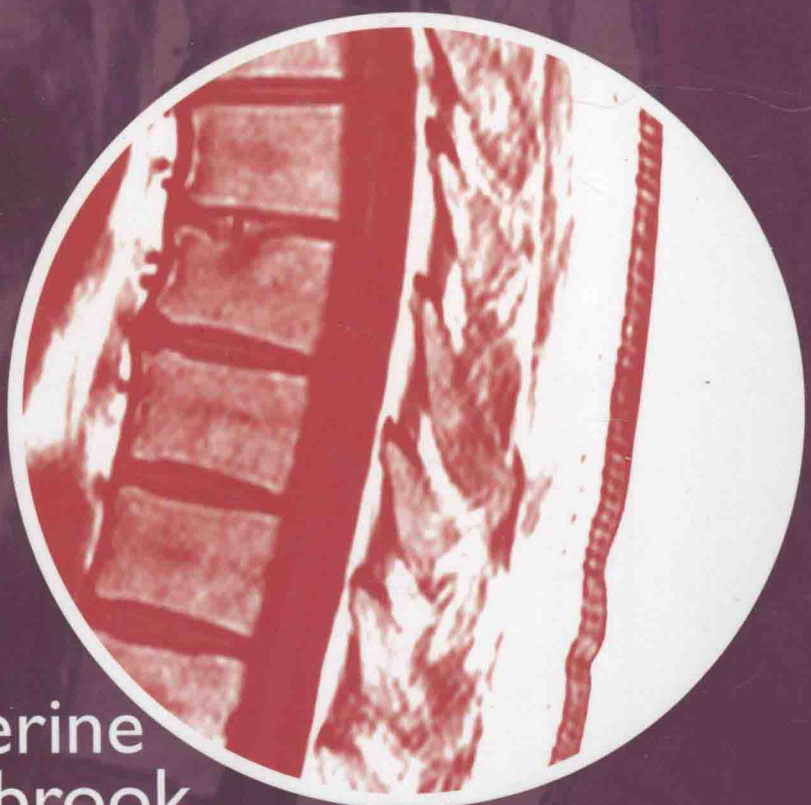
HANDBOOK OF MRI TECHNIQUE

FOURTH EDITION



Catherine Westbrook

with website

WILEY Blackwell

Handbook of MRI Technique

Fourth Edition

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Handbook of MRI Technique

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Catherine is also an independent teaching consultant providing teaching and assessment in MRI to clients all over the world.

Catherine has worked in MRI since 1990 and was one of the first people in the world to gain a Master of Science degree in MRI. She also has a postgraduate certificate in Learning and Teaching and a Fellowship in Advanced MRI. She is currently studying for a Doctorate in Education with a focus on MRI. Catherine is a Fellow of the Higher Education Academy and a qualified clinical teacher.

Catherine founded what is now called the "MRI in Practice" course in 1992 and has taught on the course ever since. She also teaches and examines on many other national and international courses, including undergraduate and postgraduate programmes. In particular, Catherine was involved in the development of the first reporting course for MRI radiographers and the first undergraduate course for assistant practitioners in MRI.

Catherine is the author of several books including *MRI in Practice*, *Handbook of MRI Technique*, *MRI at a Glance* and many other chapters and articles.

Catherine has been President of the British Association of MR Radiographers, Chairman of the Consortium for the Accreditation of Clinical MR Education and Honorary Secretary of the British Institute of Radiology.

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John is a senior lecturer in medical imaging at Anglia Ruskin University, Cambridge. He was formerly education and research radiographer at Oxford MRI/Oxford University. He developed an early interest in MRI as a school-leaver in 1977 and was one of the first radiographers in the world to gain an MSc in the field of medical imaging (MRI) in 1997.

He now lectures extensively around the world as copresenter of MRI in Practice | The Course, teaching up to 800 delegates per year on what has become the world's favourite MRI course.

Academically, John is a contributor to undergraduate and postgraduate MRI courses at Anglia Ruskin University. He is a senior lecturer in postgraduate MRI, supervising Masters students dissertations on this pathway. He is also a tutor in research methodology and (as a registered Apple developer) is undertaking research in the field of touch-screen mobile devices as educational tools.

John is the coauthor and illustrator of the fourth edition of *MRI in Practice* (Wiley Blackwell), the fourth edition of *Handbook of MRI Technique* (Wiley Blackwell) and coauthor of *Medical Imaging—Techniques, Reflection & Evaluation* (Elsevier).

John's main interest is exploiting the parallelism between technology and learning, and he is currently working on new pedagogical concepts in virtual learning environments. His previous contributions to the field include the construction of a 'virtual reality' MRI scanner for learning and teaching and other web-based interactive learning materials. More recently, John has been creating computer-generated high-definition movies and anaglyph 3D diagrams of MRI concepts for the all-new update of MRI in Practice | The Course. Some of these computer generated images (CGI) resources are included in the web content for the latest edition of the book *MRI in Practice* and as a range of MRI educational apps for Apple devices.

