Chapter 2

Early Daze: Your First Week in MR

2.1 Introduction

In any first week of a new job or in a new environment, it takes a little time to become orientated and to find your way around. This chapter aims to ease those initial experiences so that you will feel more like a seasoned campaigner than a raw recruit. The following are your essential instructions:

- Magnet safety, especially from ferromagnetic projectiles, is paramount to the safe operation of any MR unit; do nothing to endanger the wellbeing of your patients and colleagues.
- The MRI unit should have clearly written policies and procedures for checking that patients and staff have no contraindications.
- Aside from the magnet itself, the coils are the main items of equipment that you will have to learn to handle (don't break them!), and learn how to position patients comfortably and effectively with them.
- Good patient cooperation is essential for safe and effective scanning; you will need good people skills.

The MR environment is a bit confusing at first, but you will soon feel at home. Enjoy the experience!

2.2 Welcome to the MR Unit

On your first day you will be asked to complete a staff safety questionnaire and should undergo a thorough safety induction. (Once you are MR trained you will find yourself doing strange things such as taking off your watch and emptying your pockets when you go into a CT room!) As part of your induction you will need to become familiar with your institution's MR safety policy or Local Rules. These will contain information about access to the controlled area or zones, local policy on implants, dealing with emergencies, staff roles and responsibilities, and other site-specific safety-related information.

2.2.1 The MR Suite

The MR suite will probably be arranged differently from the remainder of the imaging department. It may have its own dedicated reception, administration, waiting and patient-handling areas. Security will be high on the staff's agenda and the suite usually has its own lockable doors. The preoccupation with security and the 'separateness' of the MR suite is principally to prevent anyone introducing ferromagnetic items into the vicinity of the magnet, where the outcome could be disastrous.

MR accommodation may comprise:

- facilities for patient management: reception, waiting areas, changing facilities, toilets, anaesthesia and recovery area, counselling room;
- facilities for staff: reception/office, administration office, reporting rooms;
- MR system: the MRI scanner room (magnet/ examination room), computer/technical room and operator's console/host computer;
- dedicated storage areas: trolley bay, general store, resuscitation trolley bay, cleaner's store.

An example of a typical MRI suite layout is given in Figure 2.1.

The MRI *scanner room*, or *magnet room* or *examination room* is a restricted access or controlled access area. See Box 'Zonal Defence: Control and Access' for further details. The MR system is actually distributed between three of the rooms in the suite: the magnet room which houses the *magnet* and *coils*, an air-conditioned technical (computer) room which is full of supporting electronics and electrical plant, and the control room which contains the MR console.

You will spend most time in the control room at the MR scanner console: where you enter patient details, select and customise scan acquisition parameters, view and post-process images, archive images and send them to the **P**icture **A**rchiving

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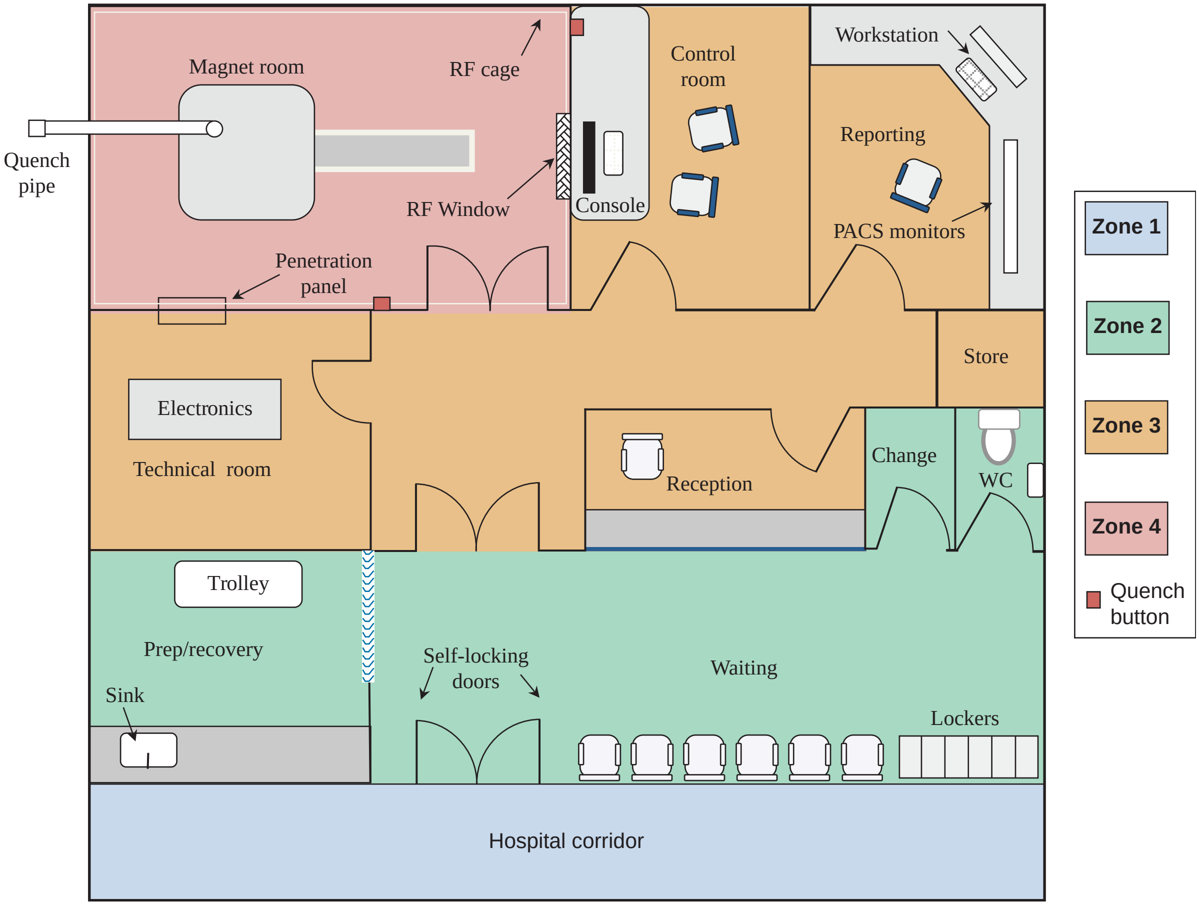

Figure 2.1 Typical MR imaging suite, showing Zones I to IV as defined by the ACR, and the controlled access area as defined by MHRA. Access to Zones III–IV and the controlled areas is strictly controlled.

and Communications System (PACS). As a trained member of MR staff you will have access to the magnet room (Zone IV) but others will not. See Box 'Can I Go In?'.

