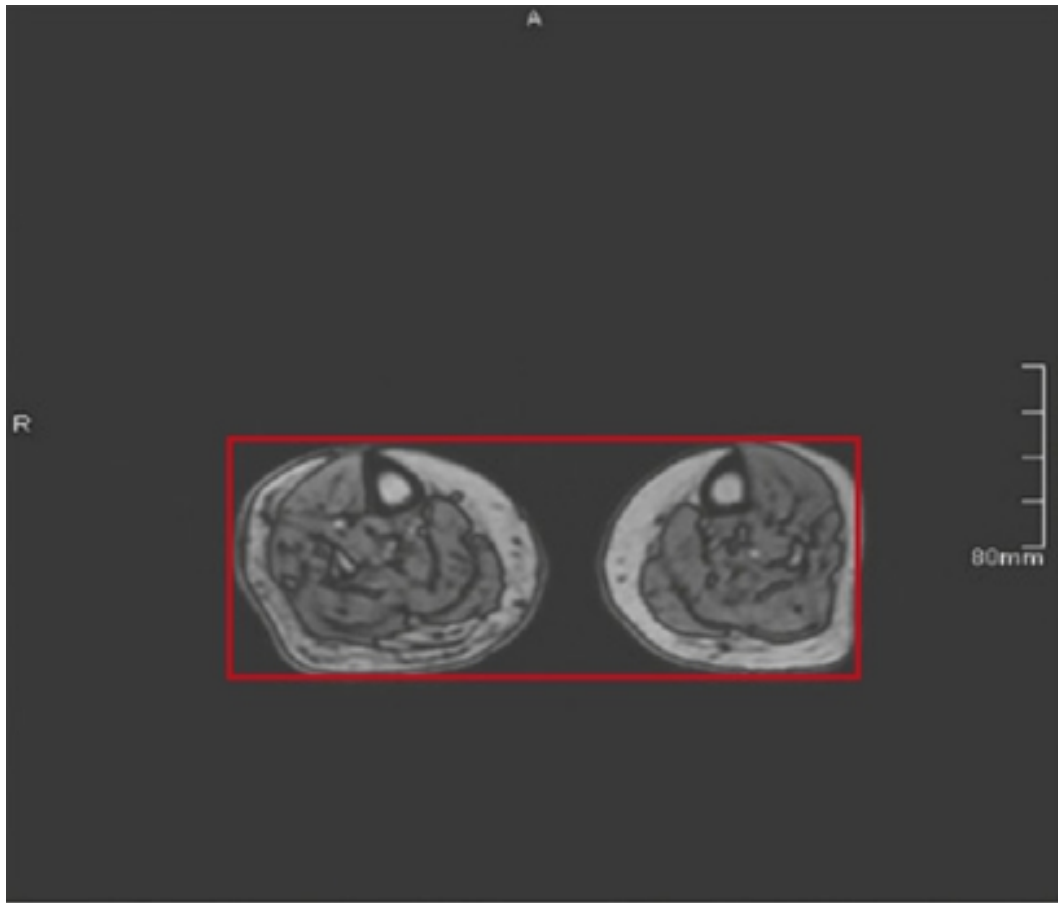


Fig. 2.118b [🔗](#)

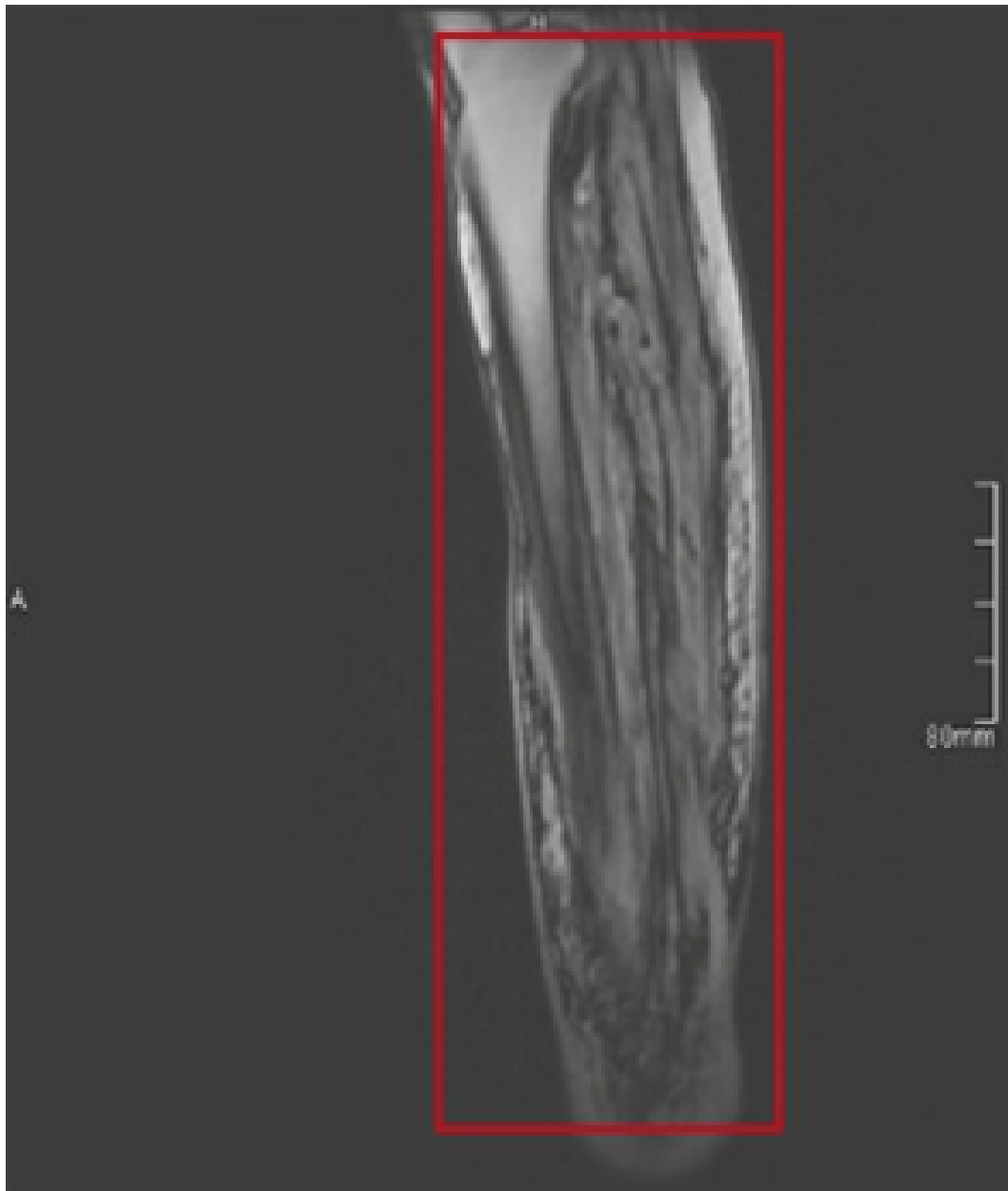


Fig. 2.118c [🔗](#)

Planning coronal sequence: angle the block parallel to the tibia on a sagittal image ([Fig. 2.118c](#)). Ensure appropriate angle across both shafts of tibia on a coronal image. Ensure enough slices to cover the lower leg to include the soft tissue of the calf.

Planning axial sequence: angle the block perpendicular to the tibia on a sagittal image. Ensure appropriate angle across both tibias on a coronal image. Ensure enough slices to cover from the knee joint to the ankle joint, or to cover a specified area of interest with either the knee or the ankle joint included as a reference point.

Planning sagittal sequence: plan left and right sagittals separately. Angle the block parallel to the tibia on a coronal image and ensure a suitable angle across the tibia on an axial image ([Fig. 2.118a](#)). Ensure enough slices to cover the soft tissue from the medial to lateral sides ([Fig. 2.118b](#)). Ensure that the FOV is large enough to cover the whole of the lower leg to include the knee and ankle joint.

Example sequences: tibia and fibula						
Routine	3 plane localiser	Cor T1	Cor T1 STIR or TIRM	Ax T1 Ax T2 FS	Sag PD FS	affected side
Additional		Ax T1 FS	Ax and Cor T1 FS pre- and post-contrast			

Acquired Images: Examples ([Figs. 2.119a,b](#))



Fig. 2.119a Coronal T1 image of bilateral tibia and fibula. [↗](#)

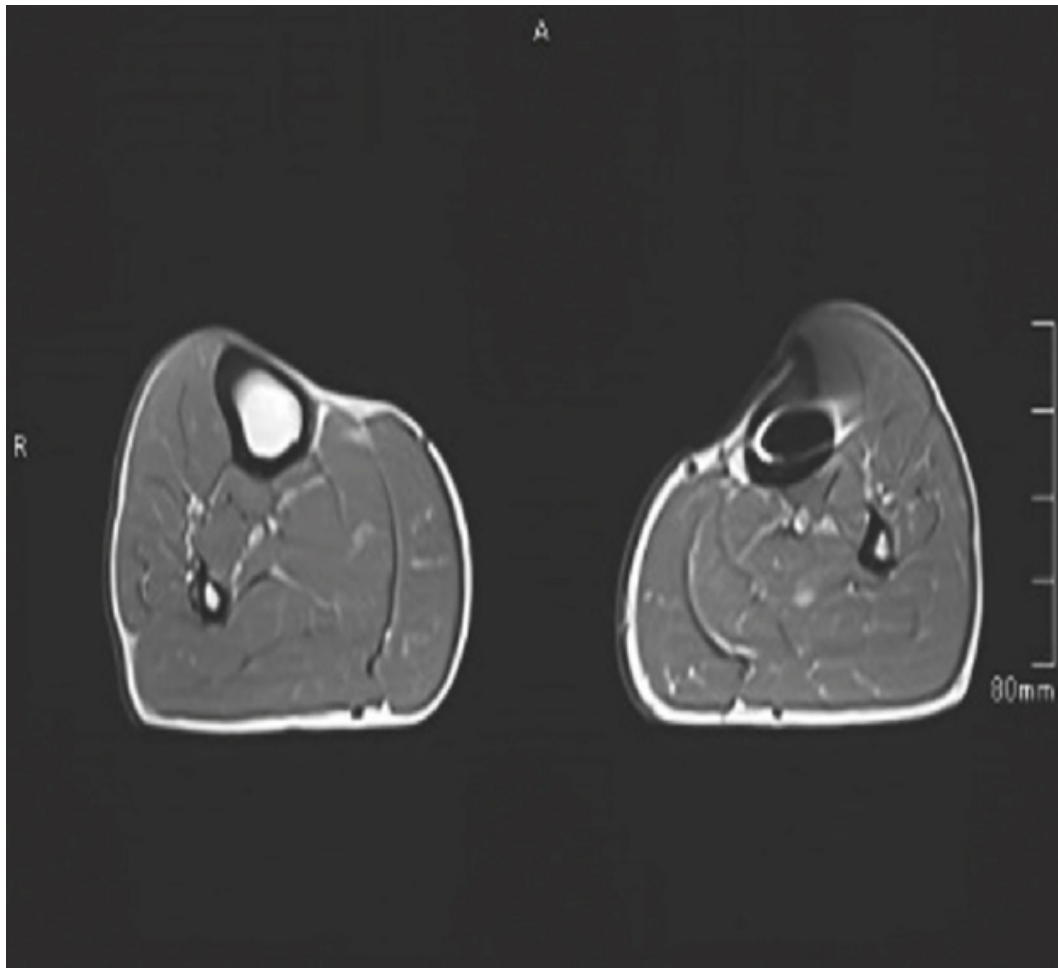


Fig. 2.119b Axial T1 image of bilateral tibia and fibula (note the metallic susceptibility artefact from metal work in the left leg). [🔗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Hand injection for all standard lower leg imaging is adequate. For vascular imaging, dynamic injection using an injection pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.120a,b](#))



Fig. 2.120a Feet first ensuring lower legs are over the spine coils on the table, with a body array coil placed across the top. [📄](#)



Fig. 2.120b A patient who is unable to straighten their legs is positioned feet first with a large pad under the knees and a body array placed over the lower legs. [↗](#)

When it is not possible to follow standard positioning due to large body habitus or swollen leg, or if the patient is unable to straighten their leg, it is possible to use adaptive techniques to obtain diagnostic images. In patients who are in pain it is important to firstly make sure that their legs are comfortable with cushions before immobilising the legs and choosing an alternative coil.

ANKLE

MRI is the most sensitive imaging modality used for looking at soft tissues in the ankle. It allows high resolution of cartilage, tendons, ligaments, muscles and blood vessels.

Indications

- When plain X-ray has excluded fracture
- Post-traumatic injury
- Suspected Achilles tendon rupture
- When there is a clinical suspicion of damaged cartilage, torn tendons or ligaments, fracture, osteoarthritis, osteochondral defects, avascular necrosis, loose bodies, infection or tumour

Imaging Procedure ([Fig. 2.121](#))

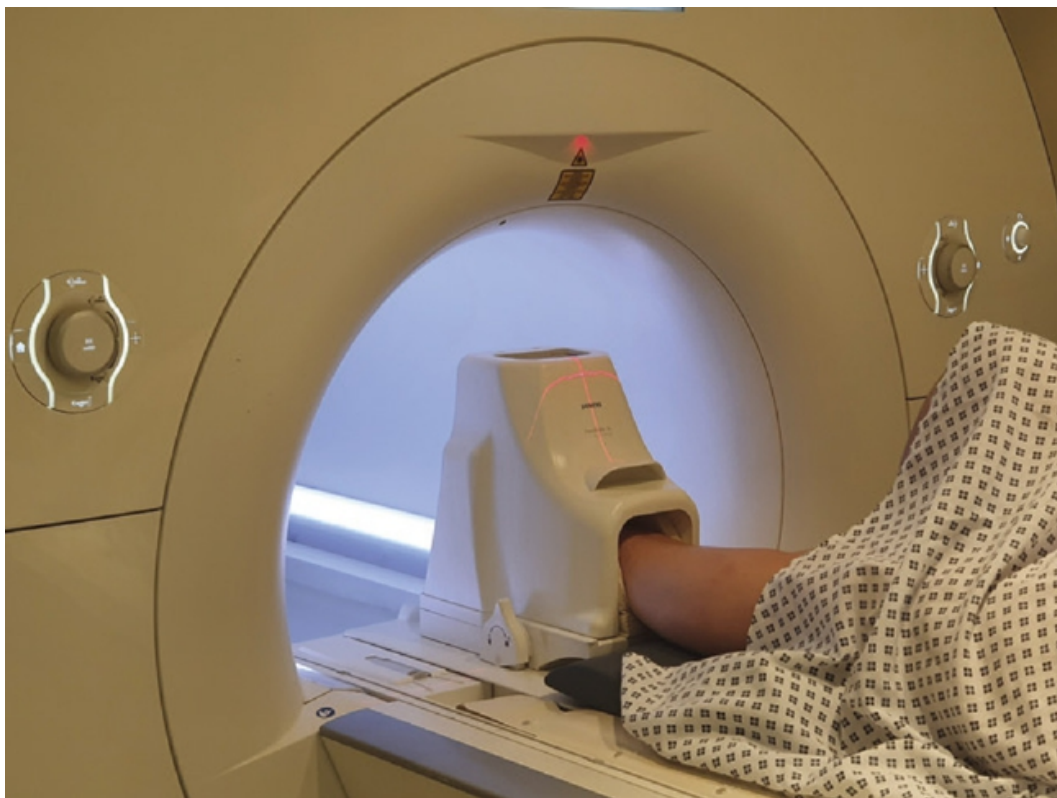


Fig. 2.121 Standard positioning in a dedicated foot and ankle coil. [↗](#)

- Position the patient feet-first supine.
- Position the ankle in the centre of a dedicated ankle coil, with foot flexed at 90 degrees and flattened against the back of the coil.
- Use cushions and pads as appropriate to ensure that the foot stays immobilised and straight throughout the scan.

