

# How to use this book

## Introduction

This book has been written with the intention of providing a step-by-step explanation of the most common examinations currently carried out using magnetic resonance imaging (MRI). It is divided into two parts.

Part 1 contains reviews or summaries of those theoretical and practical concepts that are frequently discussed in Part 2. These are:

- parameters and trade-offs
- pulse sequences
- flow phenomena and artefacts
- gating and respiratory compensation (RC) techniques
- patient care and safety
- contrast agents.

These summaries are not intended to be comprehensive but contain only a brief description of definitions and uses. For a more detailed discussion of these and other concepts, the reader is referred to the several MRI physics books now available. *MRI in Practice* by C. Westbrook, C. Kaut Roth and John Talbot (Wiley Blackwell, 2011, fourth edition) describes them in more depth.

Part 2 is divided into the following examination areas:

- head and neck
- spine
- chest
- abdomen
- pelvis
- upper limb
- lower limb.

Each anatomical region is subdivided into separate examinations. For example, the section entitled *Head and Neck* includes explanations on

imaging the brain, temporal lobes, pituitary fossa, etc. Under each examination, the following categories are described:

- basic anatomy
- common indications
- equipment
- patient positioning
- suggested protocol
- image optimization
- patient considerations
- contrast usage.

### ***Basic anatomy***

Simple anatomical diagrams are provided for most examination areas to assist the reader.

### ***Common indications***

These are the most usual reasons for scanning each area, although occasionally some rarer indications are included.

### ***Equipment***

This contains a list of the equipment required for each examination and includes coil type, gating leads, bellows and immobilization devices. The correct use of gating and RC is discussed in Part 1 (see *Gating and respiratory compensation techniques*). The coil types described are the most common currently available. These are as follows.

- **Volume coils** that both transmit and receive radio-frequency (RF) pulses and are specifically called transceivers. Most of these coils are quadrature coils, which means that they use two pairs of coils to transmit and receive signal, so improving the signal to noise ratio (SNR). They have the advantages of encompassing large areas of anatomy and yielding a uniform signal across the whole field of view (FOV). The body coil is an example of this type of coil.
- **Linear phased array coils** consist of multiple coils and receivers. The signal from the receiver of each coil is combined to form one image. This image has the advantages of both a small coil (improved SNR) and those of the larger volume coils (increased coverage). Therefore linear phased array coils can be used either to examine large areas, such as the entire length of the spinal cord, or to improve signal uniformity and intensity in small areas such as the breast. Linear phased array coils are commonly used in spinal imaging.

- **Volume phased array (parallel imaging)** uses the data from multiple coils or channels arranged around the area under examination to either decrease scan time or increase resolution. Additional software and hardware are required. The hardware includes several coils perpendicular to each other or one coil with several channels. The number of coils/channels varies but commonly ranges from 2 to 32. During acquisition, each coil fills its own lines of k-space (e.g. if two coils are used together, one coil fills the even lines of k-space and the other the odd lines. k-space is therefore filled either twice as quickly or with twice the phase resolution in the same scan time). The number of coils/channels used is called the reduction factor and is similar in principle to the turbo factor/echo training length (ETL) in fast spin echo (FSE) (see section on *Pulse sequences* in Part 1). Every coil produces a separate image that often displays aliasing artefact (see section on *Artefacts* in Part 1). Software removes aliasing and combines the images from each coil to produce a single image. Most manufacturers offer this technology, which can be used in any examination area and with any sequence.
- **Surface/local coils** are traditionally used to improve the SNR when imaging structures near to the skin surface. They are often specially designed to fit a certain area and, in general, they only receive signal. RF is usually transmitted by the body coil when using this type of coil. Surface coils increase SNR compared with volume coils. This is because they are placed close to the region under examination, thereby increasing the signal amplitude generated in the coil, and noise is only received in the vicinity of the coil. However, surface coils only receive signal up to the edges of the coil and to a depth equal to the radius of the coil. To visualize structures deep within the patient, either a volume, linear or volume phased array coil or a local coil inserted into an orifice must be utilized (e.g. a rectal coil).