Zonal Defence: Control and Access

The **A**merican **C**ollege of **R**adiology (ACR) expert panel on MR safety recommends the designation of various zones for ensuring safe practice in MR units.

- *Zone I*: areas that are accessible to the general public, generally outside the MR environment completely.
- *Zone II*: the interface between the publicly accessible area (Zone I) and the areas where strict control and supervision are required (Zones III, IV). Patients may be screened in Zone II and will generally be under supervision.
- *Zone III*: a restricted access zone under the control of designated MR personnel (i.e. you!), physically demarcated from areas of greater access, with secure access only.
- *Zone IV*: the magnet or MR examination room itself.

These zones are indicated in Figure 2.1 through shading. In the UK, the **M**edicines and **H**ealthcare products **R**egulatory **A**gency (MHRA) defines the 'MR Environment' as that which encloses the entire 0.5 mT fringe field contour, to ensure no active implant malfunction. It recommends physical demarcation, secure and restricted access to the MR Controlled Area (similar to ACR Zones III and IV). This guidance is consistent with that from the **I**nternational **C**ommission on **N**on-**I**onising **R**adiation **P**rotection (ICNIRP) and other national bodies (see Further reading).

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Can I Go In?

Strict limitations are required as to which staff have access to the MR environment. The ACR designates personnel into various categories:

- *Non-MR personnel* includes all patients, visitors and non-MR staff.
- *Level 1 MR personnel* are members of staff who have received a basic level of MR safety education, sufficient to ensure their own safety in the MR environment.
- *Level 2 MR personnel* have more extensive MR safety training, relating to the hazards to patients, and would include MR technologists/radiographers and radiologists. As you are reading this book, it is assumed that you aspire to be a Level 2 staff member.

It is helpful to designate an MR Safety Officer who supervises day-to-day safety in the unit, and the MR Safety Expert who has more extensive knowledge for special or novel cases. The **I**nstitute of **P**hysics and **E**ngineering in **M**edicine (IPEM) has published guidance on the role, knowledge base and skills of the MR Safety Expert.

2.2.2 The Magnet

The magnet is the heart of the MR system. The size of an MR system is expressed in terms of its operating magnetic field strength. The scientific name of field strength is magnetic flux density or induction, and its unit is the *tesla* (T). You may also come across the *gauss* (G) as a measure of field strength. One tesla equals 10 000 gauss, i.e. 1 G equals 0.1 mT (millitesla). The Earth's magnetic field is approximately 0.05 mT (0.5 G).

The principal types of magnet used in MRI are:

- *superconducting magnets* – typically with fields of 1.5 or 3 T;
- *permanent magnets* – capable of sustaining fields up to about 0.3 T;
- *electromagnets* – capable of fields up to about 0.6 T.

The main field usually points horizontally along the bore (the opening where the patient goes). For superconducting and permanent magnets the magnetic field is *always* present; electromagnets are electrically powered and can have their field switched off; however, it is safer to assume that it is always on.

Superconducting magnets require liquid helium as a *cryogenic* cooling fluid. A sudden loss of superconductivity results in a magnet *quench* where the windings heat up, the field collapses in less than one minute and large amounts of helium boil off as gas. Accidental quenches are a rare occurrence in modern systems. In an emergency a quench can be initiated deliberately. In normal operation, small amounts of helium 'boil off' and are released into the atmosphere outside. The helium level is usually maintained by the manufacturer's service personnel. Figure 1.1 shows a typical superconducting system.

2.2.3 Radiofrequency Coils

The MR *signals* that provide the diagnostic information are produced within the patient's tissue in response to **R**adio**F**requency (RF) pulses. These are generated by a *transmitter coil* which surrounds the whole or a part of the body. A *body coil* is usually built into the construction of the magnet. For imaging the head or extremities, smaller transmitter coils are sometimes used.

The MR signals produced in the body are detected using a *receive coil*. The MR signals are very weak and are sensitive to electrical interference. Electromagnetic shielding is built into the magnet room (known as a Faraday cage) to minimize this interference. It is important to keep the magnet room door closed during scanning to maintain the effectiveness of the shielding.

All MR systems have a head coil and integral body coil. Other coils you may encounter include those for the spine, neck, knee, wrist, shoulder, breast, **T**emporo-**M**andibular **J**oint (TMJ), abdomen, and also peripheral vascular and other general-purpose flexible coils. You can actually use any coil to obtain an image provided it encompasses the anatomical region of interest, but specialist coils, which fit closer and are smaller, usually do a better job.

Some coils are called *arrays* or *matrix coils*. This generally means they will produce better images than a non-array version of the same sort of coil. Array coils have multiple elements and you may have to select which of them you wish to scan with. Array coils allow the use of *parallel imaging* to reduce scan time.

You must store coils carefully. They are the one part of the MR system most prone to failure due principally to excessive or careless handling. Be

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Figure 2.2 Examples of coils: (a) head coil, (b) knee coil, (c) shoulder coil, (d) torso coil. Courtesy of Siemens Healthcare.

careful when connecting or disconnecting the coils: all the MR signals have to go through the coil connectors, so treat them with due respect. Examples of coils are shown in Figure 2.2.

2.2.4 Imaging Gradients

The localization of the MR signals in the body to produce images is achieved by generating short-term variations in magnetic field across the patient. These are commonly referred to as the *gradients*. The strength of steepness of the gradient is measured in milli-tesla per metre (mT m^{-1}) and the magnitude of the gradient magnetic field is in the region of tens of mT, much smaller than the main B_0 field. There is one set of *gradient coils* for each direction, x, y, z, built into the bore of the magnet. The gradients are applied repeatedly in a carefully controlled *pulse sequence*. They generate loud tapping, clicking or higher pitched beeping sounds during scanning, like a loudspeaker. Ear protection is usually required for the patient or anyone remaining in the room during scanning – you can hear the gradients, even though you can't see them!