- Centre for the localiser with the laser light over the centre of the ankle joint.
- Position the other leg out of the way to avoid aliasing/wrap on images. This will also allow reduced scan times. Caution: after scan completion, allow time for the patient to check that they can stand on the leg that has been tucked out of the way.

Sequence Planning ([Fig. 2.122a](#), [Fig. 2.122b](#) and [Fig. 2.122c](#))



Fig. 2.122a [📄](#)



Fig. 2.122b [🔗](#)

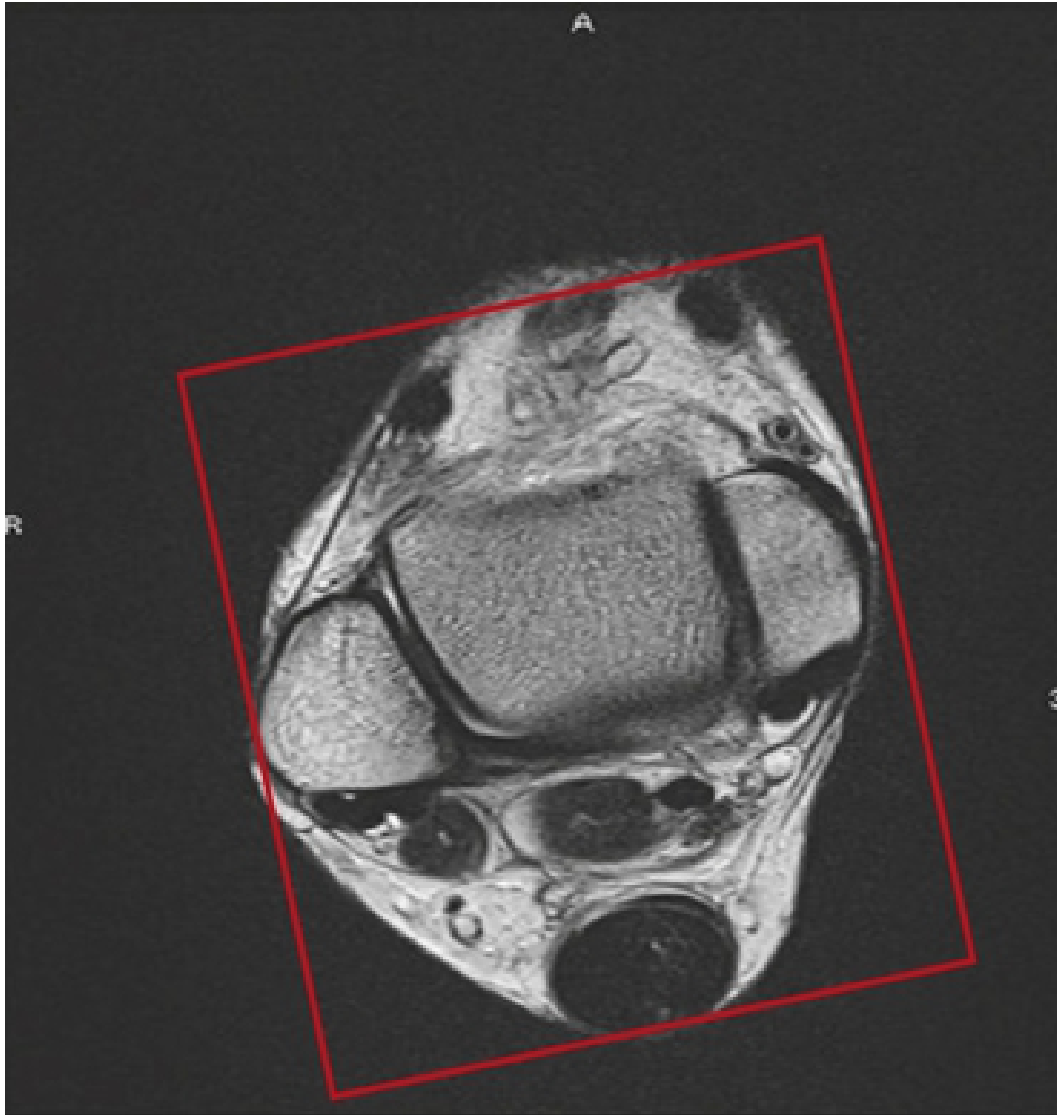


Fig. 2.122c [🔗](#)

Planning sagittal sequence: angle the block parallel to the medial and lateral malleoli on an axial image. In the coronal plane angle parallel to the tibia ([Fig. 2.122b](#)).

Planning coronal sequence: angle the block perpendicular to the medial and lateral malleoli on an axial image ([Fig. 2.122c](#)). In the sagittal plane angle parallel to the tibia. Cover from the ankle joint to the Achilles.

Planning coronal sequence: angle the block perpendicular to the medial and lateral malleoli on an axial image. In the sagittal plane angle parallel to

the tibia ([Fig. 2.122a](#)). Cover from ankle joint to the Achilles.

Example sequences: ankl55							
Routine	3 plane localiser	Ax T2	Ax PD FS	Sag T2 FS	Cor T1	Sag T1	Cor PD FS
Additional for Achilles		Large FoV T1 and T2 FS Sag					
Additional for osteochondritis dissecans		T2 TRUFI/DESS/FLASH volume sequence					

Acquired Images: Examples ([Figs. 2.123a,b](#))



Fig. 2.123a STIR sagittal image of the ankle joint. [📄](#)



Fig. 2.123b T2 axial image of the ankle joint. [📄](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions and diagnosis of conditions such as synovitis in joints. Hand injection for all standard ankle imaging is suitable.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Fig. 2.124a](#), [Fig. 2.124b](#), [Fig.126](#), [Fig. 2.124d](#), [Fig. 2.124e](#) and [Fig. 2.124f](#))



Fig. 2.124a Large body array placed over the ankle in a patient who cannot lie flat. The spine coils are also used here. Add immobilisation devices as needed. [📄](#)

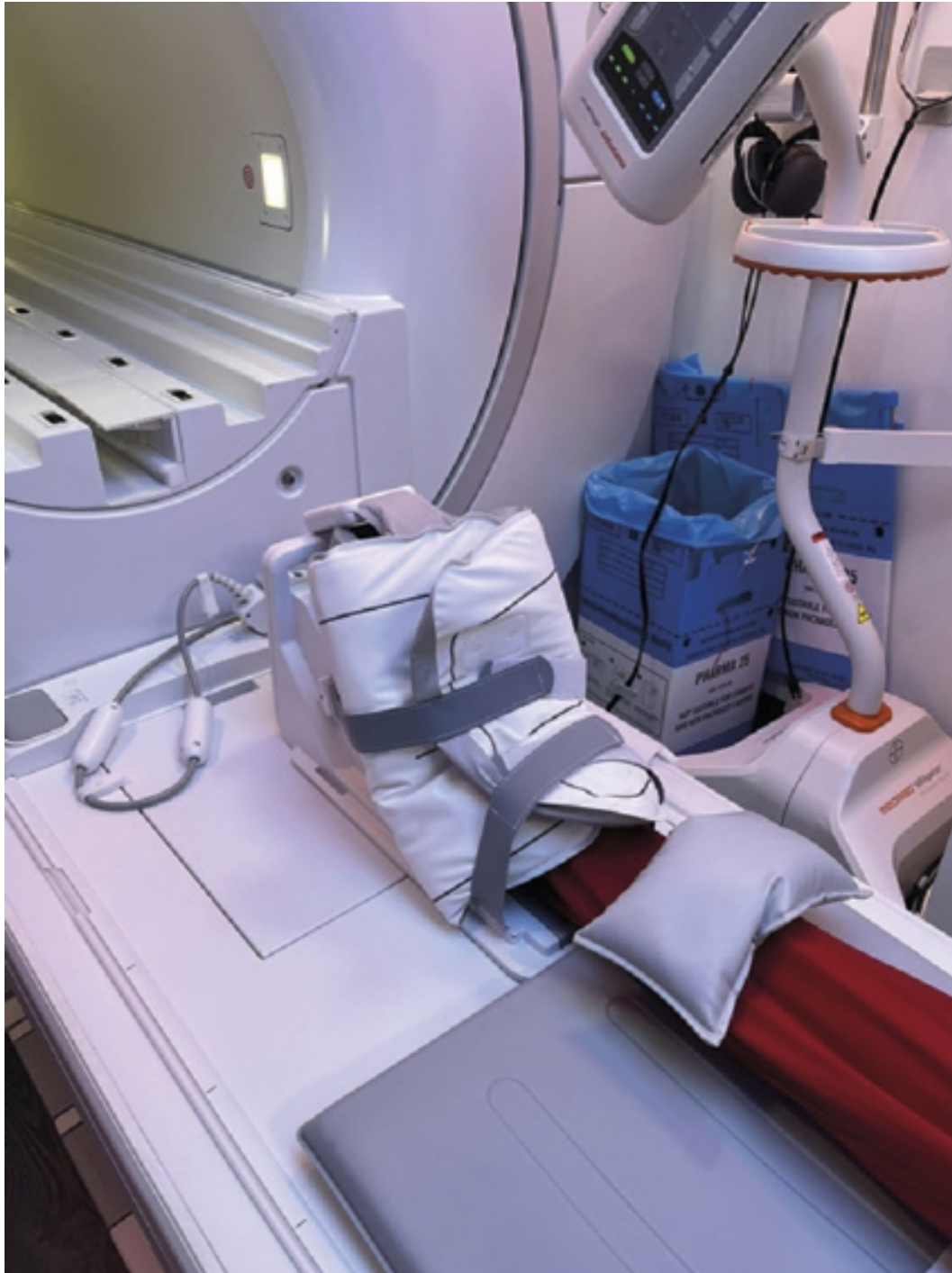


Fig. 2.124b If a foot and ankle coil is not available an ‘air wrap coil’ can be used. [🔗](#)



Fig. 2.124c The ankle is positioned in head coil. Add immobilisation devices as needed. If the patient is unable to bend the other leg out of the way add phase oversampling to avoid aliasing artefact. [↗](#)



Fig. 2.124d The other leg is left by the side in a patient who is unable to bend it out of the way. Add phase oversampling to avoid aliasing artefact ([Fig 2.124f](#)).^٤



Fig. 2.124e A flex coil is wrapped around the ankle in a patient who cannot tolerate the dedicated foot/ankle coil. Add immobilisation devices as needed. [📄](#)



Fig. 2.124f Aliasing on image, caused by the other leg remaining in the scan field. If the patient cannot move the other leg out of the way, add phase oversampling during planning to avoid this. This may lengthen scan times. [🔗](#)

When it is not possible to follow standard positioning due to large body habitus or swollen ankle or leg, if the patient is unable to straighten their

leg, or if the patient is unable to move the other leg out of the scanning field, it is possible to use adaptive techniques to obtain diagnostic images. In patients who are in pain it is important to firstly make their legs comfortable with cushions before immobilising the legs and choosing an alternative coil.

There are options of using a flex coil wrapped around the patient's ankle, a body array coil, or a head coil, whichever is the best fit on assessment. Ensure that when using the flex coil or body array coil the ankle is not too close to the edge of the magnet as this will result in reduction in fat saturation and signal loss.

FOOT, FOREFOOT AND TOES

An MRI of the forefoot and toes is usually carried out to evaluate various conditions that can cause pain or injury. High-resolution MR imaging of the forefoot allows for accurate assessment of many of these conditions. The MR can demonstrate any bony abnormality or any inflammatory process that may be present.

Indications

- Marrow abnormalities such as bone contusions, osteonecrosis, marrow oedema and stress fractures
- Synovial-based disorders such as synovitis, tenosynovitis, bursitis and ganglion cysts
- Congenital and developmental conditions such as dysplasia and tarsal coalition
- Infections of bone, joint or soft tissue such as osteomyelitis and osteoarthritis

- Plantar plate injury, plantar fasciitis, fascial rupture and plantar fibromatosis
- Neoplasms of bone, joint or soft tissue
- Abnormalities of other hindfoot tendons
- Abnormalities of foot tendons
- Morton's neuroma
- Avascular necrosis
- When plain X-ray has excluded fracture
- Clinical suspicion of Morton's neuroma
- Where there is a clinical suspicion of damaged cartilage, torn tendons or ligaments and loose bodies

Imaging Procedure ([Fig. 2.125](#))

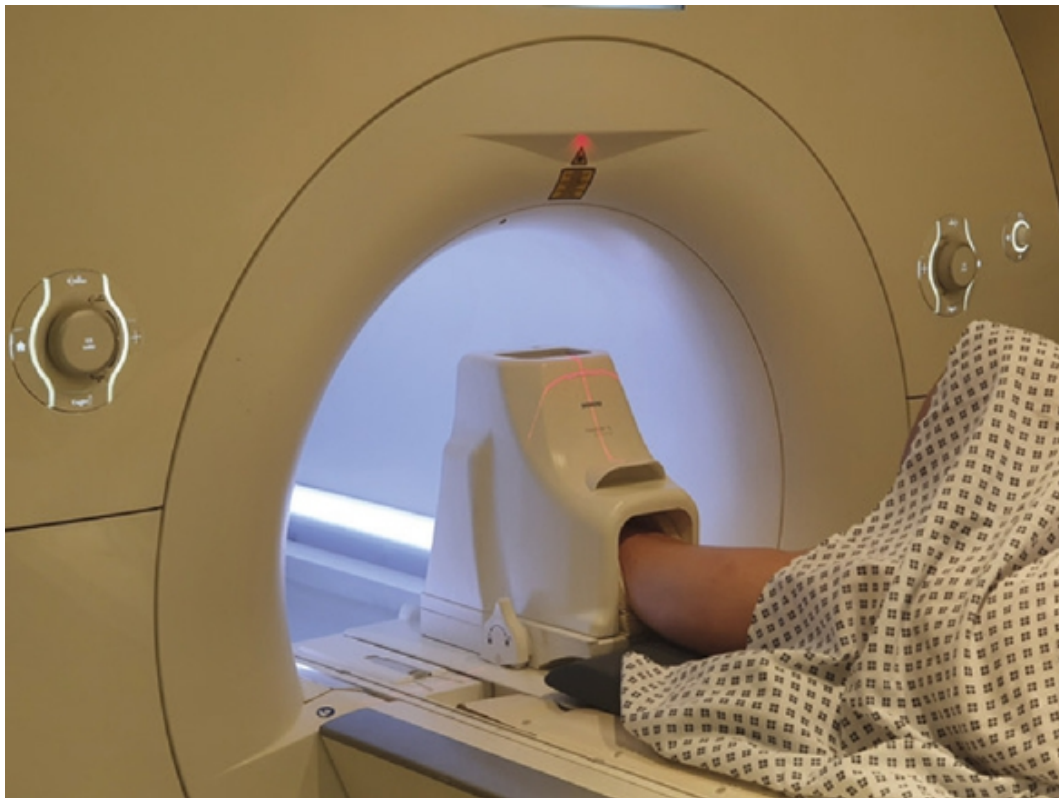


Fig. 2.125 Standard positioning. [↗](#)

- Position the patient feet-first supine.
- Position the foot in a dedicated foot/ankle coil, with foot flexed at 90 degrees and flattened against the back of the coil.
- Use cushions and pads as appropriate to ensure that the foot stays immobilised and straight throughout the scan.
- Centre for the localiser with the laser light over the centre of the foot or forefoot depending on the area being scanned.
- Position the other leg out of the way to avoid aliasing/wrap on images, and this will allow reduced scan times. Caution: after scan completion allow the patient time to check they can stand on the leg that has been bent out of the way if this was the chosen method.