William Faulkner, BS, RT(R)(MR)(CT), FSMRT
Bill Faulkner is currently working as an independent consultant with his own company, William Faulkner & Associates, providing MRI and CT education as well as MRI operations consulting. His clients have included health care facilities, major equipment vendors, manufacturers and companies such as GE, Philips, Siemens, Toshiba, Invivo, Medtronic, Bracco Diagnostics Inc. and others in the medical imaging field. He has been teaching MRI programmes in Chattanooga, TN, for over 20 years and has been holding MRI certification exam review programmes for more than 15 years. He has been recognized for his contributions to MRI technologist education through several awards including the Crues–Kressel Award from the Section for Magnetic Resonance Technologists (SMRT) and being named 'Most Effective Radiologic Technologist Educator' by AuntMinnie.com. Bill is an active member and Fellow of the SMRT serving as its first president.

Joseph Castillo, MSc (Health Service Management), MSc (MRI)
Joseph is manager for Medical Imaging Services for the National Health Service in Malta. Joseph is also a visiting lecturer at the University of Malta providing teaching and assessment for the Masters degree in MRI. Joseph has worked in MRI since 1995 and has an MSc in MRI, in addition to MSc in Health Service Management. He is currently reading for a PhD with a focus on MRI education and service management. In 2005, Joseph has founded the Malta Magnetic Resonance Radiographers Group which is a community of practice fully dedicated towards MRI education. The group has organised several MRI symposia and workshops.

Erik Van Landuyt, EVL, MC
Erik is the manager for CT and MRI ASZ Campus Aalst, Belgium. As is common in Belgium, Erik first trained as nurse and specialized in CT in 1987. He has a postgraduate certificate in radiography from UZA/VUB, Belgium, and has been an applications specialist for Siemens and GE Healthcare for many years. He currently works on Siemens 1.5T and GE 3.0T systems. Erik's clinical interests include musculoskeletal, neurological and MRA imaging. Erik has several educational responsibilities including acting as a mentor for radiographers and nurses at colleges in Brussels and Aalst. He is also the Belgium organizer of the "MRI in Practice" course.

Preface

The *Handbook of MRI Technique* is now an established text for many MRI practitioners around the world. *MRI in Practice* (also published by Wiley Blackwell) provides radiographers and radiologists with a user-friendly approach to MRI theory and how it may be applied in practice. The book is intended to guide the uninitiated through scanning techniques and protocols and to help more experienced practitioners improve image quality and recognize and rectify common artefacts. In many countries, a lack of educational facilities and funding, as well as the complex nature of the subject, has resulted in practitioners experiencing difficulty in learning MRI techniques. The book has filled this gap and has proven to be a useful clinical text. In this, the fourth edition, it has been my intention to continue with the objectives of previous editions but update the reader on recent advances. Experienced MRI practitioners from the United Kingdom, United States and Europe have made important contributions to reflect these advances and their practice.

The book is split into two parts. Part 1 summarizes the main aspects of theory that relate to scanning and also includes practical tips on equipment use, patient care and safety, and information on contrast media. Part 2 includes a step-by-step guide to examining each anatomical area. It covers most of the techniques commonly used in MRI. Under each examination area, categories such as indications, patient positioning, equipment, suggested protocols, common artefacts and tips on optimizing image quality are included. Guidance on technique and contrast usage is also provided. Each section also includes key facts, and the basic anatomy section has been improved with the inclusion of sophisticated computer-generated diagrams. The accompanying web site consists of multiple-choice questions and image flash cards to enable readers to test their knowledge.

The book provides a guide to the operation of MR systems to enhance the education of MR users. It is not intended to be a clinical book as there are plenty of clinical specialist books on the market. Therefore diagrams and images focus intentionally on scan planes, slice prescriptions and sequencing to reflect the technical thrust of the book. This edition should continue to be especially beneficial to those technologists studying for

board certification or postgraduate and MSc courses, as well as to assistant practitioners, radiographers and radiologists who wish to further their knowledge of MRI techniques. The contributing authors and I hope that it continues to achieve these goals.

Catherine Westbrook

Acknowledgements

I must give my heart-felt thanks to the contributing authors John Talbot, William Faulkner, Joseph Castillo and Erik Van Landuyt without whom this book could never have been updated. As usual, I am extremely impressed with their professional and thoughtful contributions and I am very grateful for their valued opinions and support.

CW

About the companion website

This book is accompanied by a companion website:

www.wiley.com/go/westbrook/mritechnique

The website includes:

- Interactive MCQs for self-assessment
- Interactive flashcards of book images

Contents

1 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

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Companion website: www.wiley.com/go/westbrook/mritechnique

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