2.3 Safety First

Although MRI has no known long-term or harmful biological effects, the MRI environment is potentially very hazardous to both patients and staff if metal objects get pulled into the magnet bore. It is imperative that any person responsible for their own safety

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or the safety of patients undergoing an MRI investigation is aware of the risks associated with taking metallic objects into the vicinity of an MRI magnet.

2.3.1 Will I Feel Anything? Bio-Effects

Unlike other medical imaging modalities, such as X-rays and CT, MRI is non-ionizing, and there is no evidence that it can cause cancer or any other disease. Biological effects of magnetic field exposures are examined in more detail in Chapter 20.

As staff you will be primarily exposed to only the static field. There are no known hazardous bio-effects for this, although some mild sensory effects may be experienced around high-field magnets. Your patients will be exposed to the main static field, the imaging (time-varying) gradient fields and RF fields. In extreme cases, the gradients can induce *peripheral nerve stimulation*. This may be alarming or annoying, but it is not harmful. The main effect of RF is the heating of tissue; however, the scanner does not let you exceed certain values of RF exposure or **S**pecific **A**bsorption **R**ate (SAR) – see Box 'Modes and Options'. Sometimes you may need to alter the scan parameters to keep within the permitted values. Care is required to avoid the potential for RF burns when electrodes for physiological monitoring are used in the scanner. See Box 'Burning Issues'.

Modes and Options

The international standard for the safety of MR equipment intended for medical diagnosis is the **I**nternational **E**lectrotechnical **C**ommission (IEC) 60601-2-33. IEC 60601-1 is the general standard for the safety of medical electrical equipment. An important aspect of the IEC standard is the establishment of three operating modes:

- *normal mode* – requires only routine monitoring of the patient, the usual mode of operation;
- *first-level controlled mode* – requires medical supervision and a medical assessment of the risk versus benefit for the patient having the scan;
- *second-level controlled mode* – requires an approved human studies protocol. Security measures, e.g. a lock or password, are provided to prevent unauthorized operation in this mode.

These modes confine the SAR and imaging gradients to certain levels, considered further in Chapter 20.

The **F**ixed **P**arameter **O**ption: **B**asic (FPO:B) was developed jointly by MRI equipment manufacturers and implant manufacturers, and implemented as IEC TS10974. When available, the FPO:B will restrict the scanner's RF and imaging gradient output to levels that are within the conditions for that device, if it has been manufactured to comply with the standard. Not all active devices will comply, and great care is still needed for implanted cardiac devices and deep brain and other neurological stimulators.

Burning Issues

There is a small risk of patients receiving burns through the coupling of RF energy into wires or cables, such as those used for **E**lectro**C**ardio**G**ram (ECG) triggering, that are touching the patient. Care must be exercised in ensuring that cables are not formed into loops, that dry flame-retardant pads are placed between cables and the patient and that any unnecessary cables are removed from the patient prior to imaging. All cables should also be inspected every time before use to ensure that there is no damage to the insulation. Furthermore, only ECG cables specifically deemed MR safe should be used. Insulating pads should be placed between the patient's legs, if bare, and against their shoulders and upper arms if touching the side of the bore.

The MR scanner is very noisy during operation, often exceeding safety guidelines. It is recommended that all patients and any other person in the room during scanning are given ear-plugs and/or ear-defenders to reduce their exposure to acoustic noise.

Potential hazards of working with cryogens include asphyxiation in oxygen-deficient atmospheres, cold burns, frostbite and hypothermia. Additionally there is the possibility of inducing asthma in susceptible persons if cold gas is inhaled. Resist the temptation to touch the feed pipes just after a helium fill to see how cold they get! Contact with cryogens should be restricted to fully trained engineering staff.

Adverse reactions to common MR contrast agents, injected into the patient to provide better diagnostic information, are rare. However, for proper safety, there should be a 'crash trolley' in the MR suite with appropriate resuscitation equipment and drugs, ideally made of non-magnetic material so that it can be taken into the magnet room in an emergency. It is recommended that a trained physician is nearby

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whenever Gd-based agents are being used. Restrictions on the use of contrast agents may apply during pregnancy and for nursing mothers. Hazards associated with contrast agents are considered in Chapter 20.

2.3.2 Beware: Strong Magnetic Field

The primary hazard associated with the static magnetic field arises from forces on ferromagnetic objects. The magnetic field extends beyond the physical covers of the scanner, referred to as the *fringe field* – see Figure 2.3. The strength of the fringe field decreases rapidly with distance, but this *static field spatial gradient* is responsible for the attractive force. If a ferromagnetic object, e.g. one containing iron or steel, is introduced, it will experience a force. If sufficiently close, this can turn the object into a dangerous projectile. Items such as scissors could become deadly and even a coin could inflict serious damage or injury. The bigger the object, the stronger the force involved. There has been one known death of a patient caused by an oxygen cylinder being inappropriately taken too close to the magnet. The location of the maximum value of the spatial gradient, and therefore the greatest attractive force, is usually close to the *bore entrance*, around the rim.

Even in the absence of a static field change, any ferromagnetic object will twist with a force considerably greater than its mass in an attempt to align its long axis with the static magnetic field lines of force. This twisting force is called *torque* (see Box 'Force Fields'). It will be greatest within the magnet bore.

This ability to twist objects and to turn them into high-velocity projectiles presents a major risk to both staff and patients within an MRI unit. In modern MRI systems the stray field may decrease very rapidly with distance: an object that does not appear to demonstrate ferromagnetic properties as you approach the magnet may suddenly be torn from your grasp or pocket as you take one further step closer. By the time you feel it, it's already too late, so be very careful at all times!