Sequence Planning: Foot ([Fig. 2.126a](#), [Fig. 2.126b](#) and [Fig. 2.126c](#))



Fig. 2.126a [↗](#)



Fig. 2.126b [📄](#)

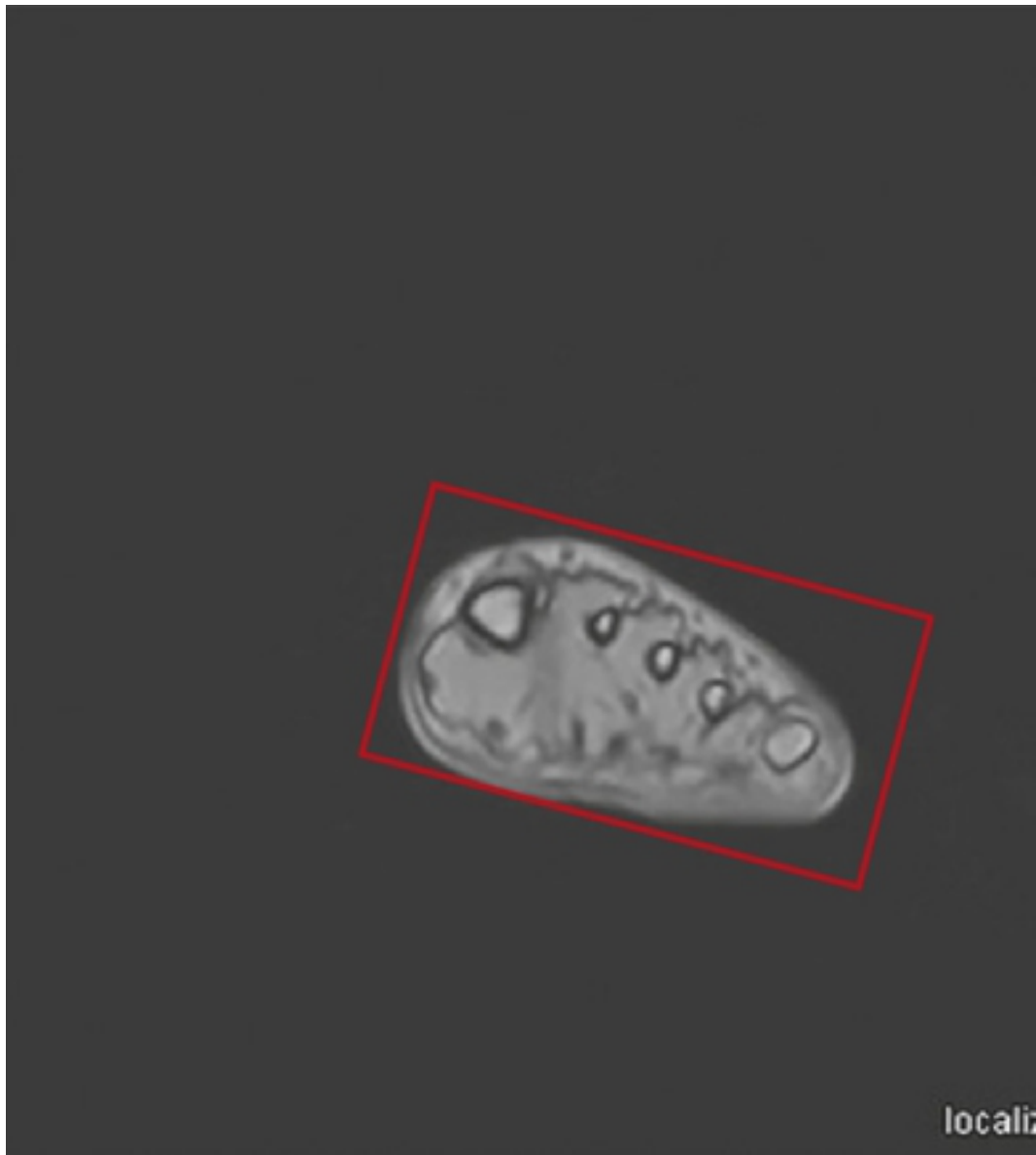


Fig. 2.126c [🔗](#)

Planning coronal (long axis) sequence: angle slices parallel to the metatarsal and phalanges ([Fig. 2.126a](#)).

Planning axial (short axis) sequence: angle the block perpendicular to the metatarsal and phalanges within the area of interest ([Fig. 2.126c](#)).

Planning sagittal sequence: angle the block parallel to the metatarsal and phalanges ([Fig. 2.126b](#)). In the axial plane angle perpendicular to the line across the metatarsal bones.

Sequence Planning: Forefoot ([Fig. 2.127a](#), [Fig. 2.127b](#) and [Fig. 2.127c](#))



Fig. 2.127a [↗](#)



Fig. 2.127b [🔗](#)



Fig. 2.127c [🔗](#)

Planning axial (short axis) sequence: plan the axial slices on the sagittal plane, angling the positioning block perpendicular to the metatarsal and phalanges bones. Check the positioning block in the other two planes. An appropriate angle must be given in the coronal plane (perpendicular to the metatarsal and phalanges bones). Cover the forefoot from the tip of the toe up to the metatarsal bones, demonstrated by the yellow box in [Fig. 2.127c](#).

Planning coronal (long axis) sequence: plan the coronal slices on the sagittal plane, ensuring that the positioning block is angled parallel to the

metatarsal and phalanges bones. Verify the positioning of the block in the other two planes. Establish an appropriate angle in the axial plane, aligning it parallel to the line across the metatarsal bones ([Fig. 2.127b](#)). The slices should adequately cover the foot from the plantar aspect up to the dorsal aspect. Use a FOV small enough, such as 120 to 150 mm, to encompass the metatarsal and phalanges bones, demonstrated by the red box in [Fig. 2.127c](#).

Planning sagittal sequence: plan the sagittal slices on the coronal plane and angle the positioning block parallel to the metatarsal and phalanges bones ([Fig. 2.127a](#)). Verify the block's positioning in the other two planes. Establish an appropriate angle in the axial plane, perpendicular to the metatarsal bones. Ensure that the slices adequately cover the foot from side to side. Utilise a small FOV to encompass the metatarsal and phalanges bones.

Sequence Planning: Toe(s) ([Fig. 2.128a](#), [Fig. 2.128b](#) and [Fig. 2.128c](#))



Fig. 2.128a [🔗](#)



Fig. 2.128b [🔗](#)

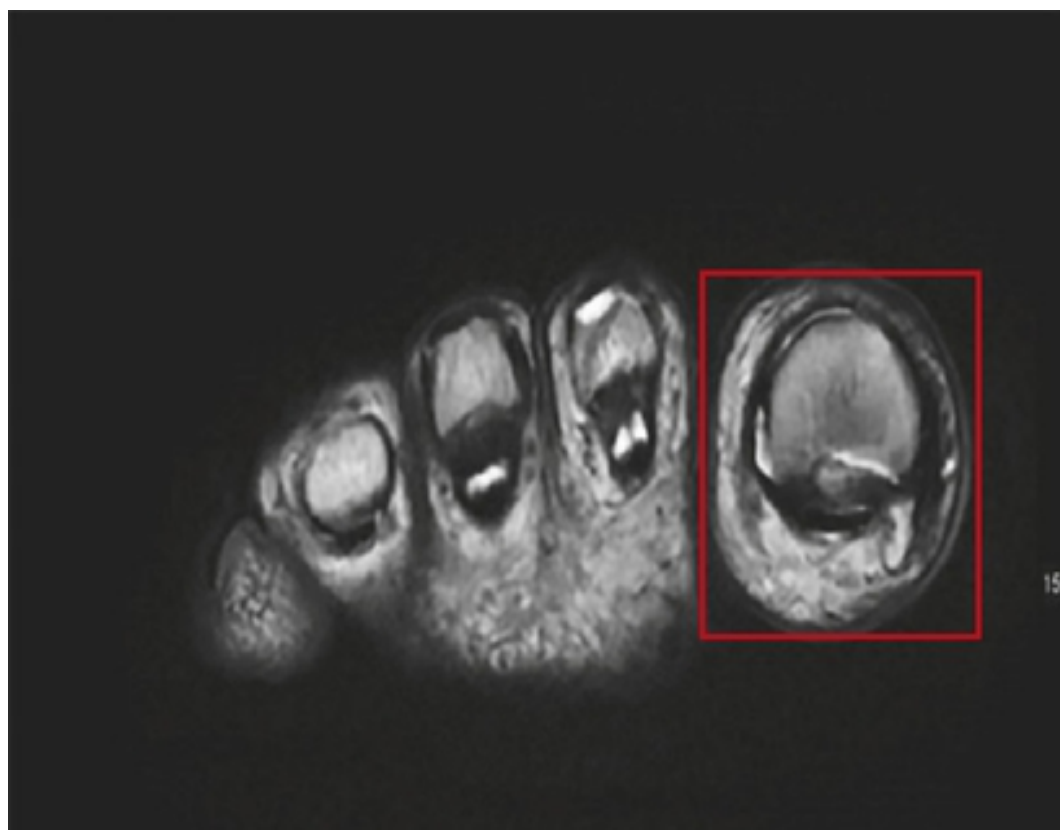


Fig. 2.128c 

Refer to the planning used for the forefoot as guidance. Use a FOV and plan in true orthogonal planes relevant to the toe that is being scanned.

Example sequences: foot, forefoot and toes							
Routine for foot	3 plane localiser	3.5 mm Ax T2 short axis	3.5 mm Ax STIR short axis	3.5 mm T2 SPAIR Ax short axis	4 mm T1 Cor long axis	4 mm Sag PD FS	4 mm Sag STIR
Routine for forefoot/toes		3 mm Ax T1 short axis	3 mm Ax T2 FS short axis	2.5 mm T2 SPAIR Cor long axis	2.5 mm T1 Cor long axis	Sag PD FS	
Additional for Morton's neuroma		Ax T1 FS short axis	T1 FS short and long axis pre- and post-contrast				

Acquired Images: Examples ([Figs. 2.129a](#), [Figs. 2.129b](#), [Figs. 2.129c](#), [Figs. 2.129d](#), [Figs. 2.129e](#), [Figs. 2.129f](#))



Fig. 2.129a Axial STIR images of the foot. [📄](#)

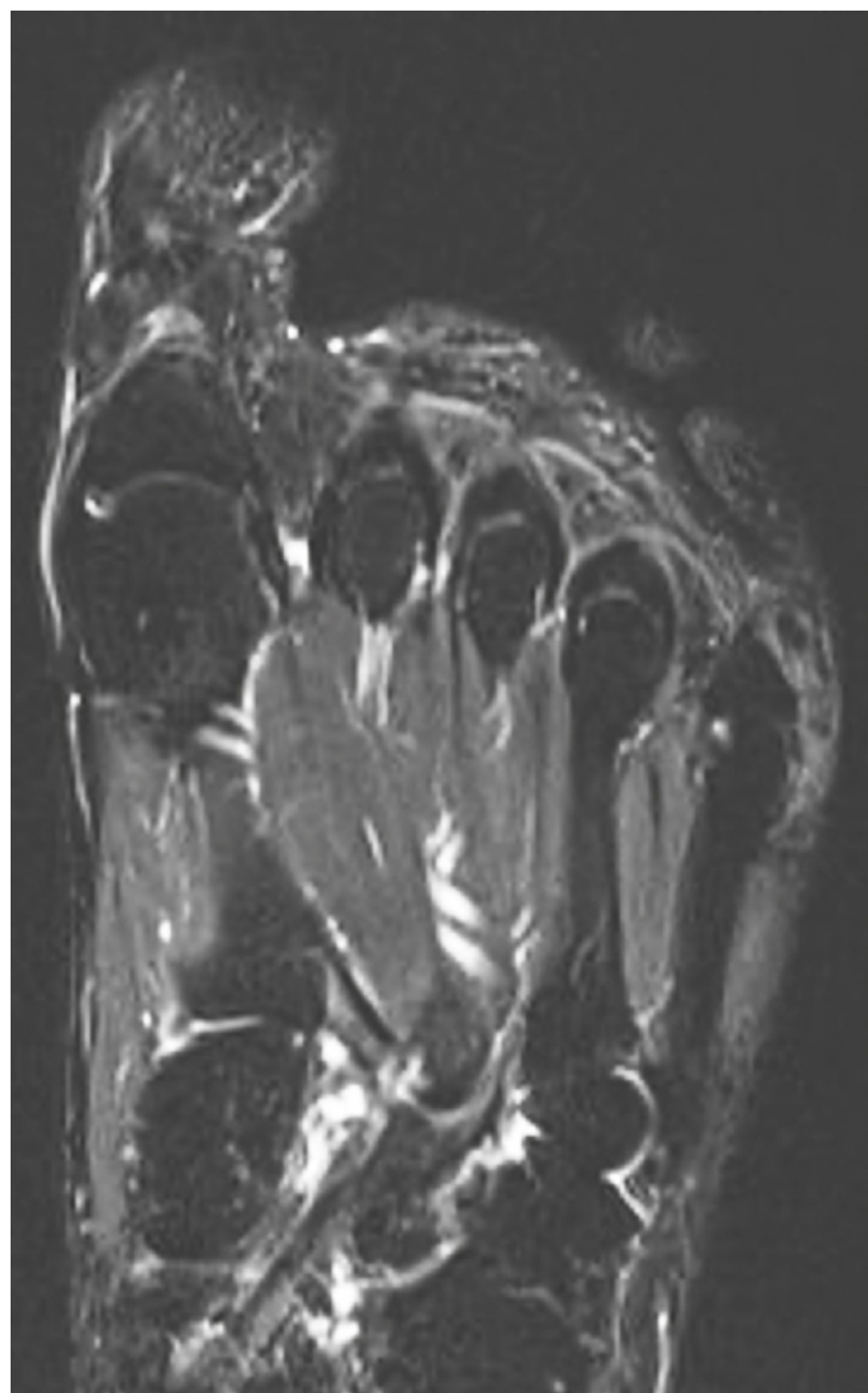


Fig. 2.129b Coronal STIR images of the foot. [↗](#)



