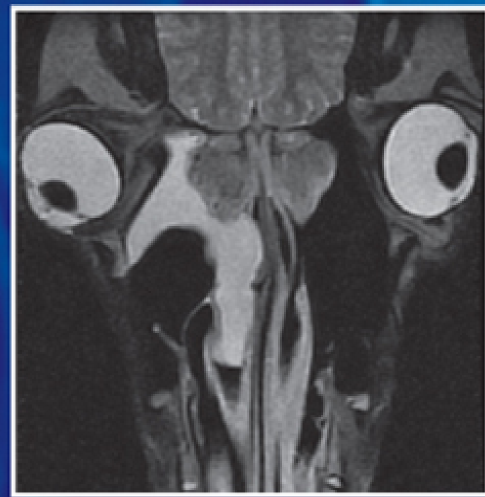
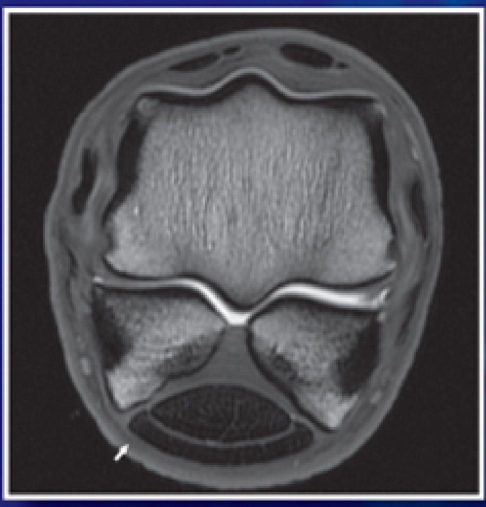
Equine MRI

Edited by Rachel C. Murray





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Equine MRI

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Foreword

No aspect of medical imaging requires the understanding of such complex physics as that required for magnetic resonance imaging (MRI). However, since Röntgen first produced a radiographic image of his wife`s hand, no imaging technique has excited such interest nor presented such potential opportunities. MR scanning owes its origin to a number of scientists and physicians during a period of over a hundred years. These include Tesla, Lamor, Rabi, Bloch, Purcell, Lauterbur and Mansfield, who all contributed to the recognition and application of the phenomenon we call nuclear magnetic resonance. However, it was not until 1977 that Damadian, Goldsmith and Minkoff produced the first human MR scanner. Since then the technique has come to occupy a central role in medical imaging throughout the developed world.

MRI was first used in veterinary medicine in the 1990s, predominantly for the evaluation of anaesthetised or heavily sedated small animal patients. The high field magnets employed in imaging human patients were also adapted to be used on anaesthetised horses and ponies. However it was the development of low field magnets which could be used on standing equine patients, which really saw widespread recognition of the potential value of the technique for equine use. Initially restricted to the foot and distal limb, the development of software packages to correct for patient movement, plus increasing expertise of clinicians in obtaining and interpreting the images, now allows examination of the more proximal limb to include the carpus and hock.

This is not to say that the high field magnet has been superseded. The superior image quality possible makes it the diagnostic method of choice along with computed tomography for imaging the equine head. However, risks associated with general anaesthesia in equine patients have encouraged the use of MRI in standing patients whenever possible. Numerous clinics around the world have introduced MR scanning into their protocols for investigating equine lameness. Consequent understanding of the technique, with its benefits and limitations, has accelerated dramatically in the last few years.

As a surgeon benefitting from the skill of those who obtain and interpret MR images of patients with orthopaedic problems, it never ceases to astonish just what information about tendon, ligament, bone and articular cartilage can be collected. Exquisite detail of the anatomy and pathology of, for example, the foot is clear, provided one is equipped with an expert in the sophisticated language so alien to those of us brought up solely on a diet of radiographic and ultrasound images. This allied to additional information obtained by complementary techniques such as radiography, computed tomography, ultrasound, arthroscopy or gamma scintigraphy and of course underpinned by a thorough physical examination, has armed the modern clinician with investigative powers undreamt of by veterinary predecessors.

The future is hard to predict. It is likely that improvements in both hard and software will enable imaging of more proximal portions of the limb or other parts of the body. We can anticipate the development of a standing system using a more powerful magnet, new sequences and further improvements in motion correction by the physicists, with concurrent clinical research to enable more accurate interpretation of the images. For those of us being carried along by and experiencing the benefits of this wave of development of MR imaging, it is difficult to believe that the momentum will cease. Whilst inevitably there may be practical limitations to further progress, imagination should not be allowed to constrain those enthusiasts who have taken up the challenge of this technology and created a valuable diagnostic resource.