Some MR sites employ either hand-held or static metal detectors. It is important to know whether any device employed in your institution detects all metals, or (preferably) only ferromagnetic ones. It is also essential to appreciate that such devices are simply tools to supplement MR safety practice and should never replace thorough screening of the patient by a person competent to do so. The key to MR safety in this respect is to be acutely vigilant at all times. Metallic objects taken into the bore of a magnet may at worse cause serious injury or death and at best may produce unwanted artefacts on the images.

In the vast majority of MRI systems (those with superconducting or permanent magnets), the magnetic field *is always present*, even when the electrical power is switched off. Therefore *everyone* entering the magnet room should be carefully screened, using a checklist and/or detailed questioning, to ensure they do not have any contraindications to MRI either internally or about their person. This includes the patient's relative(s), friend(s) or other staff who may enter the MR scanner room to assist the patient.

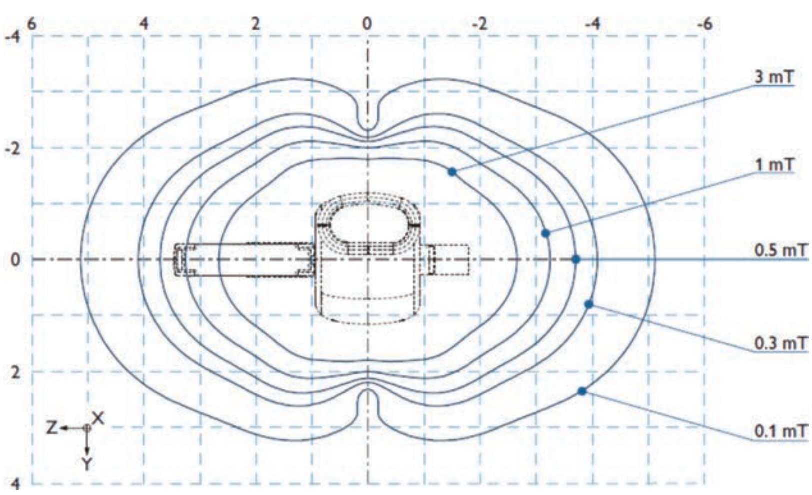

Figure 2.3 Fringe field contours for a typical actively shielded 1.5 T MRI magnet. Courtesy of Philips Healthcare. Each square represents 1 m^2. The field contours will be three-dimensional.

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The fringe field can also interfere with the operation of nearby equipment, as detailed in Table 2.1.

Force Fields

The translational force (F) on an unsaturated object volume V with magnetic susceptibility χ is proportional to the product of the static field (B) and its spatial gradient:

$$F \propto \chi V B \cdot \frac{dB}{dz}$$

where dB/dz is the rate of change of B with position (z). F gets stronger the closer you are to the opening of the magnet bore. Once a ferromagnetic object becomes saturated, i.e. fully magnetized, the maximum force is simply proportional to the fringe field gradient dB/dz.

If an object is elongated in any way it will experience a twisting force or torque (T) aligning it with the field proportional to the square of the static field. The force depends upon the angle the object makes with the field direction

$$T \propto \chi^2 V B^2$$

An elongated ferromagnetic object may experience a torque even in a uniform field. This is extremely important for implanted objects, e.g. aneurysm clips.

It may be necessary for a patient to be moved quickly from the scanner room, either for an emergency procedure, such as resuscitation, or because of a situation related to equipment failure, for example in the event of a magnet quench. Local safety rules will detail the evacuation procedures for various emergencies. As a general rule, when a patient needs resuscitating or other emergency treatment, the priority is to get the patient out of the scanner room as quickly as possible. This is because arriving emergency personnel, who may not understand the dangers of the strong magnetic field, can unintentionally make matters worse by bringing MR-unsafe ferromagnetic equipment (stethoscopes, laryngoscopes, oxygen tanks, metal crash carts, etc.) into the scanner room. Remember that not all clinical staff have your level of knowledge of MR safe behaviour.

2.4 Safety Second: Additional Practical Guidelines

Implanted ferromagnetic items such as vascular aneurysm clips may also experience these forces and torques. There has been at least one reported death of a patient scanned with a ferromagnetic aneurysm clip that moved, rupturing the blood vessel, as they were moved into the magnet. Similar hazards arise with patients who may have metallic foreign bodies located in high-risk areas such as the eye. Alternatively, the function of **A**ctive **I**mplanted **M**edical **D**evices (AIMDs) such as pacemakers or cochlear implants may be severely impaired by the static magnetic field and persons with pacemakers are normally excluded from the 0.5 mT fringe field. The same rules apply to any pieces of medical equipment that may also need to be taken into the room; for example, a pulse oximeter for monitoring a sedated patient. Devices such

Table 2.1 Maximum fringe field values and minimum distances to avoid interference on device operation

Fringe field (mT)	Item	Minimum distance (m) 1.5 T		Minimum distance (m) 3 T	
		On axis	Radially	On axis	Radially
10	Oxygen monitors, laser imager	2.2	1.6	2.6	1.8
3	Magnetic media, LCD displays	2.8	2.0	3.3	2.2
1	Computer hard disks, X-ray tubes	3.4	2.2	4.3	2.7
0.5	Conventional pacemakers	4.0	2.5	4.6	2.6
0.2	CT scanners	4.9	3.0	5.6	3.2
0.1	Gamma cameras, image intensifiers, PET scanners	5.6	3.3	6.8	3.9
0.05	Linear accelerators	6.8	3.9	8.2	4.6

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as these must be designed to operate safely within the MR environment. Older devices labelled as 'MR compatible' may have a maximum operating proximity to the magnet and care must be taken that the device is not moved any closer.

This book is not intended to give comprehensive advice on the MR safety of medical devices, since this is covered in great detail in specialized books and on the internet (see Further reading at the end of this chapter), but the following provides a general overview. You must check your institutional polices to know which patients you may scan and what additional checks are required to do so.

2.4.1 Contraindications and Caution

MRI examinations are usually contraindicated for patients with:

- conventional cardiac pacemakers or implanted cardiac defibrillators;
- abandoned cardiac leads;
- cochlear implants.