The choice of coil for any examination is one of the most important factors that determine the resultant SNR of the image. When using any type of coil remember to:

- Check that the cables are intact and undamaged.
- Check that the coil is plugged in properly and that the correct connector box is used.
- Ensure that the receiving side of the coil faces the patient. This is usually labelled on the coil itself. Note: Both sides of the coil receive signal, but coils are designed so that one side receives optimum signal. This is especially true of shaped coils that fit a certain anatomical area. If the wrong side of the coil faces the patient, signal is lost and image quality suffers.
- Place the coil as close as possible to the area under examination. The coil should not directly touch the patient's skin as it may become warm during the examination and cause discomfort.

A small foam pad or tissue paper placed between the skin surface and the coil is usually sufficient insulation.

- Ensure that the coil does not move when placed on the patient. A moving coil during acquisition means a moving image!
- Always ensure that the receiving surface of the coil is parallel to the Z (long) axis of the magnet. This guarantees that the transverse component of magnetization is perpendicular to the coil and that maximum signal is induced. Placing the coil at an angle to this axis, or parallel to the X or Y axis, results in a loss of signal (Figure 1.1).

### ***Patient positioning***

This contains a description of the correct patient position, placement of the patient within the coil and proper immobilization techniques. Centring and land-marking are described relative to the laser light system as follows (Figure 1.2):

- The **longitudinal alignment light** refers to the light running **parallel** to the bore of the magnet in the **Z axis**.
- The **horizontal alignment light** refers to the light that runs from **left to right** of the bore of the magnet in the **X axis**.
- The **vertical alignment light** refers to the light than runs from the **top to the bottom** of the magnet in the **Y axis**.

It is assumed in Part 2 that the following areas are examined with the patient placed head first in the magnet:

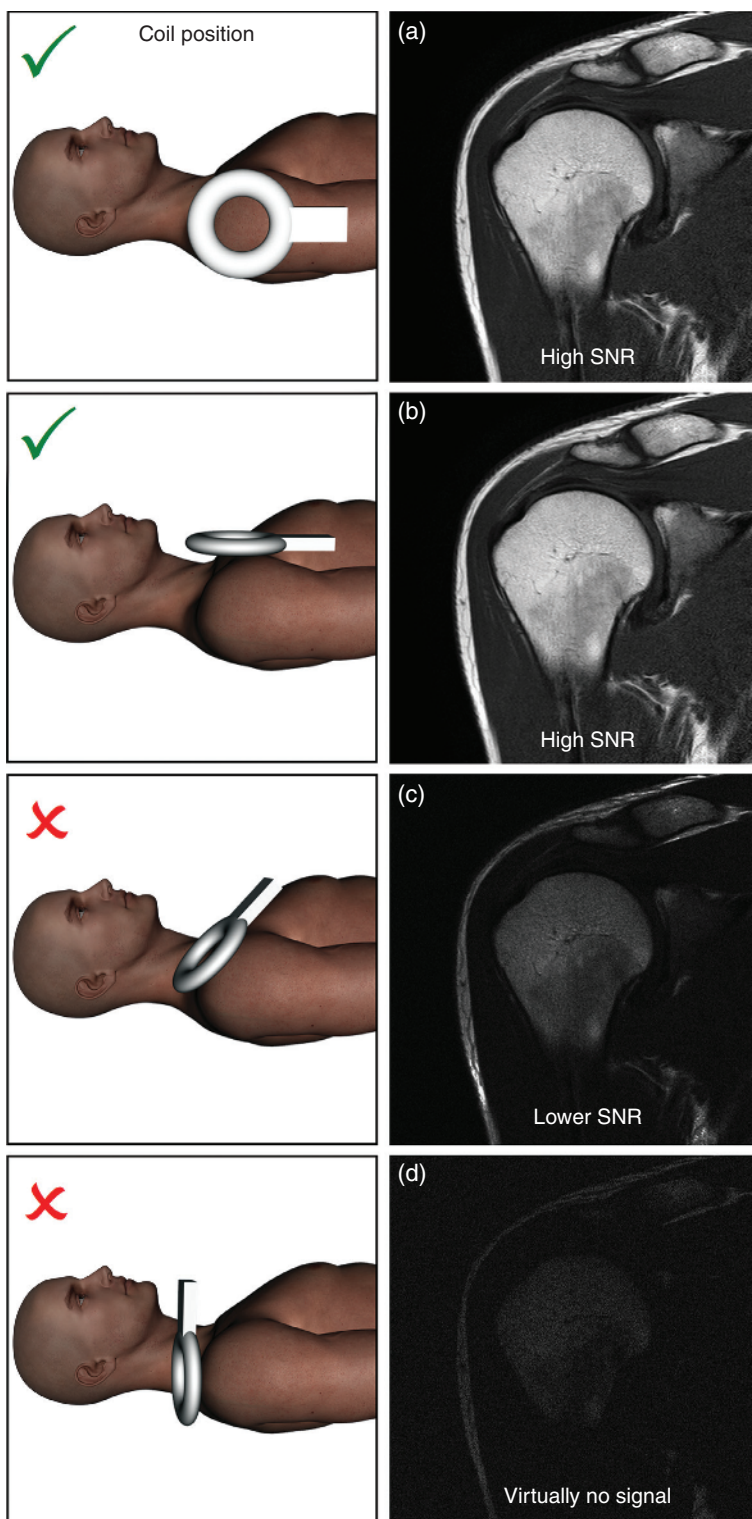
- head and neck (all areas)
- cervical, thoracic and whole spine
- chest (all areas)
- abdomen (for areas superior to the iliac crests)
- shoulders and upper limb (except where specified).