Fig. 2.129c Coronal T1 image. [↗](#)



Fig. 2.129d Sagittal PD Fat sat image. [↗](#)



Fig. 2.129e Coronal T1 image of the forefoot to demonstrate the toes. [📄](#)

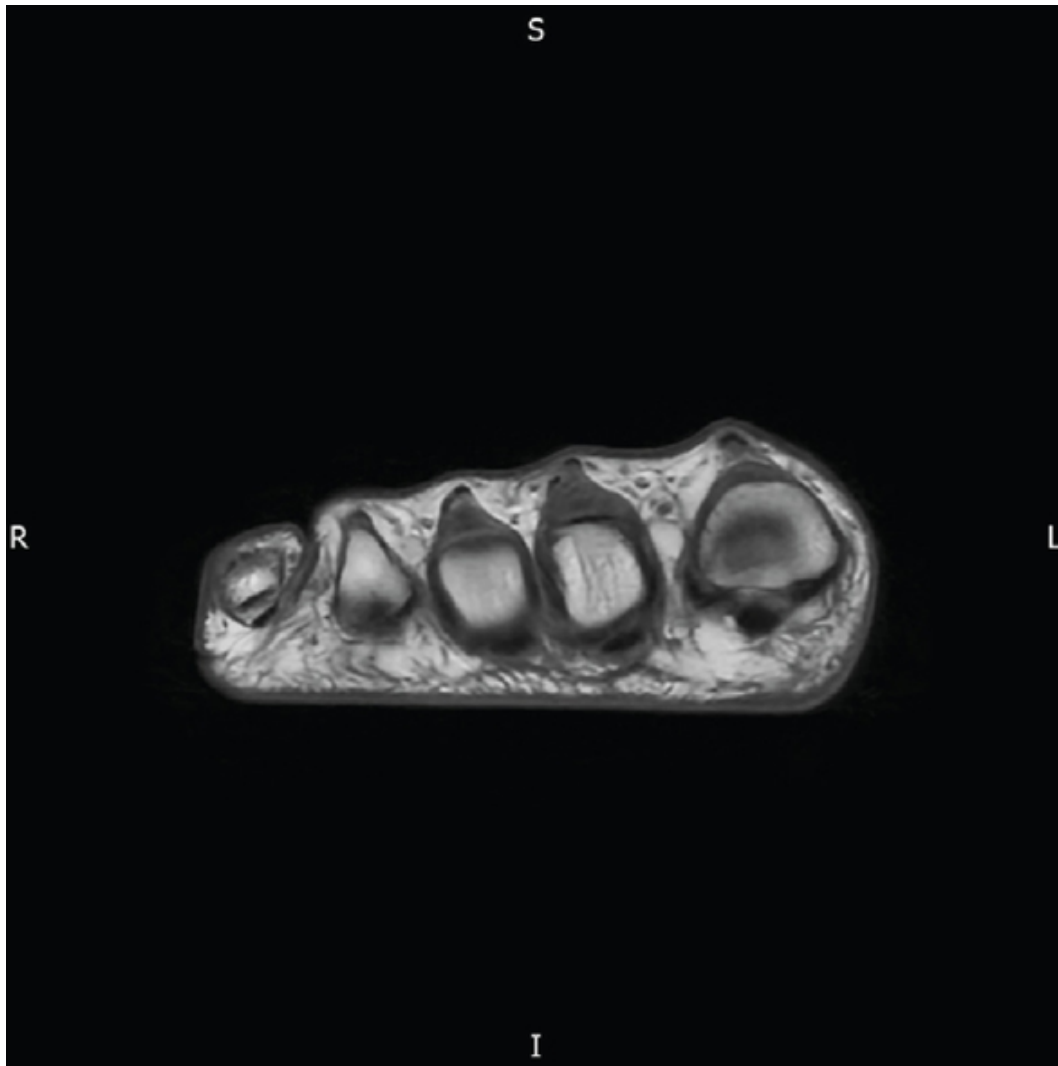


Fig. 2.129f Axial T1 image through the forefoot to demonstrate the toes. [↗](#)

Contrast Media and Injection Data

Intravenous contrast enhancement (if indicated in protocol)

- Gadolinium enhancement aids in the assessment of lesions. Hand injection for all standard foot imaging is suitable.
- For vascular angiography, a dynamic injection using a contrast injector pump with a flow rate of 1–2 mL/sec is recommended.
- Dose, in terms of volume injected is based on the patient weight. The recommended dose depends on the amount of gadolinium contained in the agent and for this reason it should be calculated using the contrast manufacturer information.

Adaptive Techniques ([Figs. 2.130a,b](#))

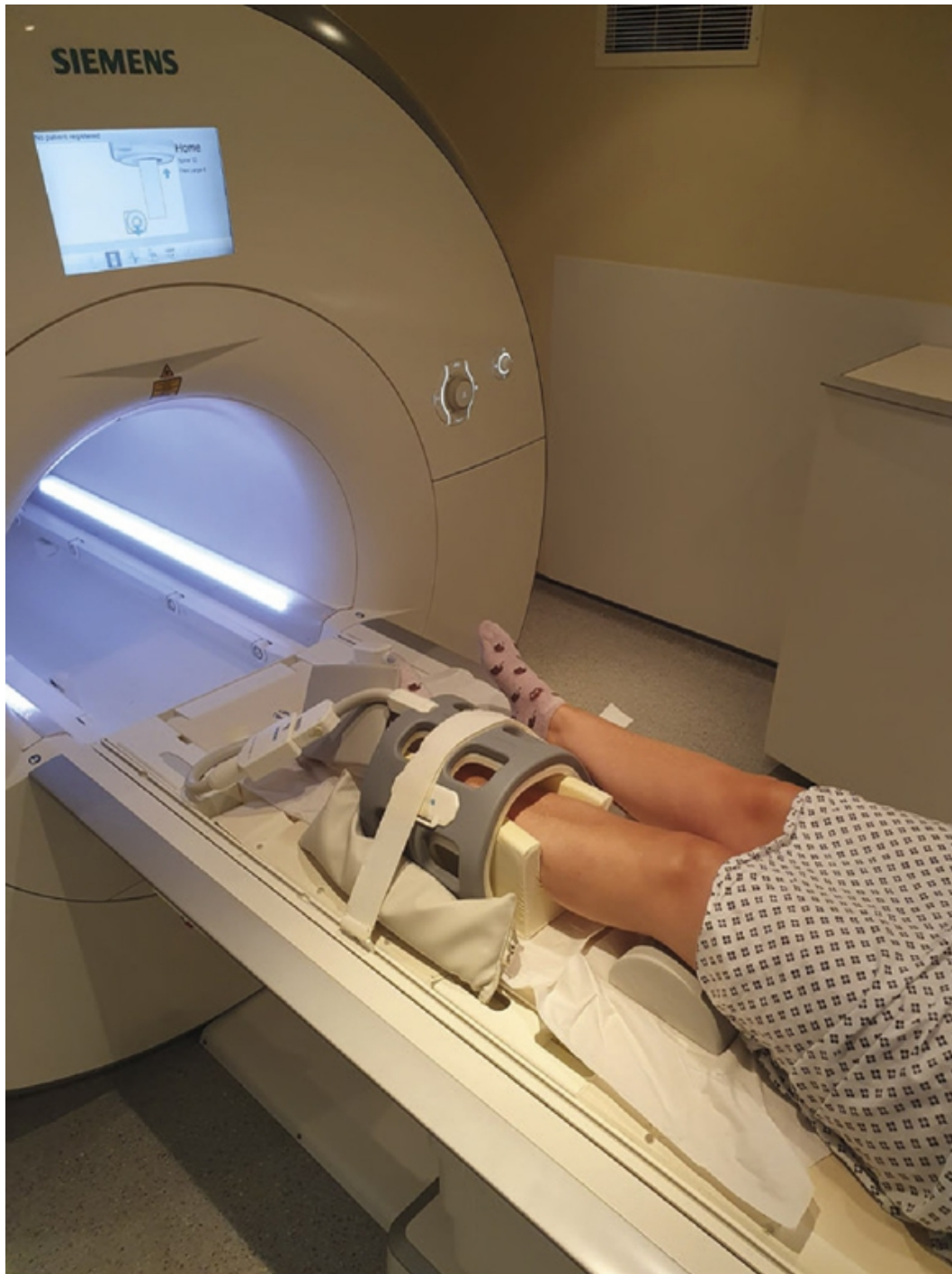


Fig. 2.130a Wrap the flex coil around the foot. Add immobilisation devices as needed. [📄](#)

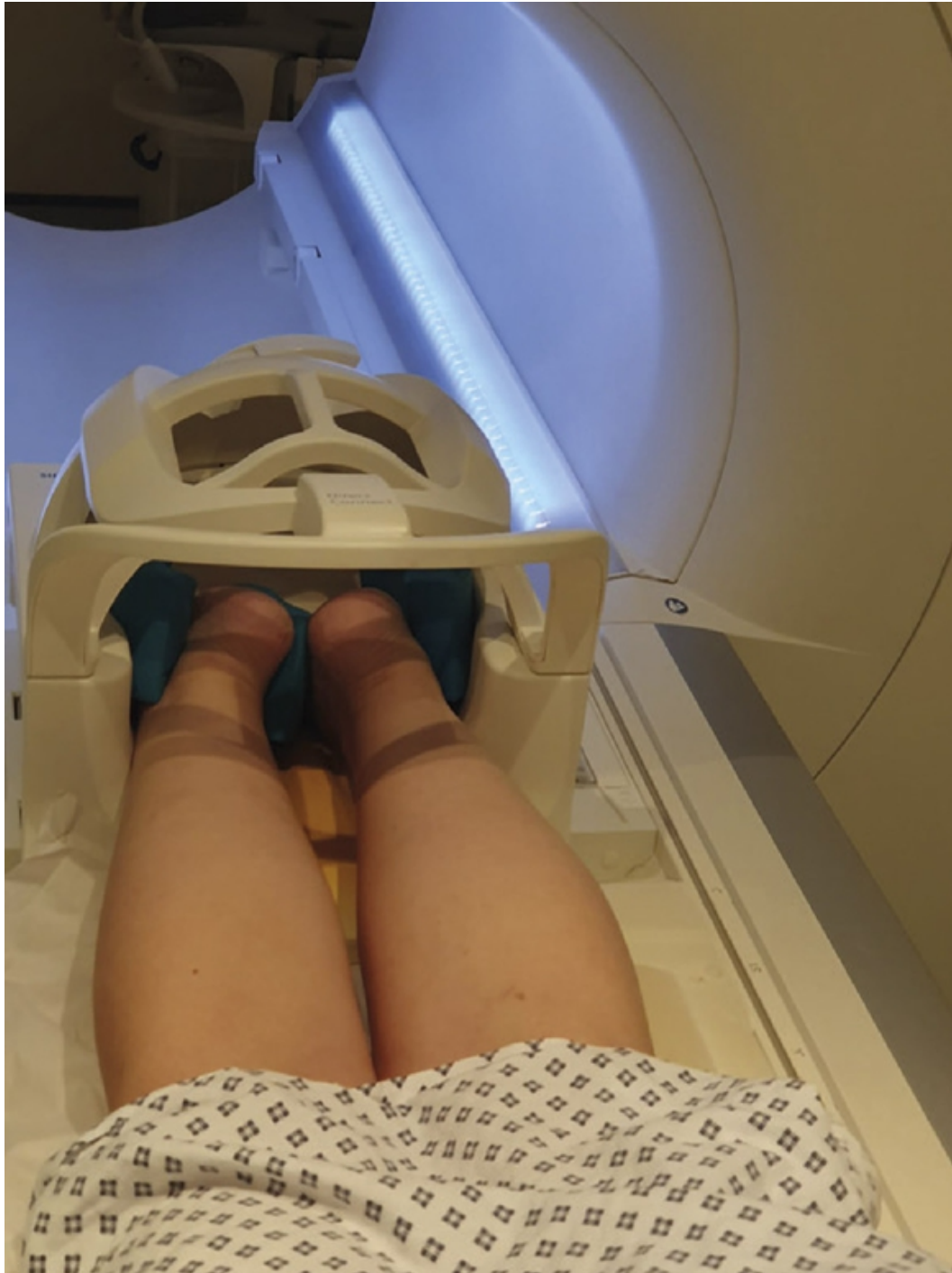


Fig. 2.130b A patient who is unable to tolerate the dedicated foot/ ankle coil is positioned prone with feet in the dedicated head coil. An alternative here is to position the patient supine if more comfortable. Add immobilisation devices as needed. [🔗](#)

When it is not possible to position in the dedicated foot coil due to large body habitus or swollen foot/ankle/leg, if the patient is unable to straighten

their leg or if the patient is unable to move the other leg out of the scanning field, it is possible to use adaptive techniques to obtain diagnostic images.

There are options of using flexible coils wrapped around the patient's foot, body array coils, or the knee or head coil, whichever is the best fit on assessment. Ensure that when using flexible coils or a body array coil the foot is not too close to the edge of the magnet as this will result in reduction in fat saturation and signal loss. Due to the use of altered technique if the patient cannot move the other leg out of way add phase oversampling on during planning to avoid aliasing on images (see [Fig. 2.124f](#)). Note: this may lengthen scan times.

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SECTION 3

ADVANCED IMAGING OVERVIEW

DOI: [10.1201/9781003230229-3](https://doi.org/10.1201/9781003230229-3)

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ARTIFICIAL INTELLIGENCE

The use of deep learning reconstruction algorithms (DLRAs) has become common in recent years. Each of the main MR scanner vendors now offer DLRAs, which when applied to the raw data during MR acquisitions improve the SNR, resolution or image sharpness, or both. The improved SNR or resolution can be exploited to improve diagnostic image quality or sequences can be adapted to maintain SNR and resolution while reducing acquisition time. The impact of DLRAs, when optimally applied, can be significant, with time savings of 75%, or more, achievable while also maintaining diagnostic image quality. However, it should be noted that DLRA software will in general require significant expert input to optimise and realise the full benefits, and there are known subtle changes to image appearance that will require local review and approval prior to routine clinical use. In addition to the vendor-provided DLRA software, there are third-party offerings that intercept images between the scanner console and

the hospital picture archive and communication system (PACS), providing a similar potential improvement in SNR and resolution, but it should be noted that these act on the already reconstructed data, not the raw acquired data.

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MAGNETIC RESONANCE ANGIOGRAPHY

MRA is an imaging modality, as described for cardiac MRI later in this chapter, that uses MRI to assess the anatomy of the blood vessels to provide information on vessel pathology such as luminal vascular stenosis/occlusion or aneurysms to help plan treatment of the disease, with either minimally invasive endovascular treatment or surgery.

Compared with other imaging modalities, MRA takes less time than traditional catheter angiography, is non-invasive and requires no recovery period. It is less costly than catheter angiography and can provide equivalent or better luminal assessment than computed tomography angiography (CTA). Also with CTA there are potential problems related to wall calcification, a higher risk of contrast reactions and risks of nephrotoxicity. No single MRA technique images all vessels with the same accuracy as digital subtraction angiography (DSA).