This first book dedicated to equine MRI will I am quite certain assume its rightful role as the “bible” of equine MR imaging. It endeavours to explain some of the complex physics which underpin the technology and gives practical guidance to obtaining and interpreting images of the limbs and head. At the current speed of development, I am certain that future editions will be necessary to keep pace with this.

Tim Greet

President, World Equine Veterinary Association

Preface

When I started clinical veterinary diagnostic work in the horse, I could only have dreamed of an imaging modality that could provide detailed anatomical and physiological information of both soft tissues and bone. Using magnetic resonance imaging (MRI) in the horse has transformed my expectations of how much can potentially be evaluated and how much more there is to learn about normal structure, normal variation and pathology. There are increasing demands on the athletic horse, and improvements in diagnosis and management are constantly being sought. Application of MRI has revolutionized our understanding of foot pathology and demonstrated the presence of numerous previously unrecognized or poorly understood conditions in the limbs and head. Early work with MRI was focused on validation and investigation into the significance of MRI findings. However, expanding clinical knowledge, improvements in technology and practical application of MRI to the standing and recumbent horse has meant that MRI has become an integral and essential part of the diagnostic evaluation in lameness, and a realistic option for investigation of ophthalmological, neurological and cranial pathology. Despite the rapidly expanding use of MRI for equine clinical investigation, until now there has been no reference book that covers this field. This book seeks to fill that gap.

The aim of *Equine MRI* is to provide a comprehensive guide to MRI in the horse, based on the information currently known worldwide. It aims to cover information from the basics of MRI to the practicalities of image acquisition and interpretation, to describe normal anatomy and normal variations, to describe different types of pathological change and to discuss options for clinical management and prognosis for different conditions. MRI produces large amounts of data with great potential for over-interpretation due to image acquisition problems or insufficient knowledge or experience. This book should help the reader understand the best ways to achieve good-quality images, and give a guide to the problems that may occur. As image interpretation is based on an understanding of MR physics, normal variation and detection of pathology, this book should guide the inexperienced reader towards their initial steps in interpretation; it also provides considerable detail, with numerous examples of both common and uncommon problems to expand knowledge for the more advanced reader. The information given is based on previous validation work and clinical experience of many experts, which should allow the reader to improve their understanding and clinical application of MRI faster than the trial and error often needed in clinical practice.

Equine MRI is for the radiologist interpreting MR images from horses, for the diagnostic imaging technician who is acquiring MR images in the horse, for the clinical veterinarian using MRI for diagnosis, and for veterinary and science students. The clinical aspect of the book is of particular use for the practising and specialist veterinarian, and the diagnostic imaging technician. The detailed anatomy and image interpretation is for the specialist and practising veterinarian who is either using MRI or referring to a centre with MRI, and for both scientists and students. The detailed anatomy visible on the images make MR images ideal for teaching anatomy to veterinary and equine science students. As the book is divided into sections based around the principles of MRI and image acquisition, normal anatomy, pathology and clinical outcome, with use of numerous examples in each section it should be clear for the reader to navigate around the sections most applicable for their specific uses.

We are still on a steep learning curve in our understanding of the applications of MRI in the horse. I hope that this book provides a small step forward in distributing current knowledge as a basis for future work with MRI and in helping our patient – the horse.

Rachel C. Murray

Acknowledgements

I would like to thank the individuals who have provided their time and expertise in contributing to this book. We are continuing to learn with every patient, and it is this combined information that is improving our understanding to help future patients, so I am grateful to everyone who has given permission for use of images and material. Many people have been involved in developing MRI in the horse, and it is their dedication and skill that has led to the recognition of MRI as a vital diagnostic tool in the horse – and from which this book has been derived. I am grateful to so many of these people for passing on their knowledge and for questioning what the images actually represent in the horse. These include the authors of the chapters in this book, the veterinary surgeons who have been involved in validation and clinical use of MRI, and the medical radiologists who have helped translate MRI from the veterinary field. I need to mention in particular the members of the diagnostic imaging and clinical teams at the Animal Health Trust, the MR radiologists and physicists from Addenbrookes Hospital, University of Cambridge, and Russ Tucker from Washington State University, who have been integral in developing my understanding of high field MRI and its applications. I am indebted to the physicists from Hallmarq for continually improving my understanding of MRI physics and interpretation during development of practical MRI in the standing horse.

On a personal basis, I will be forever grateful to my parents for showing me that editing a book is achievable, and to Duncan, Ruth and Clare for allowing me the time to do so.

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Chapter 1

Basic MRI principles

Nick Bolas

INTRODUCTION

Since its introduction into human medicine in the early 1980s, magnetic resonance imaging (MRI) has become established as the gold standard for orthopaedic and neurological diagnostic imaging. The first scans on live equine patients were performed in the late 1990s, and since that time more than 20,000 horses have been scanned, primarily for investigation of pain in the foot.