The remaining anatomical regions are examined with the patient placed feet first in the magnet. These are:

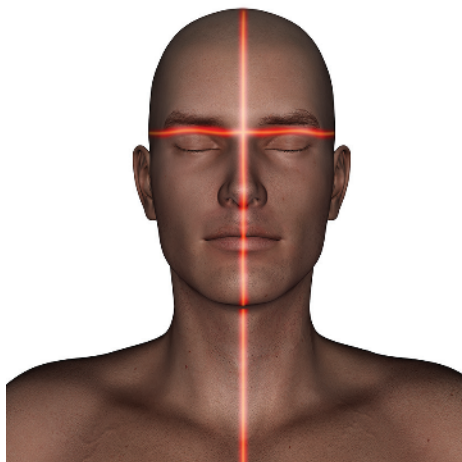
- pelvis
- hips
- lower limbs.

### ***Suggested protocol***

This is intended as a **guideline only**. Almost every centre uses different protocols depending on the type of system and radiological preference. However, this section can be helpful for those practitioners scanning without a radiologist, or where the examination is so rare that perhaps



**Figure 1.1** Correct placement of a flat surface coil in the bore of the magnet. The surface of the coil (shaded) area must be parallel to the Z axis to receive signal. The coil is therefore positioned so that transverse magnetization created in the X and Y axes is perpendicular to the coil.



**Figure 1.2** Positioning of the alignment lights.

neither the radiologist nor the practitioner knows how to proceed. The protocols given are mainly limited to scan plane, weighting, suggested pulse sequence choices and slice positioning.

**It must be stressed that all the protocols listed are only a reflection of the authors' practice and research, and are in no way to be considered the law!**

If all your established protocols are satisfactory, this section is included for interest only. If, however, you are unfamiliar with a certain examination, the suggested protocol should be useful.

Occasionally in this section coordinates for slice prescription are given in bold type in millimetres (mm) where explicit prescription can be utilized (mainly for localizers). Graphic prescription coordinates cannot be given as they depend on the exact position of the patient within the magnet and the region of interest (ROI). The explicit coordinates are always given as follows:

- |                         |                |
|-------------------------|----------------|
| ● Left to Right         | <b>L to R</b>  |
| ● Inferior to Superior  | <b>I to S</b>  |
| ● Posterior to Anterior | <b>P to A.</b> |

In the suggested protocols, a certain format is adopted when some parameters remain constant and others change. For example, in the protocol for a coronal spin echo (SE), proton density (PD)/T2 sequence of the brain the text reads.

### **Coronal SE/FSE PD/T2**

As for axial PD/T2, **except** prescribe slices from the cerebellum to the frontal lobe.