Different techniques are used to optimise signal from each area; however, compared with the gold standard of DSA, MR is considered safer as it does not use ionising radiation. It can show low/slow flow and has excellent concordance with reference standard fluoroscopic DSA for the severity and extent of disease in aortoiliac and femoral vessels. Whilst Duplex ultrasound can provide more accurate functional assessment of the blood flow in the vessels, it has significant limitations in the time taken to scan, it is very operator dependent and it can be difficult to perform any assessment in the presence of calcification. It can take a long time to map the circulation by Duplex ultrasound compared with the relatively quick acquisition of MRA images.

In MRI there are several methods of acquiring images which can be non-contrast or that use intravenous contrast:

- **TOF** – the TOF technique is based on the ‘inflow effect’.
- **Phase contrast** – several newer non-contrast techniques/sequences are frequently used.
- **Contrast-enhanced MRA** – uses a contrast enhancement agent such as a gadolinium-based product to visualise blood vessels.

Non-Contrast MRA

Non-contrast media techniques can be further divided into two groups according to the blood signal characteristics ([Fig. 3.1a](#), [b](#) and [c](#)).

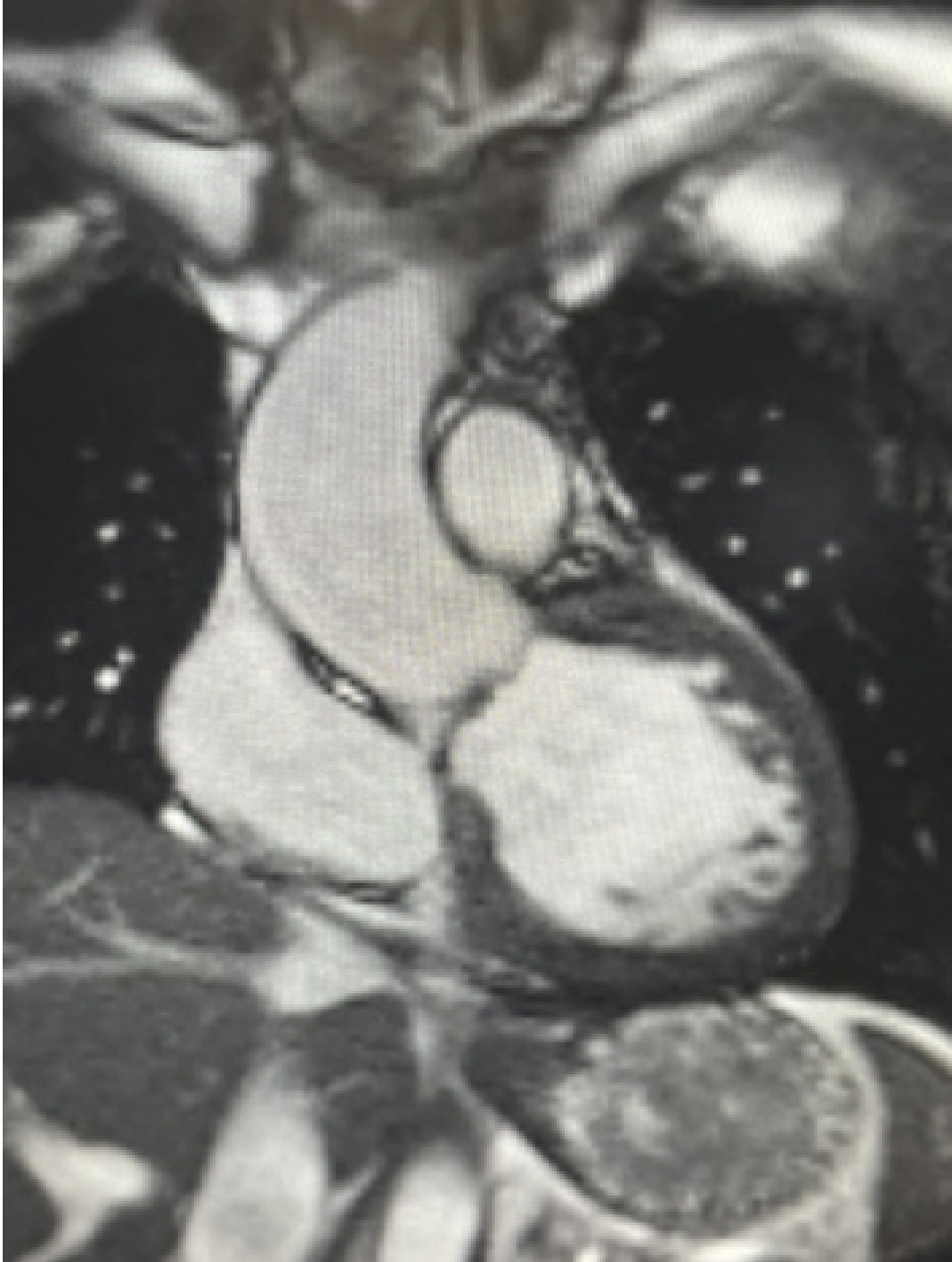


Fig. 3.1a Coronal white-blood cardiac image. [🔗](#)

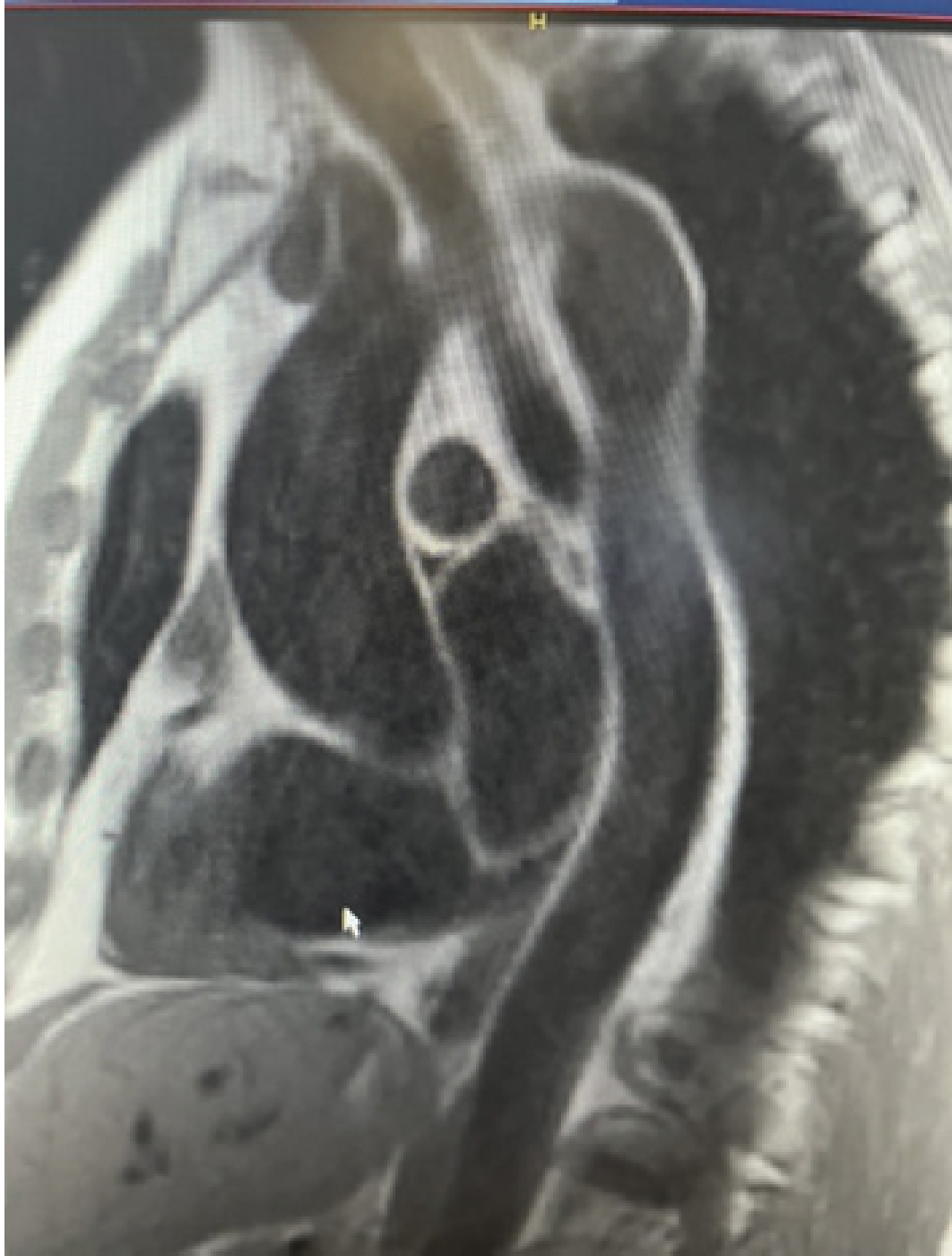


Fig. 3.1b Sagittal black-blood cardiac image. [↗](#)

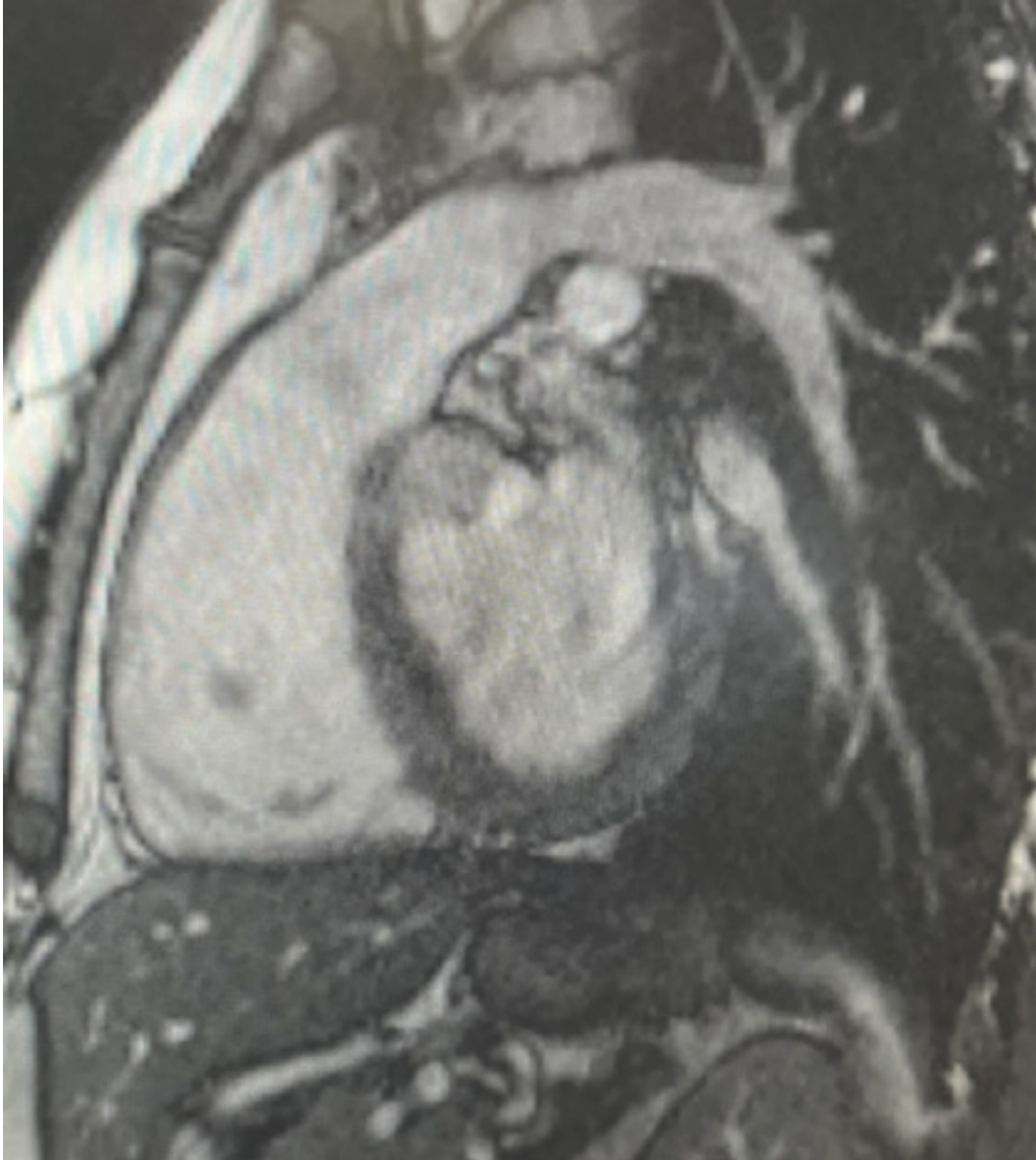


Fig. 3.1c Sagittal white-blood cardiac image. [📄](#)

In **black-blood (or dark-blood) sequences**, the intravascular signal is lower than that of the surrounding stationary tissues. This sequence is beneficial in carotid vessel assessment. These are not used routinely in the peripheral vasculature, but for specific conditions or areas, such as vasculitis or to look at the larger vessels such as the aorta. The rapidly flowing blood has a naturally low signal because of phase-dispersion and TOF signal losses.

In **bright-blood (or white-blood) sequences**, the intravascular signal is higher than that of the surrounding stationary tissues. This sequence is beneficial in cardiac MRI to evaluate cardiac flow and vascular function. These are used to assess vascular lumen, but they have less accuracy in the evaluation of the vessel wall than dark-blood techniques. Limitations of non-contrast studies can include flow artefacts due to turbulence and pulsatile flow or susceptibility effects, e.g. related to thrombus.

Contrast-Enhanced MRA

Contrast-enhanced MRA involves a fast GRE sequence and bolus of contrast media as well as timed acquisition in the arterial phase centred on the levels required, e.g. the three levels of images acquired for a peripheral lower limb angiogram: abdominal, groin to knee and knee down to foot. Timing the start of imaging is critical and the scan should be triggered as the contrast bolus enters the region of interest: too soon and the MR signal may be too weak while too late and visualisation will be hampered by venous enhancement.

3D MRA has become a standard technique for body/peripheral vessels due to high speed, high SNR, minimal artefacts and good but not perfect resolution ([Fig. 3.2a](#), [b](#), [c](#) and [d](#)). This technique resolves some of the problems of non-contrast studies as there is no pulsatile artefact or slice misregistration. It gives high-resolution images, and the gadolinium contrast material is statistically less likely to cause an allergic reaction than the iodine-based contrast materials used for CTA. A digital subtraction of the pre-contrast images from the post-contrast images gives an accurate map of the contrast-filled vessels.