MRI examinations require particular caution in the following cases:

- patients with implanted *surgical clips* or other potentially ferromagnetic material, particularly in the brain;
- patients with *AIMDs*, e.g. neuro-stimulators, MR conditional cardiac placements, ingested endoscopic cameras;
- patients who have engaged in occupations or activities that may have caused the accidental lodging of *ferromagnetic materials*, e.g. metalworkers, or anyone who may have embedded metal fragments from military duties;
- *neonates* and *infants*, for whom data establishing safety are lacking;
- patients with *tattoos*, including permanent eye-liner;
- patients with compromised *thermoregulatory systems*, e.g. neonates, low-birth-weight infants, certain cancer patients;
- patients with *prosthetic heart valves*;
- *pregnant patients*: although no MRI effects have been found on embryos and fetal MRI is performed in specialist centres, many units still avoid scanning pregnant women during the first trimester. The unknown risk to the fetus must be weighed against the alternative diagnostic tests, which may involve ionizing radiation.

The screening process should identify any of these issues. Aspects relating to the safety of gadolinium-based contrast agents are considered in Chapter 20.

2.4.2 Dealing with Implants

A passive implant is one that has no requirement for electrical power, e.g. a titanium hip joint. The usual conditions for these relate to magnetic forces (attraction and torque) and RF heating (SAR). Box 'Good Metal, Bad Metal' contains information about the magnetic properties of common metals.

Active implants or AIMDs are those that utilize electrical power, either through in-built power supply (batteries) or through coupled external supply (e.g. using RF energy). Examples include pacemakers, neuro-stimulators such as deep brain stimulators or vagal nerve stimulators. Active implants pose the additional risks of malfunction, modification of their operating mode, inhibition, unintended stimulation or permanent damage. Also there are increased risks of excessive heating in any internal leads. Active implant conditions will also often include a maximum imaging gradient slew rate (T m^{-1} s^{-1}).

In every case, be aware of local practice and policies and check that your scanner and protocol satisfies the conditions before introducing the patient to the magnet environment. Be wary of such statements as 'I've had a scan before and it was fine', as all scanner models are different; an uneventful previous scan does not necessarily mean that a particular device is safe in all other scanners.

A system for categorizing the risk from implants has been developed by the **A**merican **S**ociety for **T**esting and **M**aterials (ASTM), regulated by the **F**ood and **D**rug **A**gency (FDA) in the USA, and incorporated into the standards of the **I**nternational **E**lectrotechnical **C**ommission (IEC). This categorizes implants and other devices as either *MR safe*, *MR conditional* or *MR unsafe*. The internationally recognized symbols for each category are shown in Figure 2.4.

MR safe means that the device or object poses no additional risk in the MR environment. For example, it may be that it is non-metallic. It may, however, result in image quality degradation if it is within or close to the imaging **F**ield **O**f **V**iew (FOV).

MR conditional forms by far the largest group of implanted medical devices. Patients may be scanned safely subject to compliance with certain specified

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Figure 2.4 MR symbols as defined by standard ASTM F2503 and IEC 62570:2014.

conditions. These usually include the maximum static field strength (T), the maximum static fringe field gradient (T m^{-1} or G cm^{-1}) and the maximum time-averaged SAR. See Box 'Working Conditions' for an example of MR conditions and further explanation. Sometimes other conditions apply – for example, an anatomical or positional restriction, or a specific coil to be used. Remember that even if you comply with all the MR conditions, metal objects will cause image artefacts in the region of the implant.

MR unsafe devices or objects must never be introduced into the MR environment.

Working Conditions

Typically the wording on MR conditions may contain something like the following:

> *'Non-clinical testing has demonstrated that the Company X Implant model number Y can be scanned under the following conditions:*
>
> > *Static magnetic field of 3 tesla or less*
> > *Spatial gradient of 720 G cm^{-1} (7.2 T m^{-1})*
> > *Maximum whole-body-averaged specific absorption rate (SAR) of 2.0 W kg^{-1} for 15 minutes of scanning.'*

The static field condition is easy to interpret, although note that not all implants have been tested at 3 T.

The second and third conditions often cause confusion. The maximum spatial gradient refers to the static fringe field spatial gradient. The condition means that the device has exhibited a magnetic force less than the force due to gravity in the stated fringe field gradient. Note that units quoted vary and that 1 T m^{-1} equals 100 G cm^{-1}. Plots of fringe field gradients are shown in Figure 2.5. Each manufacturer presents this information in different ways, so it is important that you understand how to interpret it for your scanner.

The SAR condition relates to potential heating (in a non-clinical test phantom). Note that 15 minutes is the time per sequence, and does not relate to the maximum time you can scan. In the USA, SAR used to be averaged over a 15 min period, whereas, elsewhere under the IEC guidelines, SAR is calculated over every 6 min period. Often the SAR limitation condition restricts scanning to the Normal Mode (see Box 'Modes and Options').

Good Metal, Bad Metal

There are three major categories of magnetic properties for materials, each characterized by their magnetic susceptibility, often denoted by the Greek letter χ.

- *Diamagnetic* materials have a small, negative susceptibility. This means that the force, although tiny, is repulsive. Water and most biological tissues are diamagnetic with values less than 10^{-5} (0.00005).
- *Paramagnetic* materials have a slightly larger and positive susceptibility. Example materials are oxygen molecules and ions, such as gadolinium. Values range from 10^{-5} to 10^{-2}. The attractive forces on paramagnetic or even weakly ferromagnetic materials are small.
- *Ferromagnetic* materials have large positive χ. For example, iron has values in the range 1000–10 000 depending upon how it is produced. Some stainless steels are ferromagnetic. The large susceptibility means that magnetic forces and torques will be very strong. Some metals used for implants, e.g. 316LV or surgical stainless steel, titanium, and some metal alloys, e.g. cobalt–chromium–molybdenum alloy, nitinol, are only weakly or non-ferromagnetic. These would not be expected to be displaced in the magnet, especially after six weeks from implantation.

Figure 2.6 shows the range of materials in the susceptibility spectrum.