This indicates that the pulse sequence, timing parameters, slice thickness and matrix are the same as the axial except the slices are prescribed through a different area. This format is intended to avoid repetition. In most examinations, there is a section reserved for additional sequences. These are extra sequences that we do not regard as routine but may be included in the examination. Of course, some practitioners may regard what we call ‘additional’ as ‘routine’, and vice versa.

## **Image optimization**

This section is subdivided into:

- Technical issues
- Artefact problems

**Technical issues:** This includes a discussion of the relationship of SNR, spatial resolution and scan time pertaining to each examination. Suggestions on how to optimize these factors are described (see *Parameters and trade-offs* in Part 1). The correct use of pulse sequences and various imaging options are also discussed (see also *Pulse sequences* in Part 1).

**Artefact problems:** This contains a description of the common artefacts encountered and ways in which they can be eliminated or reduced (see also *Flow phenomena and artefacts* in Part 1).

## **Patient considerations**

This encompasses the condition of the patient, including symptoms and claustrophobia. Suggestions to overcome these are given (see also *Patient care and safety* in Part 1).

## **Contrast usage**

The reasons for administering contrast in each particular area are discussed. Again, contrast usage varies widely according to radiological preferences. This section is a guideline only (see also *Contrast agents* in Part 1).

Follow this 10-point plan for good radiographic practice:

1. Review all cases carefully and select appropriate protocols.
2. Have flexible protocols that can reflect the needs of each individual clinical case.
3. Regularly review your procedures and benchmark them against current best practice.
4. Have clear diagnostic goals including the minimum accepted sequences necessary to obtain a useful diagnostic/clinical outcome.
5. Regularly review your protocols and procedures.



6. Understand the capabilities of your system.
7. Recognize your limitations and if necessary refer to another site rather than risking an incomplete or diagnostically unacceptable procedure.
8. Educate all levels of staff to new procedures and/or system capabilities.
9. Be safety paranoid to ensure your unit does not fall victim to the dreaded MRI incident.
10. Most importantly, enjoy your patients and give them the highest standard of care possible.

## **Terms and abbreviations used in Part 2**

Wherever possible, generic terms have been used to describe pulse sequences and imaging options. Explanations of these can be found in the various sections of Part 1. To avoid ambiguity, the specific following terms have been used:

- **Tissue suppression:** includes all suppression techniques such as fat saturation (FAT SAT), spectrally selective inversion recovery (SPIR) and Dixon methods
- **Gradient moment nulling (GMN):** gradient moment rephasing (GMR) and flow compensation (FC)
- **Oversampling:** no phase wrap, antialiasing and anti-foldover
- **Rectangular/Asymmetric FOV:** rectangular FOV
- **Respiratory compensation (RC):** phase reordering and respiratory triggering techniques

Abbreviations are used throughout the book for simplification purposes. A summary of these can be found in the following section, *Abbreviations*. In addition, a comparison of acronyms used by certain manufacturers to describe pulse sequences and imaging options is given in Table 3.1 under *Pulse sequences* in Part 1.

## **Conclusion**

To use this book:

- Find the anatomical region required and then locate the specific examination.
- Study the categories under each section. It is possible that all the categories are relevant if the examination is being performed for the first time. However, there may be occasions when only one item is appropriate. For example, there could be a specific artefact that is regularly observed in chest examinations, or image quality is not up to standard on lumbar spines. Under these circumstances, read the subsection entitled *Image optimization*.
- If the terms used, or concepts discussed, in Part 2 are unfamiliar, then turn to Part 1 and read the summaries described there.



## Abbreviations

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A summary of common abbreviations used in the field of MRI and throughout this book is given below.