Fig. 3.2a Contrast-enhanced MRA coronal maximum intensity projection. [📄](#)



Fig. 3.2b Contrast-enhanced MRA sagittal oblique maximum intensity projection. [📄](#)



Fig. 3.2c CE-MRA Coronal MIP of subclavian and carotid arteries. [📄](#)

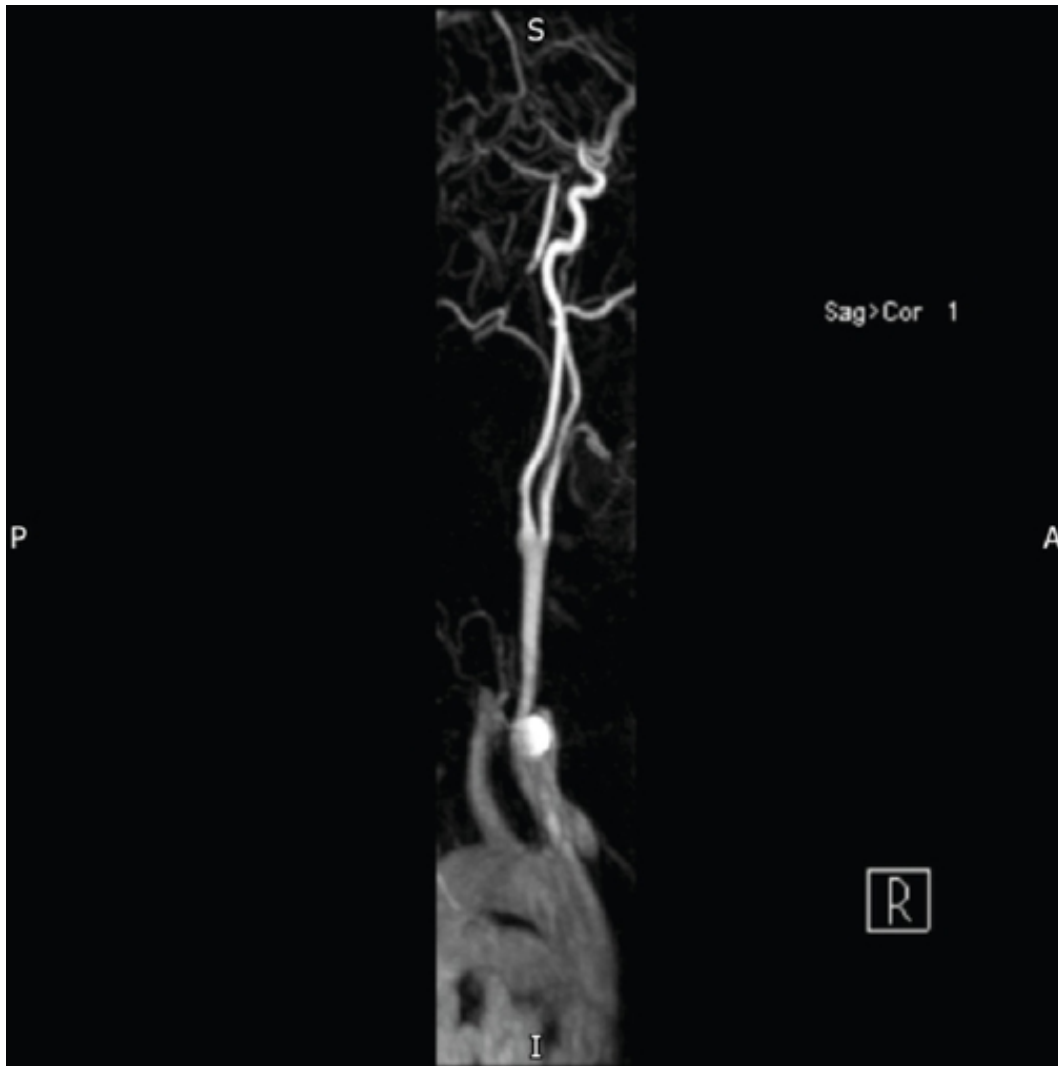


Fig. 3.2d CE-MRA Sagittal MIP of a single carotid artery. [📄](#)

Clinical applications for MRA are expanding as technological advances in both hardware and imaging techniques are overcoming previous limitations.

Hybrid MR and time-resolved imaging is also increasingly being considered for clinical use. It involves a single-dose contrast-enhanced MRA with DSA at the same time. In hybrid cardiovascular imaging the clinical MRI protocol is used to acquire contrast-enhanced MRA images of the human vascular tree together with assessment of heart structure and function; this is done through a single examination using a two-injection

technique with a 15-min delay window between the first and second injection.

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MAGNETIC RESONANCE ARTHROGRAMS

This is a specialised imaging examination used to obtain detailed images of a joint, such as the hip, knee or shoulder ([Fig. 3.3a](#), [b](#), and [c](#)). It involves the injection of a local anaesthetic and a small amount of iodinated contrast and gadolinium contrast into the joint, performed under fluoroscopy, which is then followed by an MRI scan.

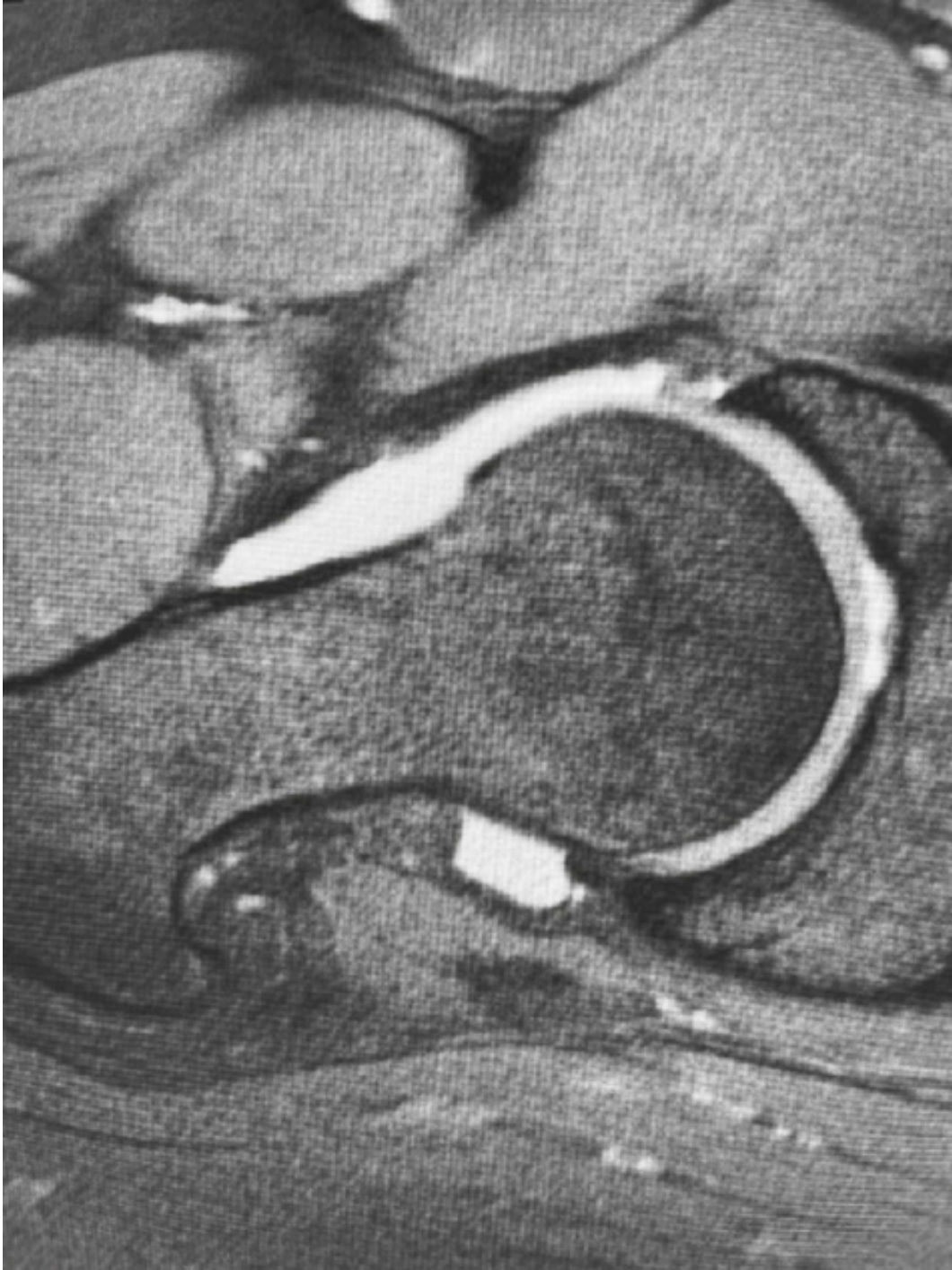


Fig. 3.3a Example of a hip arthrogram image. [📄](#)

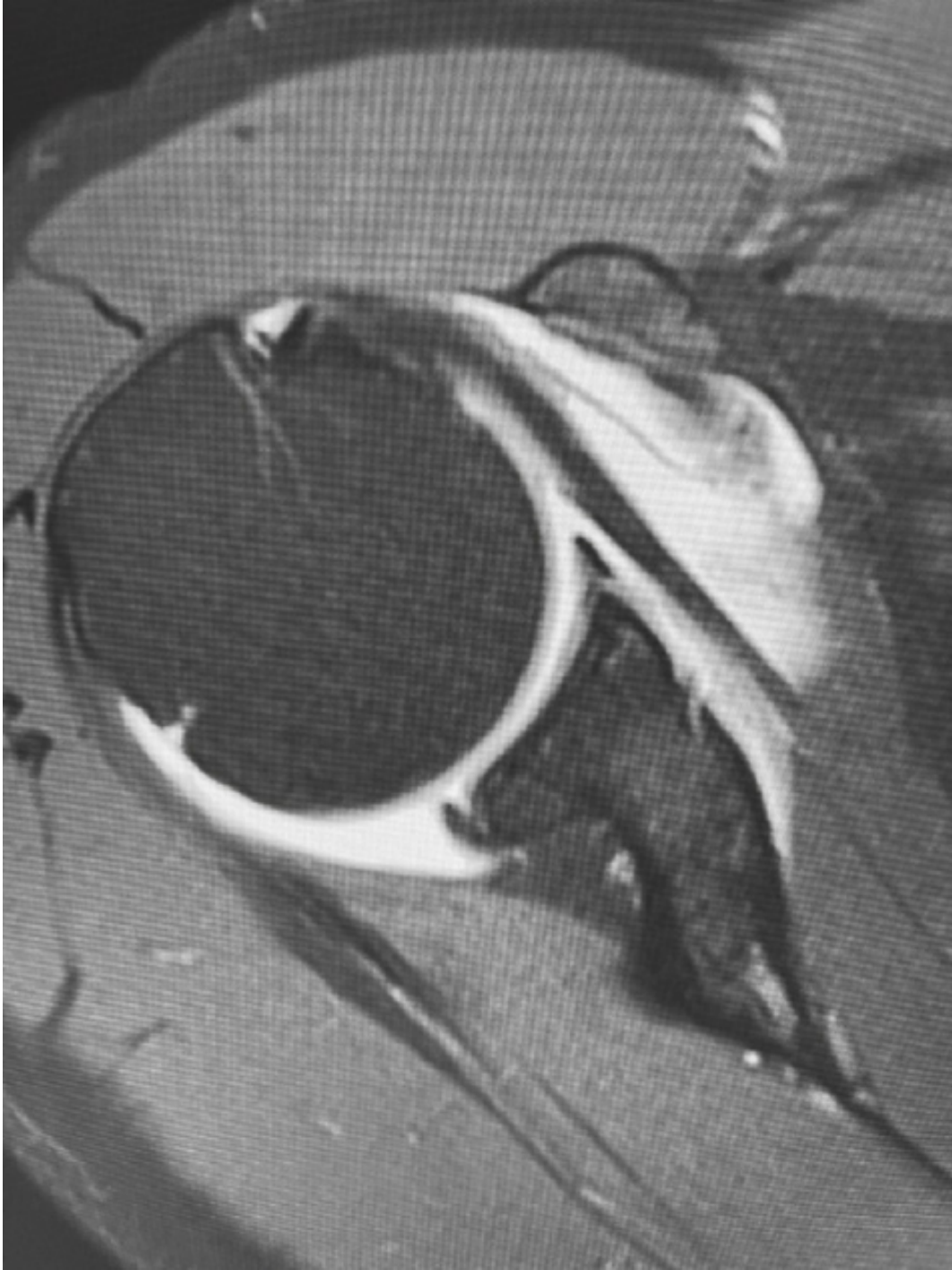


Fig. 3.3b Example of a shoulder arthrogram image. [📄](#)

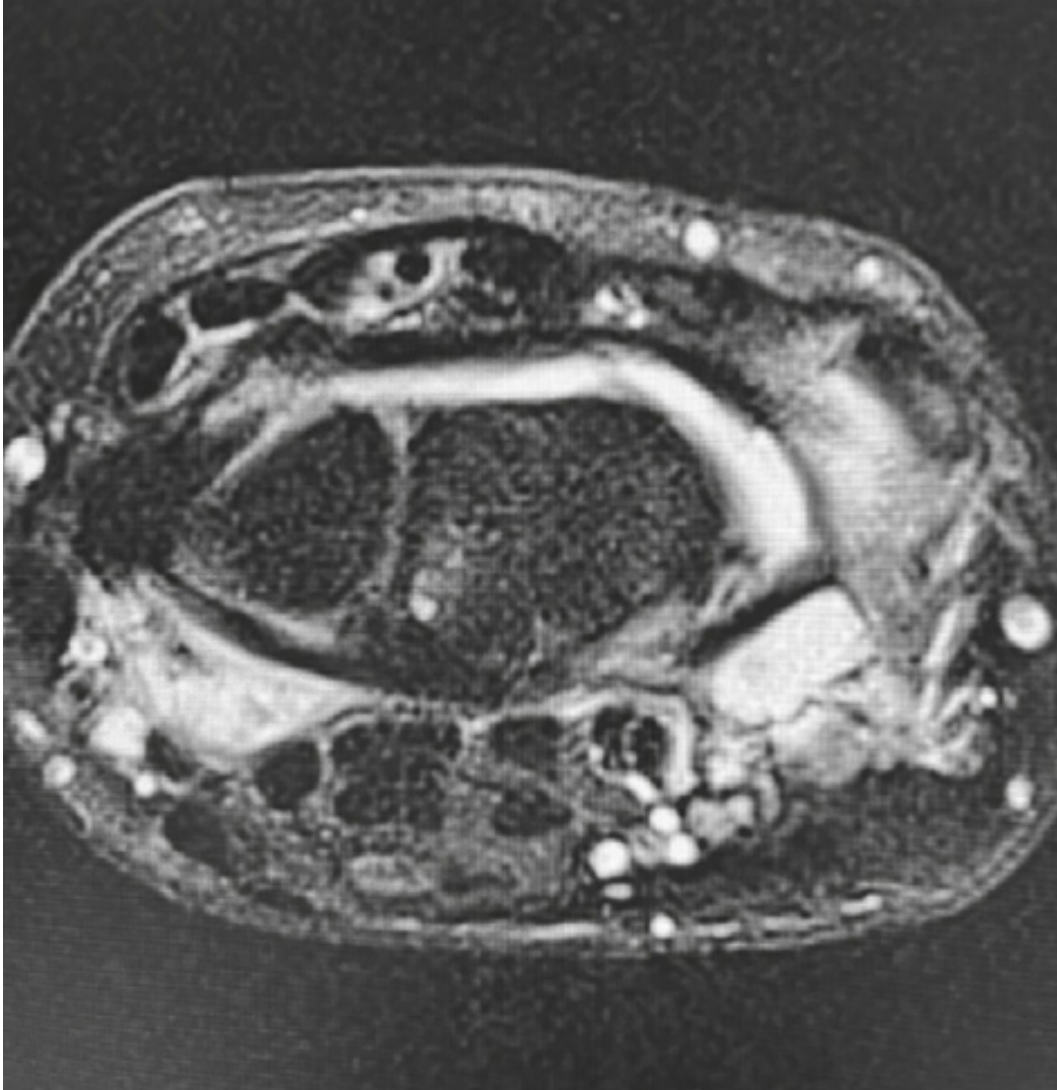


Fig. 3.3c Example of a wrist arthrogram image. [📄](#)

Arthrograms provide superior intra-articular assessment of joints but should not be used routinely as they are invasive and carry a small risk of joint sepsis (1 in 30 000 procedures). Pain and discomfort are common in the first 24 hours but if this persists then evaluation for joint sepsis and potential washout is needed. Due to safety considerations around NSF and gadolinium retention, Magnevist has recently been withdrawn from the market and no licensed contrast medium is now available. Off-label use of other contrast media is an option but a safer alternative is to use normal

saline for intra-articular distension. Saline is comparable in performance to gadolinium arthrography.