As a diagnostic imaging technique MRI has some features in common with other imaging modalities, such as radiography, computed tomography (CT), nuclear scintigraphy and ultrasound. But it also has unique characteristics related to the underlying physics behind the generation of signal and the formation of the image.

MRI:

- forms images of radically different appearance depending on the adjustment of key settings on the scanner
- is inherently of low sensitivity, and therefore the images are usually suboptimal in some respect. Improving any one aspect involves understanding the trade-offs and how they will affect features of the resulting image
- poses unique hazards related to magnetic and electrical effects on common tools, equipment and surgical

implants.

The origin of the MRI signal relies on exotic quantum physics, which unfortunately is impossible to describe fully in terms of the behaviour of familiar objects. A formal description requires a mathematical approach. Fortunately, however, such a rigorously correct approach is not necessary to obtain enough understanding for the purposes of medical imaging. The purpose of this introductory chapter is to explain how the image is produced, how it is influenced by scanner settings and the environment, and to lay the foundations for the descriptions of image acquisition and interpretation in later chapters.

HOW THE IMAGE IS CREATED

Overview

At about the time Xenophon (431–355 BC) was writing the first recorded discourse on horsemanship and conformation, his contemporary Democritus (ca. 460–370 BC) was expanding on the idea that all matter is made up of various imperishable 'indivisible units', termed atoms. The Greek word *tomos* (from the verb to cut) has given the English language both *atom* and *tomography*.

Today we are familiar with the idea that all material is made up of atoms, and that atoms themselves are composed of protons, neutrons and electrons. The protons and neutrons are condensed together to form a nucleus at the core, surrounded by a cloud of electrons. Magnetic resonance imaging depends on the manner in which that nucleus interacts with external magnetic fields.

The key principles are as follows.

1 In the presence of a static magnetic field, certain nuclei (including the proton, ^{1}H) become sensitive to oscillating magnetic fields and resonate in a synchronized manner.

2 The frequency of magnetic oscillations at which such nuclei resonate is *exactly* proportional to the strength of the static field.

3 At commonly used static field strengths of about 1 Tesla, the nuclei resonate at the MHz range of radio frequencies. Magnetic oscillations of this frequency are easy to create and detect electrically. Thus magnetic resonance provides a way to:

(a) create and detect signal using the biological tissue itself, using the ^{1}H in water (H_2O) and fat (with many –CH_2– chains)

(b) very precisely measure the magnetic field at the location of the biological tissue.

4 By applying a linear magnetic field gradient, so that the magnetic field is stronger on one side of an object than on the other, the position of the resonating nuclei can be determined by measuring the exact resonance frequency.

5 A mix of signals from nuclei all resonating at different frequencies (e.g. because they are in different places in a field gradient) would almost immediately cancel each other out. Special methods are needed to make the signals refocus, or echo, so that they can be detected.

6 To locate a position in the three dimensions of space, three field gradients are required. However, they can only be applied one at a time (otherwise only a single gradient at a diagonal angle would result), so special techniques are needed to code the three dimensions of space by a succession of gradients applied in the three directions, one after the other.

7 Other properties of the nuclei, called relaxation times, give additional clinically useful information, and imaging techniques are adapted to make this information available.

MRI physics

Nuclei

The nucleus has a positive electrical ***charge***,[1] carried by ***proton***s. The ***mass*** of the nucleus comes from these protons and also from almost equally heavy, electrically neutral, ***neutron***s. As well as these familiar concepts of charge and mass the sub-atomic protons and neutrons have a property called ***spin***. While this spin is not really caused by a physical rotation of the particles, it does create some properties comparable to those of rotating charged bodies; properties that give rise to the phenomenon of nuclear magnetic resonance (NMR).

Magnetic resonance signals can be detected from a wide range of nuclei with odd ***atomic number***s[2] (MR active nuclei), and NMR has been used in chemistry and physics since the 1950s. The amount of detectable signal varies between nuclei, with hydrogen (^{1}H) being almost the most sensitive of all.[3] Hydrogen is a component of water (H_2O) and of fat (with many –CH_2– chains), both of which are very common in biological tissue, so images of patients can be created without a need to add any external substance. In normal biological tissue the natural abundance of the ^{1}H ***isotope*** is almost 100%,[4] and the resulting high sensitivity makes hydrogen (or almost synonymously the proton, the nucleus of the hydrogen atom) by far the most important nucleus for clinical magnetic resonance imaging. With the commercialization of clinical magnetic resonance imaging the word ‘nuclear’ was dropped and the abbreviation MRI introduced.

The quantum property of spin causes the nucleus to generate its own magnetic field (or magnetic moment),