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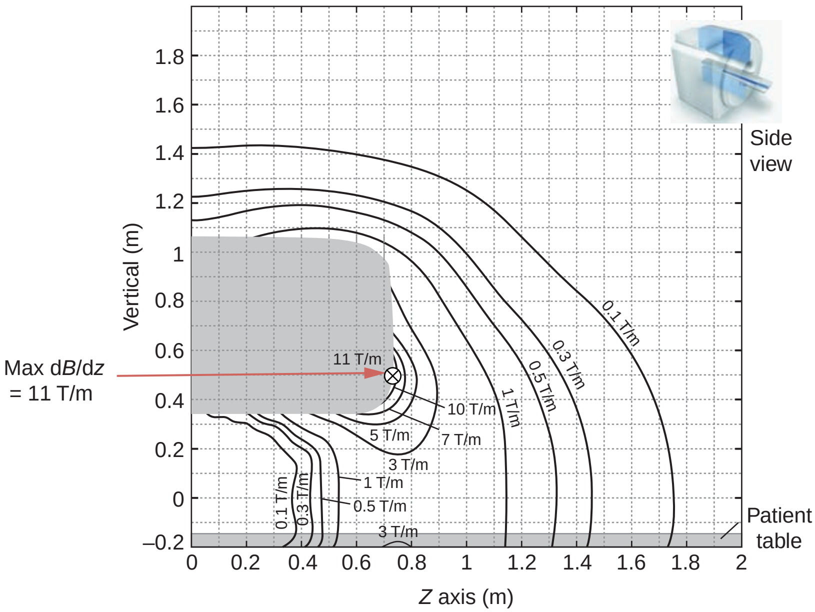
(a)



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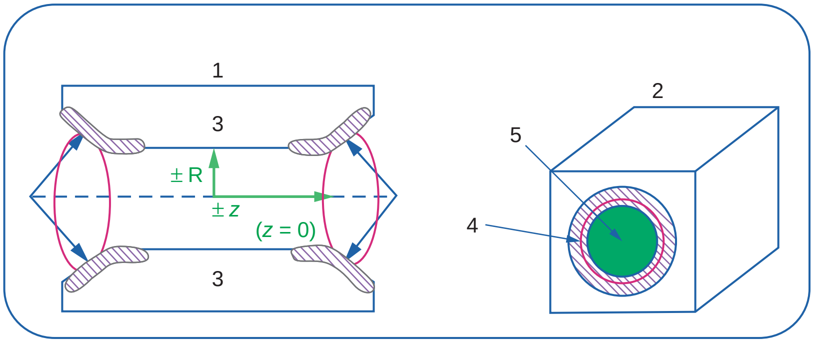

Parameter	Radial location R (m)	Location along Z (m)	B(T)	Grad (B) (T/m)	Max (B) * grad (B) (T^2/m)
Peak B	0.35	0.64	3.9	7.2	28.2
Peak gradient	0.51	0.92	0.92	12.4	22.6
Peak product	0.36	0.73	3.6	10.7	38.7

Figure 2.5 Static fringe field gradients (a) Contour plots for a Siemens Aera 1.5 T scanner. The plot shows one quadrant with the origin (0,0) being the isocentre of the magnet. (b) Diagram and table showing maximum values of dB/dz and its product with B for the GE Healthcare MR750w 3 T scanner. (c) Iso-gradient surfaces from a Philips Achieva and Intera 1.5 T scanners. Each contour represents a cylinder with the maximum spatial gradient indicated. For ease of interpretation, the patient couch is also shown.

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(c)

Achieva and Intera 1.5T		
	T/m	Gauss/cm
On patient axis	2.5	250
Cylindrical shape of 20 cm diameter	2.6	260
Cylindrical shape of 30 cm diameter	2.8	280
Cylindrical shape of 40 cm diameter	3.1	310
Cylindrical shape of 50 cm diameter	3.6	360

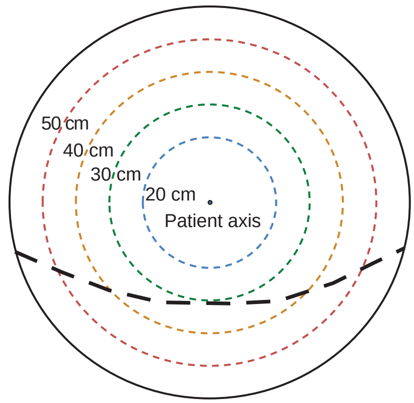
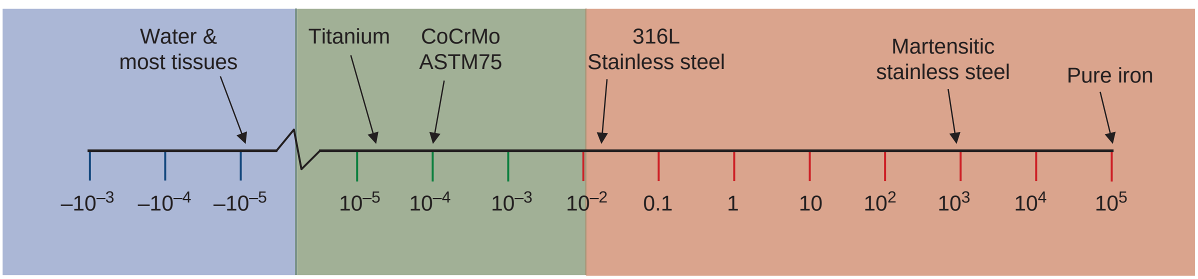


Figure 2.5 *(cont.)*



Diamagnetic

- Susceptibility small, negative
- water, most organic molecules
- 'non-magnetic'

Paramagnetic

- Susceptibility small, positive
- ions, metal salts, O_2, Gd
- affect relaxation times

Ferromagnetic

- Susceptibility large, positive
- e.g. iron
- 'magnetic'

Figure 2.6 Magnetic susceptibility spectrum.

2.5 The Patient's Journey

Patient cooperation is essential for obtaining high-quality images, and their initial chat with MR staff can make all the difference. All patients require counselling to explain the nature of the examination and must complete a questionnaire to assess their suitability and safety for being scanned. This should take place in an appropriate quiet and private place. During this interview you should also follow your institutional identity policy, confirming you have the right patient and body region to be scanned. Pay particular attention where 'left' or 'right' is specified on the request form as this is a common source of error. Sometimes it's helpful to mark the area to be scanned with a vitamin E or cod liver oil capsule to ensure correct positioning. This is useful when you are scanning someone with a moveable 'lump', especially the ones which are there one minute and gone the next!