Typical arthrogram sequences

Gadolinium enhanced: T1 FS, T2 FS, PD in all planes and T2 FS 3D

Saline enhanced: PD FS or T2 FS sequences replace T1 FS for saline arthrograms. A T1 sequence should also be used for anatomical evaluation

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HYBRID MAGNETIC RESONANCE IMAGING

Hybrid imaging refers to the fusion of two imaging modalities i.e. PET-MR. MRI acquires high-resolution structural and anatomical information with high soft tissue contrast and by combining techniques in a hybrid system, it is possible to obtain both anatomical and functional information in one scan (1). The use of these systems results in a decreased exposure to ionising radiation and an increased accuracy of diagnosis. Combining MRI with another modality is costly so therefore these systems are few in numbers and often located in specialist centres.

In PET-MR the excellent anatomical detail of MRI is combined with the metabolic and molecular information obtained by positron emission

tomography (PET) (2). It uses advanced functional MR techniques such as diffusion, perfusion and spectroscopy and combines them with the functional information obtained by PET.

SPECT-MR is the combination of MRI with a single-photon emission computed tomography system. It combines the functional and structural imaging that these modalities provide to give a comprehensive view of the patient's functional and structural properties. In neuroimaging it is being used to improve understanding of brain function which leads to better diagnoses and treatments for neurological and psychiatric disorders (3).

In oncology MR Linac systems are a combination of an MRI scanner with a linear accelerator. They are used as a crucial tool by using MRI to identify clinical targets and allowing real time radiation therapy delivery. MR guided radiation therapy has been proven to considerably improve a patient's prognosis when treating tumours (4) ([Fig. 3.4a](#)).



Fig 3.4a The MRI Linac system is a combination of an MRI scanner with a linear accelerator. Image courtesy of Royal Marsden NHS Foundation Trust. [📄](#)

The combination of X-ray fluoroscopy and MRI is used as a powerful tool for image guided interventions. The use of an open MRI system allows interventional X-ray procedures to be carried out at the same time (5). As previously mentioned, hybrid MR and time-resolved imaging is used in a cardiac setting. The anatomical and functional MRI information provided by the MRI images allows for more accurate diagnosis and treatment. There is also a benefit to the patient in that they do not need two separate appointments or moved between imaging suites within the department, and will receive a reduced radiation dose because their diagnostic and interventional procedures are combined into one ([Fig. 3.4b](#) and [c](#)).



Fig. 3.4b C-arm imaging fluoroscopy unit. Image courtesy of Nottingham University Hospitals NHS Trust. [\[4\]](#)





Fig. 3.4c MRI in intraoperative paediatric neurosurgery. Image courtesy of Nottingham University Hospitals NHS Trust.[\[4\]](#)

The head coil is placed around the head at the start and remains under the drapes throughout the surgery and imaging using a mobile C-arm imaging fluoroscopy unit ([Fig. 3.4c](#)). The patient's head is wrapped in plastic to maintain sterility and all non-MRI conditional equipment is removed prior

to transfer to MRI ([Fig. 3.4b](#)). Under direction of a lead operating practitioner, the table top with patient slides carefully onto a MRI Conditional transfer trolley. After final MR safety checks are completed the anaesthetist disconnects the breathing circuit and the patient is transferred to MRI where the anaesthetist reconnects to the MRI conditional anaesthetic machine and the trolley is docked to the intraoperative MRI scan table ([Fig. 3.4c](#)).

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CARDIAC MRI

Cardiovascular MRI is a well-established imaging modality that uses the principles of MRI to assess and evaluate the anatomy and function of the heart and blood supply, and in doing so provides clinicians with detailed information that may not be achieved via other modalities ([Fig. 3.5a](#), [Fig. 6](#) and [Figure c](#)). Cardiac MR (CMR) is a non-ionising, non-invasive modality, which can acquire images in multiple planes. There are a wide variety of sequences available, which when used in combination can aid in the characterisation of normal and abnormal cardiac structure and function.

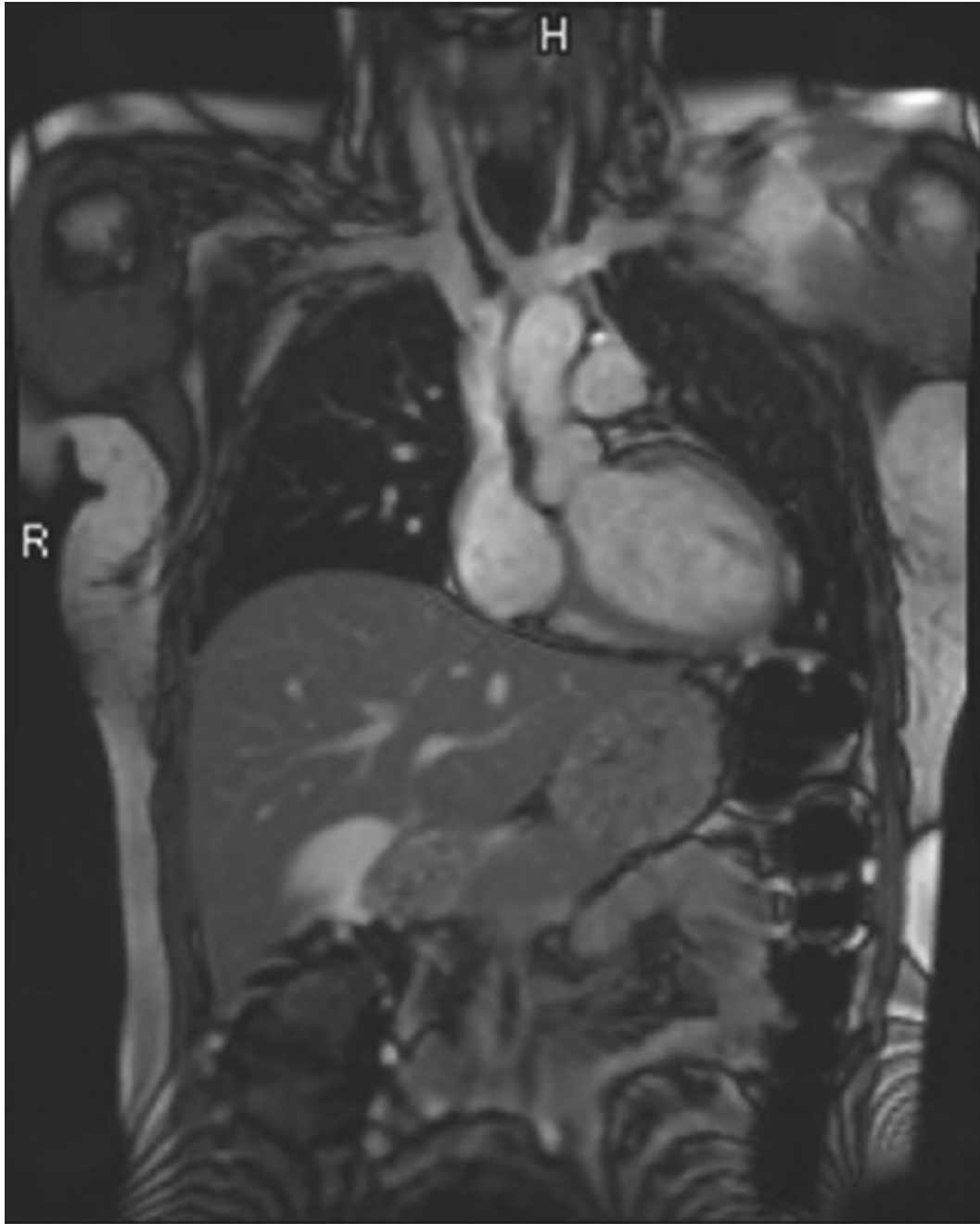


Fig. 3.5a Left ventricular outlettract (LVOT) true FISP. [↗](#)

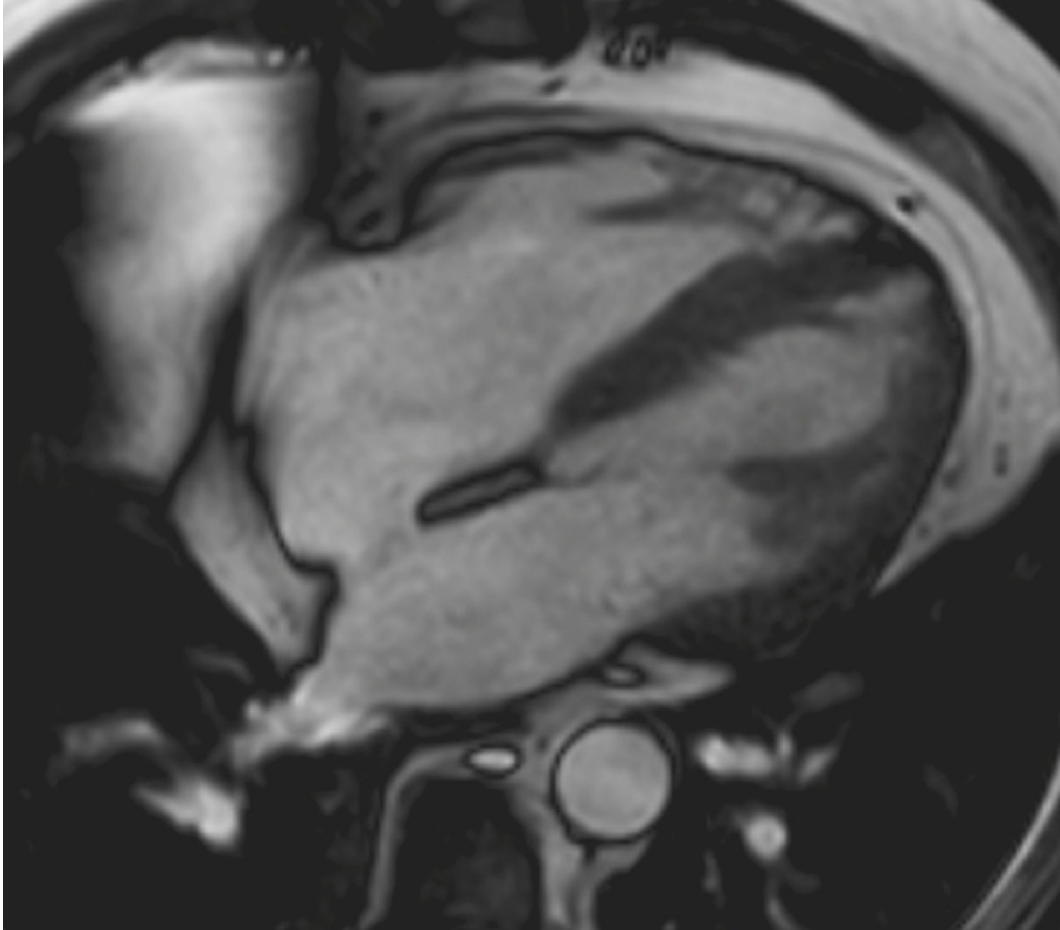


Fig. 3.5b Four chamber true FISP. [↗](#)

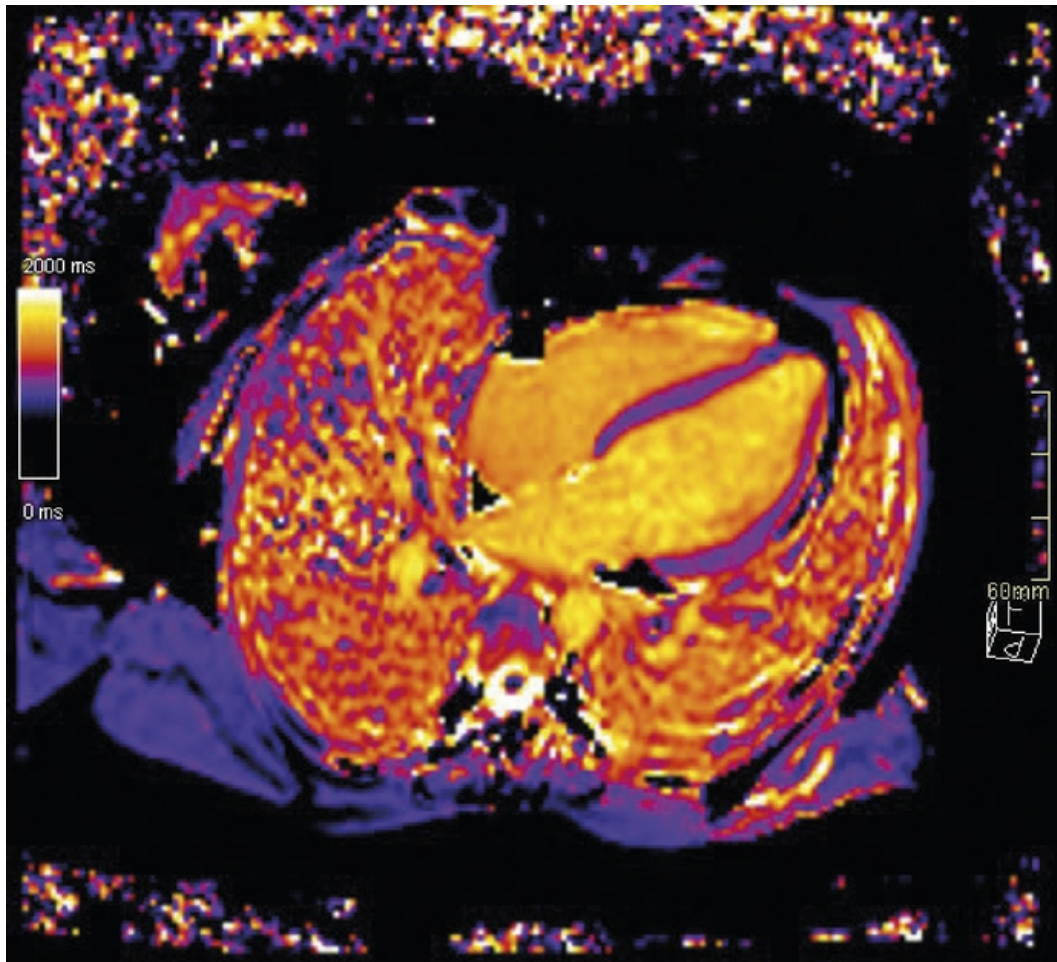


Fig. 3.5c Four chamber T1 mapping sequence. [↗](#)

CMR uses two fundamental types of sequences: **gradient echo** and **spin echo**.