|         |   |
|---------|---|
| A       | Anterior  |
| AC      | Number of acquisitions                            |
| ADC     | Apparent diffusion coefficient                    |
| ADEM    | Acute disseminating encephalomyelitis             |
| ASIS    | Anterior superior iliac spine                     |
| AVM     | Arteriovenous malformation                        |
| AVN     | Avascular necrosis                                |
| BFFE    | Balanced fast field echo                          |
| BGRE    | Balanced gradient echo                            |
| BOLD    | Blood oxygenation level dependent                 |
| CE-MRA  | Contrast-enhanced MRA                             |
| CNR     | Contrast to noise ratio                           |
| CNS     | Central nervous system                            |
| CSE     | Conventional spin echo                            |
| CSF     | Cerebrospinal fluid                               |
| CT      | Computer tomography                               |
| CVA     | Cerebral vascular accident                        |
| DE prep | Driven equilibrium magnetization preparation      |
| DTI     | Diffusion tensor imaging                          |
| DWI     | Diffusion weighted imaging                        |
| ECG     | Echocardiogram                                    |
| EPI     | Echo planar imaging                               |
| ETL     | Echo train length                                 |
| FA      | Fractional anisotropy                             |
| FAT SAT | Fat saturation                                    |
| FC      | Flow compensation                                 |
| FDA     | Food and Drugs Administration                     |
| FFE     | Fast field echo                                   |
| FID     | Free induction decay signal                       |
| FIESTA  | Free induction echo stimulated acquisition        |
| FISP    | Fast imaging with steady precession               |
| FLAIR   | Fluid-attenuated inversion recovery               |
| FLASH   | Fast low angled shot                              |
| fMRI    | Functional MRI                                    |
| FOV     | Field of view                                     |
| FSE     | Fast spin echo                                    |
| GFE     | Gradient field echo                               |
| GMN     | Gradient moment nulling                           |
| GMR     | Gradient moment rephasing                         |
| GRASS   | Gradient recalled acquisition in the steady state |
| GRE     | Gradient echo                                     |
| GRE-EPI | Gradient echo EPI                                 |
| HASTE   | Half acquisition single-shot turbo spin echo      |

|         |  |
|---------|--|
| I       | Inferior                                     |
| IAM     | Internal auditory meatus                     |
| IM      | Intramuscular                                |
| IR      | Inversion recovery                           |
| IR-FSE  | Inversion recovery FSE                       |
| IR prep | Inversion recovery magnetization preparation |
| IV      | Intravenous                                  |
| IVC     | Inferior vena cava                           |
| L       | Left   |
| MP RAGE | Magnetization prepared rapid gradient echo   |
| MR      | Magnetic resonance                           |
| MRA     | Magnetic resonance angiography               |
| MRCP    | Magnetic resonance cholangiopancreatography  |
| MRI     | Magnetic resonance imaging                   |
| MS      | Multiple sclerosis                           |
| MT      | Magnetization transfer                       |
| NEX     | Number of excitations                        |
| NSA     | Number of signal averages                    |
| P       | Posterior                                    |
| PC      | Phase contrast                               |
| PC-MRA  | Phase contrast MRA                           |
| PD      | Proton density                               |
| Pe      | Peripheral                                   |
| PEAR    | Phase encoding artefact reduction            |
| PSIF    | Reverse FISP                                 |
| R       | Right  |
| RC      | Respiratory compensation                     |
| REST    | Regional saturation technique                |
| RF      | Radio frequency                              |
| ROI     | Region of interest                           |
| RR      | R to R interval                              |
| S       | Superior                                     |
| SAR     | Specific absorption rate                     |
| SAT     | Saturation                                   |
| SE      | Spin echo                                    |
| SE-EPI  | Spin echo EPI                                |
| SNR     | Signal to noise ratio                        |
| SPAMM   | Spatial modulation of magnetization          |
| SPGR    | Spoiled GRASS                                |
| SPIR    | Spectrally selective inversion recovery      |
| SS      | Single shot                                  |
| SS-EPI  | Single-shot EPI                              |
| SSFP    | Steady-state free precession                 |
| SS-FSE  | Single-shot FSE                              |
| STIR    | Short TAU inversion recovery                 |
| SW      | Susceptibility weighted                      |
| TE      | Echo time                                    |
| TFE     | Turbo field echo                             |

|           |                            |
|-----------|----------------------------|
| TI        | Inversion time             |
| TIA       | Transient ischaemic attack |
| TLE       | Temporal lobe epilepsy     |
| TMJ       | Temporomandibular joint    |
| TOF       | Time of flight             |
| TOF-MRA   | Time of flight MRA         |
| TR        | Repetition time            |
| True FISP | Siemens version of BGE     |
| TSE       | Turbo spin echo            |
| VENC      | Velocity encoding          |