Patients need to remove all metallic objects, jewellery, watches and credit cards, which can be stored in lockers. Locker keys should be non-magnetic to be safe in the magnet room. Local policy will determine whether patients should undress and wear a gown for the examination. The inconvenience and extra prep time should be balanced against the

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common problem of 'finding' metal in items of clothing, e.g. in zips and underwires, when the patient is in the magnet. Non-ambulatory patients will be transferred to non-ferromagnetic, MR-safe trolleys or wheelchairs prior to being taken into the MRI examination room. Many MR systems incorporate removable patient couch systems or table-tops to allow for efficient and comfortable moving of bed-bound patients.

The patient will usually be weighed before entering the scanner. This is required to enable the scanner to operate with a safe level of RF exposure (see Chapter 20). On some scanners, the patient's height may also be required for the SAR calculation. Patient details will be registered on the scanner either manually or from a **H**ospital or **R**adiology **I**nformation **S**ystem (HIS/RIS) worklist.

Choose the coil most suitable for the examination. This should completely cover the area to be scanned. Position the patient on the couch as appropriate to the examination and ensure their comfort before positioning any additional coils that are required. Ensure the patient does not provide unnecessary conduction loops, for example, by clasping their hands together, or crossing their ankles. Insulating padding to prevent their thighs touching is also recommended. Ensure that the patient inserts ear plugs appropriately or wears ear defenders. Give them the hand-held alarm button, and position any other comfort devices such as mirrors or headphones. Maximizing patient comfort and relieving anxiety is essential to the success of the examination.

Use the scanner's positioning lights or lasers to indicate (or 'landmark') the centre of the region to be scanned. Select the desired position. Then ensuring the patient is comfortable, move the scan region to the magnet iso-centre (usually carried out automatically on a single button press). It is important to ensure the scan region is positioned at the isocentre as this is the location or 'sweet spot' where the magnetic field is most uniform (or homogeneous) and will produce the best image quality. 'Landmarking' on the region of interest allows the scanner to place this anatomy at the very centre of the magnet (the *isocentre*). This is the 'sweet spot' with the best magnetic field uniformity or *homogeneity*, thereby ensuring highest image quality. After landmarking the initial scan position using the laser light guides, the couch is moved into the centre of the magnet.

As the couch moves into the scanner the patient may show signs of claustrophobia, or may not fit, especially in older 60 cm bore scanners. Reposition the arms if necessary to fit comfortably and place thin pads between the elbows and the scanner. In exceptional cases you may need to ask the patient to put one or both arms above their head, to fit the bore. Be sure to scan these patients as quickly as possible, and bring them out of the magnet to rest the arms by the side if you have delays. Once the patient is comfortably positioned at the isocentre, staff can leave the scanner room, making sure to close the door properly to prevent external RF interference.

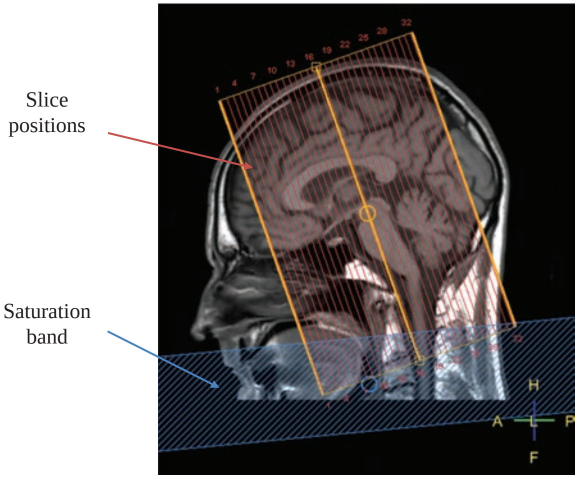

Figure 2.7 Quick localizer or scout scan for planning. Slice positions are shown as lines. A regional saturation band is also shown.

Initially a set of localiser or positioning scans is performed (Figure 2.7). These give a quick, low-resolution, overview which is then used to plan the diagnostic scans on the region of anatomy under investigation. The positioning of slices and saturation bands is usually prescribed graphically using these scout scans. The diagnostic scans or sequences can often be queued to run automatically, leaving you free to do other tasks on the console such as post-processing or archiving.

All patients need to be observed during the examination, either through the observation window from the control room or by closed-circuit TV. An intercom enables two-way audible communication between the patient in the magnet and the control room. At some point during the examination, the administration of an MR *contrast agent*, usually a gadolinium compound, to the patient may be required. Since gadolinium alters the image contrast, gadolinium-enhanced imaging is always performed towards the end of the examination. Local policy may allow a radiographer or nurse to give this injection; however the radiologist always has medical responsibility for the patient.

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During an MRI examination, the patient may be fully conscious (this is the norm), naturally asleep (e.g. for infants), sedated or anaesthetized. In the latter instances they may require life support and physiological monitoring, e.g. ECG and pulse oximetry. There is a small risk of patients receiving burns through the coupling of RF energy into wires or those used for ECG monitor or triggering, that are touching the patient. Care must be exercised in ensuring that cables are not formed into loops, that dry flame-retardant pads are placed between cables and the patient and that any unnecessary cables are removed from the patient prior to imaging. All cables should also be inspected every time before use to ensure there is no damage to the insulation. Furthermore, only ECG cables specifically deemed MR safe should be used.

After the examination the patient will be escorted from the magnet room and will need to retrieve their personal possessions. If the patient feels unwell due to the contrast agent injection or claustrophobia, it is advisable to have them remain in the MR unit where they can be observed to ensure their well-being before leaving. The reading or reporting of the scans by a radiologist usually occurs later, often via PACS where the radiologist returns his/her findings to the referring physician. The patient will usually have a follow-up appointment with the physician to discuss the diagnosis and follow-up tests or treatment.

That completes the patient journey, as far as their MRI is concerned. Now it's over to your journey. In the next section we take a look into the life of an imaginary radiographer.