A gradient echo image is often referred to as ‘white-blood imaging’ as fat and the blood pool will present as white. Spin echo imaging is referred to as ‘black-blood imaging’, as the blood pool will be black, but fat is white. Variations of gradient echo sequences include **fast low-angle shot** FISP and velocity mapping. Cine images are obtained by rapidly repeating the sequence throughout the cardiac cycle, thus producing a ‘cine’ loop.

Recent improvements in hardware and software used to perform CMR has resulted in a reduction in scanning time and increased image quality,

along with sequence development to aid tissue characterisation; this is referred to as T1 and T2 mapping.

By using a combination of sequences CMR can be used to assess anatomy and structure; acquired and congenital heart disease; functional assessment including myocardial mass, regional wall motion, ejection fraction and cardiac output, myocardial injury, ischaemia versus infarct, cardiomyopathy, valvular anatomy and function; heart chamber analysis; outflow and inflow, aortic and pulmonary aneurysms; dissections; and stenosis.

Although traditional adaptation of techniques is not performed, the CMR examination can be tailored to only answer specific questions to reduce scan time for the patient if required.

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FETAL MRI

The first published case report of the use of MRI in fetomaternal medicine was in 1983 and initially it was utilised to evaluate maternal and placental pathology but over the subsequent 40 years the modality has developed to allow evaluation initially of the fetal brain and also to evaluate anomalies of the whole body ([Fig. 3.6a](#), [b](#), [c](#) and [d](#)).

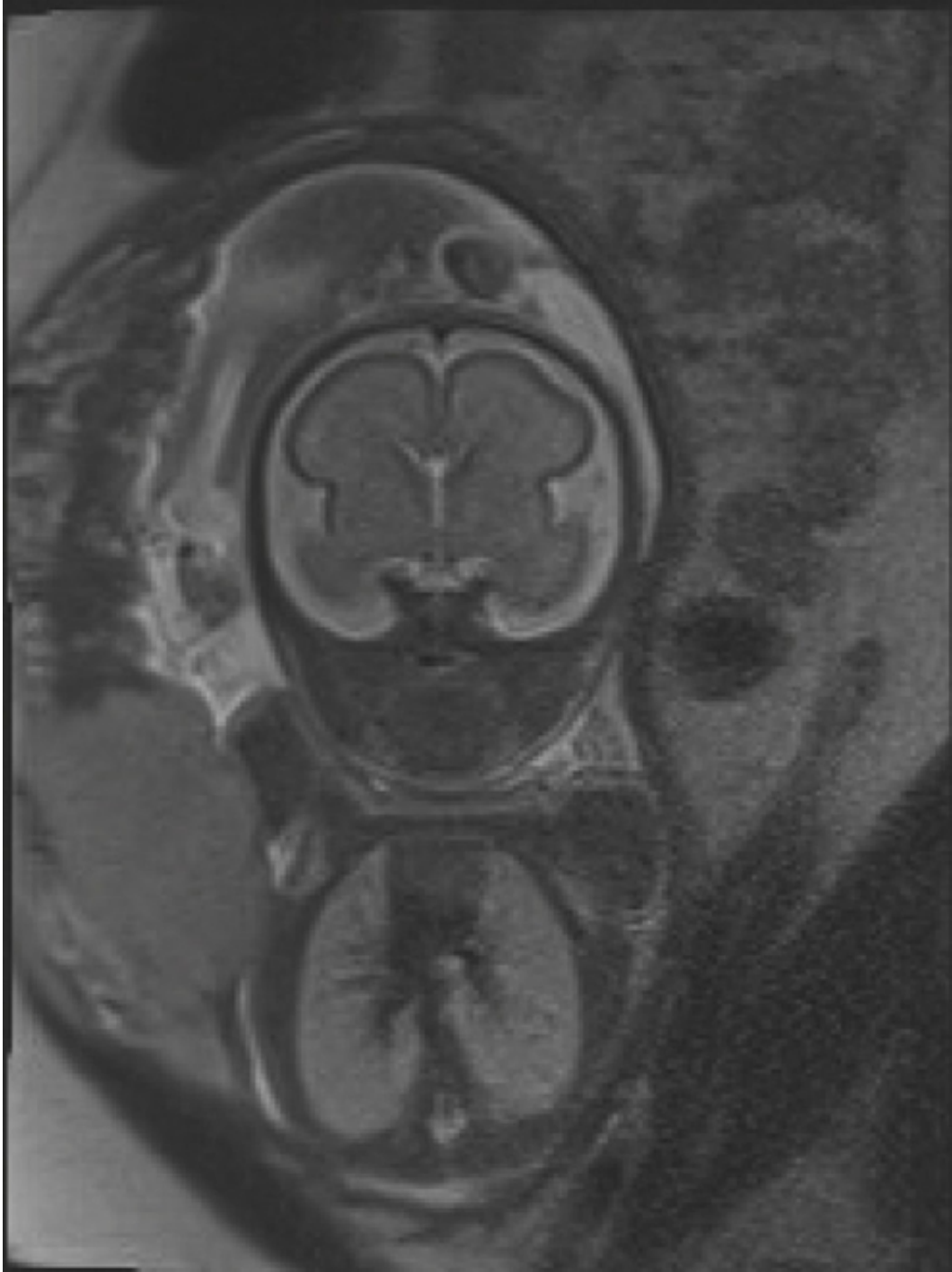


Fig. 3.6a T2 HASTE coronal image of the fetal brain. [↗](#)

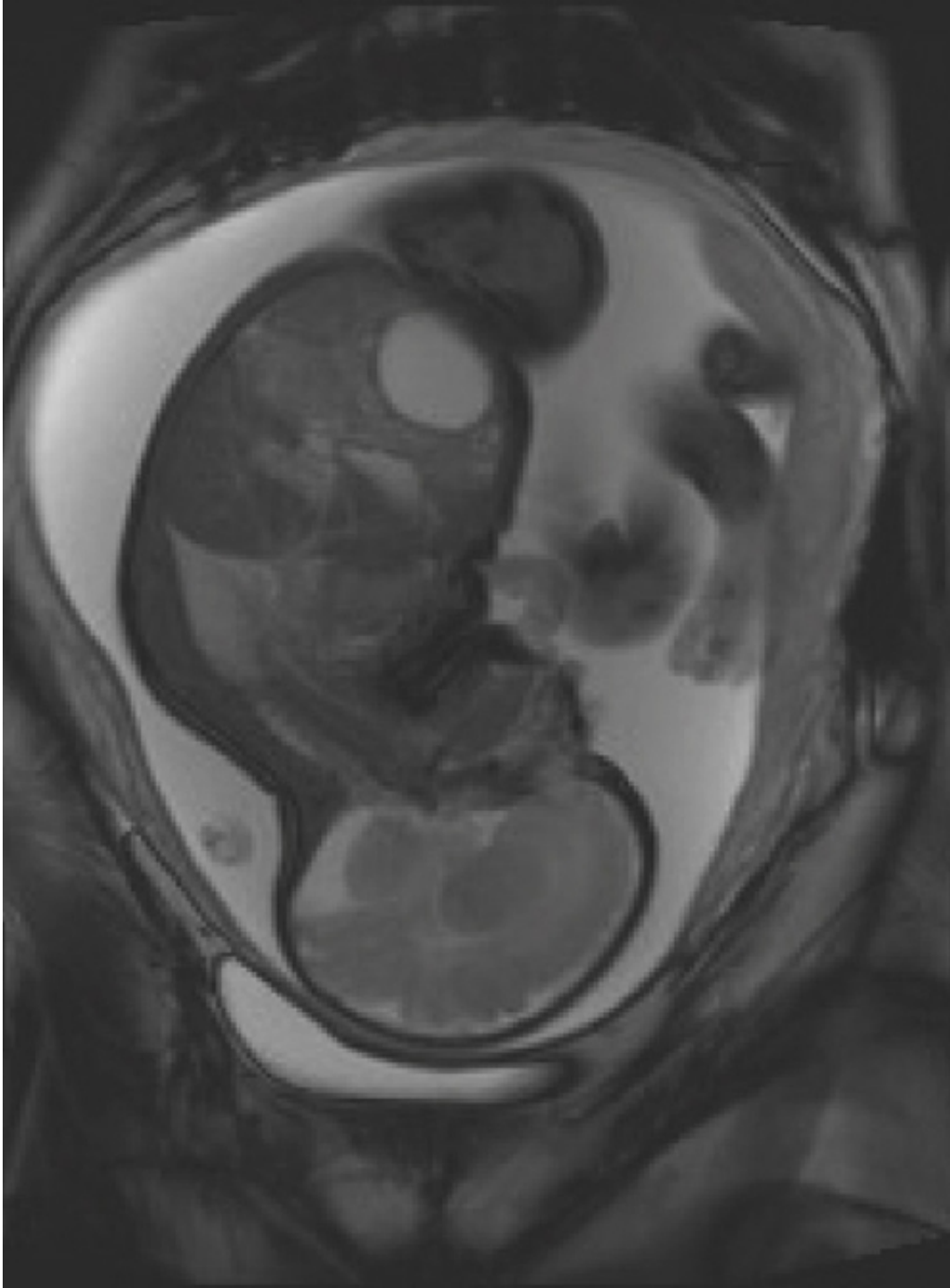


Fig. 3.6b T2 HASTE midline sagittal image of the fetal brain. [↗](#)



Fig. 3.6c Sagittal image with focal bulging and thick dark bands crossing the placenta substance. [📄](#)



Fig. 3.6d Anterior placenta with no evidence of myometrial invasion. [📄](#)

Ultrasound will always be first line in antenatal assessment of the fetus particularly in the first trimester when MRI is not recommended and is likely to be less effective due to fetal size relative to the amniotic cavity resulting in motion artefact. However, MRI has proven safe and effective as second-line imaging in the second and third trimester providing a large FOV that is not limited by maternal size or fetal position and it can confirm anomalies detected at antenatal ultrasound, give further information regarding those anomalies or detect and diagnose new and unsuspected

anomalies. Studies have shown that in the case of neurological abnormalities diagnostic accuracy can be improved in around one-third of cases resulting in a change in management strategies. Most examinations are undertaken at 1.5 tesla (T) but centres are now using 3T in both research and clinical settings with the advantage of improved SNR and higher resolution. However, scanning at 3T can have the disadvantage of more artefacts.

A standard examination will take in the region of 30–40 min and is performed with the mother in the supine or lateral decubitus position. Fasting for 4 hours prior to the scan can be advantageous in reducing fetal movement and whilst some centres will use maternal sedation this practice is not widespread. A single-shot fast spin echo T2 is the typical sequence of fetal MRI performed in three orthogonal planes and planned of the previous sequence but additional sequences include T1 weighting to look for haemorrhage, fat or calcification. Steady-state free precession (SSFP) provides high SNR and allows high-resolution imaging of small structure, e.g. craniofacial structures and thoracoabdominal structures. Cine SSFP can provide imaging of moving structures such as swallowing or bowel motility and DWI can be utilised in the same way as *ex utero*, looking for acute brain injury as well as allowing assessment of lung maturation, as apparent diffusion coefficient (ADC) values correlate with gestational age.

New approaches in fetal MRI include the use of post-acquisition motion correction and volume reconstruction of organs and defects. In addition to fetal MRI at 1.5 and 3T it may be possible to undertake examinations in low field strength magnets (0.55T). This increases its availability and acceptability using reduced scan times and, as low field strength magnets have wider bore dimensions, larger patients can be included and examinations can be undertaken outside specialist units.

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BREAST MRI

MRI of the breast should not be used as a stand-alone diagnostic tool but is very useful in problem solving in line with the triple assessment process, which involves mammography, ultrasound and biopsy. Breast MR can, however, detect lesions not seen on conventional imaging due to its inherent high sensitivity ([Fig. 3.7a](#)). Breast biopsy using MR is becoming a more readily available option when a lesion can only be demonstrated using MR. Breast MR is generally used for the evaluation of breast cancer prior to surgery, monitoring of a response to neoadjuvant chemotherapy and surveillance in patients who have a high risk of developing cancers such as patients with the *brca* gene. It is also helpful in the evaluation of ruptured breast implants ([Fig. 3.7b](#)), the recurrence of tumour in patients with implants and the detection of occult primary tumours. Due to the nature of positioning for breast scanning it is not a technique that can be easily adapted.



Fig. 3.7a T2 axial image of a high signal benign cyst in the right breast.[📄](#)



Fig. 3.7b T2 axial image of breast implants demonstrating bilateral intracapsular rupture. [📄](#)

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APPENDIX

SEQUENCE ACRONYMS

Sequence description	Siemens	GE	Philips	Hitachi
Long Tau Inversion Recovery	TIRM, DARK FLUID	FLAIR	FLAIR	FLAIR
Diffusion Weighted Imaging	DWI	DWI	DWI	DWI
Ultrafast Gradient Echo 3D with Preparation Pulse	MPRAGE	3D FGRE, 3D Fast SPGR, BRAVO	3D TFE	MPRAGE
Time of Flight	TOF	TOF, Inhance Inflow	Inflow	TOF
Gradient Echo	GRE	GRE	Fast Field Echo (FFE)	GE
Steady-State Free Precession	CISS	SSFP	T2-FFE	TRSG
3D FSE with Variable Flip Angle	SPACE	CUBE	Dual-IR TSE	DIR
Dixon Fat/Water Separation for FSE	DIXON	FLEX or IDEAL	mDixon TSE	WFS (Water Fat Separation)
Chemical Fat Saturation	FAT SAT	Fat Sat/ Chem Sat	SPIR	SINC
Single-Shot TSE	HASTE	Single-Shot TSE	Single-Shot TSE	Single-Shot TSE
Proton Density	PD	PD	PD	PD
Spectral Adiabatic Inversion Recovery	SPAIR	ASPIR	SPAIR	
Volume-Interpolated 3D GRE	VIBE	LAVA	THRIVE	TIGRE

Sequence description	Siemens	GE	Philips	Hitachi
TSE with 90° Flip Back Pulse	RESTORE (THICK SLAB)	FRFSE Fast Recovery Fast Spin Echo 3D	DRIVE	Driven Equilibriu
True FISP	TRUFI	FIESTA, COSMIC	Balanced FFE	Balanced SARGE, BASG
CAIPIRINHA for 3D sequences	CAIPI			
Double Echo Steady State	DESS			
Short Tau IR	TIRM/STIR	STIR	STIR	STIR
Spoiled Gradient Echo	FLASH	SPGR	T1-FFE	T1-FFE
Contrast Bolus Timing/Visualisation	CARE Bolus	Smart Prep, FluorTriggered MRA	Bolus Track	FLUTE

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