2.6 MRI Radiographer's Blog … A Few Years On

A scarily all-true but slightly tongue-in-cheek description of the typical working pattern in a busy MRI unit, with apologies to other better known diarists. For Emma's earlier adventures, please see older editions of the book. Note, we as authors do not necessarily condone Emma's behaviour or level of MR knowledge.

See also

- Let's talk technical: MR equipment: Chapter 10
- But is it safe? Bio-effects: Chapter 20.

MONDAY

Weight	+0.2kg from what I was expecting (you didn't think I was going to reveal my true weight, did you?)	Helium level	79.3%
Alcohol level	5 units (it was the weekend after all)	B_0 exposure	5.2 mT-hours (time-weighted average)
Twitter followers	0	Tweets/retweets	0

I found my old diary, so in keeping with the times, I decided to start a blog.

It's been a while. Not such a newbie to MRI. Older, wiser, less naive. Not drinking so much. Not exactly fitter, or healthier. Completely adapted to the MR environment, I empty my pockets every time I go near an x-ray room! Better safe than sorry.

Sorted my Twitter profile name (Yes, am going to be a Modern Person, a social medium, a Twit?). It's @Em_are_I. Genius! Was inspired by the IT help-desk call centre person who once asked when our network was down, 'How do you spell MRI?' ROFL.

TUESDAY

Weight	still plus 0.0 kg, or maybe I should say minus 0.0 kg	Helium level	79.3% (zero boil-off scanner, but old habits die hard)
Alcohol level	2 units (good for a Monday night)	B_0 exposure	7.3 mT-hours
Twitter followers	0	Tweets/retweets	1 (see below)

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@Em_are_I: Hello twittersphere

Worked on new 3 T scanner! Very exciting. Tried to get visual phosphenes by shaking my head madly round the back of the magnet but got told off by colleague who said, 'Don't do that, Em, you're upsetting the patients, and you'll get mag lag.'

'Mag lag?' I replied, 'What's that?'

'OMG! You've forgotten?' she shrieked. 'You've got it already!'

Hmm, I don't believe this 'mag lag' business. I think I'll see what *Picture to Proton* has to say about it. (author's note: see Chapter 20)

WEDNESDAY

Weight	plus 0.1 kg	Helium level	79.3%
Alcohol level	3 units (on target for the week)	B_0 exposure	23 mT-hours (on account of - see below)
Twitter followers	0 (where are you all? I'm interesting!)	Tweets/retweets	1

OMG MRI incident! No one hurt, thank goodness. Was scanning an old codger. We'd gone through the MR safety check. Pacemaker? No. Aneurysm clip? No. Recent surgery? No. Etc, etc.

'Have you got anything in your pockets,' I asked, 'Cards, money?'

'Only Paper Money?' He replied.

'Good', I say. So I position him on the table, head first, and am just putting him in the scanner when...
ZIP! WHAM! A shower of shiny objects flashes past my ear as a pocketful of coins embed themselves into the magnet, our lovely new (not quite so) shiny 3 T magnet. I checked he was all right and took him out, saying, 'I thought you said you had no money in your pockets?' I was quite shaken.

'Yes, paper money,' he said unperturbed, as if this was a daily occurrence, 'you know, for my daily newspaper.'

Took ages to pry the coins off. And scratches all over our lovely scanner.

Later on I tweeted *@Daily_News how stupid are you're readers?*

THURSDAY

Weight	plus 0.3 kg (the MR scales over-weigh – it's a safety feature)	Helium level	78.9%
Alcohol level	9 units (price you pay for cyber-celebrit /MR safety anxiety)	B_0 exposure	5.2 mT-hours
Twitter followers	151	Tweets/retweets	10,093
		Apostrophe misuse	1

Got trolled by 10,092 Daily News readers on Twitter. How stupid am I? This one's typical (and polite, relatively):

@Em_are_I you're profile sucks Em_am_I! #grammar #init

I blame the iPhone auto-spell. Still, at least I picked up some followers, but I don't want them to follow me if they think I'm an idiot.

So the new scanner ... I was concerned about the patients heating up because it was going to the First Level almost all the time. And I am a bit disappointed by the image quality. So I called the applications specialist. 'You said a hundred percent more SNR,' I accused.

There was a long pause. 'Erm ... We said a hundred percent more *SAR*, not SNR.'

Really? Can one letter make that much difference? Time for another MR physics course?

Authors' note: theoretically twice the SNR (for the same bandwidth and T_1/T_2) and four times the SAR.

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FRIDAY			
Weight	minus 0.2kg (sometimes I do believe the MR scales)	Helium level	78.9%
Alcohol level	0 units (post hangover dry night)	B_0 exposure	3 mT-hours
Twitter followers	152	Tweets/retweets	2 (thank goodness! I've had my fill of virality)

Browsing through Twitter, I saw a patient had just published his scans on Instagram. What's *wrong* with these Gen-Y people? Oh I see … meniscal tear! At least he didn't put a sepia filter on the images (#hipsterscan).
Tweet of the day: *so I went in for a #MRI scan for my shoulder, and they diagnosed me with claustrophobia! #medicalgenius*
Scanned a patient with an MR Conditional pacemaker this afternoon. Scary! And Fridays are meant to be relaxing! Monitored his ECG. Hated the way the scanner interference looked like violent arrhythmias! And the cardiac tech was happily chatting about his holidays, like a hairdresser, all nonchalantly. Relieved when the patient walked out smiling. He didn't seem worried at all. It's great for the patients, but it sure does add an edge to MR safety. Must remember to search Twitter with hashtag *#MRIsafety*.

SATURDAY			
Weight	Don't care. It's the weekend.	Helium level	Don't care. It's the weekend.
Alcohol level	Ditto	B_0 exposure	Ditto
Twitter followers	155 (up three!)	Tweets/retweets	2

What a week! But Sunday is my fun day. Still undecided about the MRI course. Maybe I'll just buy the new edition of *MRI from Picture to Proton*. I see they're on Twitter too…
@MRI_p2p I love that diary thing you do. I wish I could be in it. #dreamscometrue

Further Reading

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