



PROVISION OF ANAESTHETIC SERVICES IN MAGNETIC RESONANCE UNITS

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Section I: Summary

1. The continuous presence of a strong magnetic field, and restricted access to the patient, means that the provision of anaesthesia within MR units presents unique problems.
2. Whenever a new MR unit is planned, the possibility of managing sedated or anaesthetised patients should be considered.
3. In the planning process, adequate space should be made available for the provision of anaesthesia services.
4. A nominated consultant anaesthetist should be responsible for anaesthesia services in MR units.
5. The level of assistance for the anaesthetist must be equal to that expected in the operating theatre environment.
6. Immediate access from the scanning room to the anaesthetic preparation/ resuscitation area is essential as in the event of an emergency, the patient must be removed from the magnetic field without delay.
7. Anaesthetic equipment that is used in the scanning room should be MR compatible.
8. The monitoring of patients in MR units during anaesthesia, sedation and recovery must comply with minimum monitoring standards.
9. It is essential that a remote monitoring facility is available to allow the anaesthetic team to remain outside the scanning room once the patient's condition is stable.
10. Only authorised personnel, who have received appropriate training and are fully conversant with the local protocols, are allowed to enter the controlled area unsupervised.
11. Resources should be provided to minimise the risk of personal exposure to strong magnetic fields and noise levels.

Section II: Introduction

Magnetic resonance imaging (MRI) is now a routine investigation for many conditions. The continuous presence of a strong magnetic field, and restricted access to the patient, means that the provision of anaesthesia within MR units presents unique problems. Some patients, e.g. children and adults with movement and learning disorders or claustrophobia, are unable to lie still during the MR scan and consequently sedation or general anaesthesia is required. Patients requiring general anaesthesia are often difficult to manage e.g. rare paediatric syndromes and critical care patients.

At the end of 2001 in Great Britain and Ireland there were approximately 3.9 MR units per million head of population while the average ratio throughout the rest of Europe was approximately 5.5 MR units per million. In order to reduce waiting lists for MR scans, there is a need for investment in new and replacement MR systems. Some of these may be located in hospitals that currently do not provide anaesthesia for MR examinations.

This document aims to assist anaesthetists in the planning and provision of anaesthesia services in new and existing MR units. When planning for a MR service, radiologists, radiographers, referring clinicians and managers also need to be aware of the problems associated with the provision of anaesthetic care in MR units. When introducing a new MR service, it is important that funding is identified to cover the cost of anaesthetic equipment and associated personnel who are essential to the provision of anaesthetic care. This will be additional to the MR equipment costs. (see Appendix 1).

Section III: Planning

Whenever a new MR unit is planned, the possibility of managing sedated or anaesthetised patients should be considered. This will have specific staffing and equipment implications as well as significant effects on capital and revenue costs.

Building

NHS Estates have published guidelines relating to accommodation for MR units [1-3].

Input from an anaesthetist, early in the planning process, will ensure that adequate space is made available for the provision of anaesthesia services. While recognising that space is at a premium, the unit should be designed to allow patients to follow a logical progression through each area, with the appropriate level of privacy.

The MR unit should contain a **Controlled Area** that contains the 0.5mT (5 gauss) magnetic field contour. Only **Authorised Personnel** should have free access to the controlled area to which there should be strict control of access via self-locking doors.

Consideration of the requirements to provide adequate space for an anaesthesia service should occur during the design of the following areas:

- Reception area
- Waiting area and changing facilities
- Anaesthesia preparation/ resuscitation room
- Scanner room i.e. the **MR examination room or Inner Controlled Area**
- Control room
- Recovery area

The preparation area must be large enough to accommodate patients who arrive on a bed. Adequate space must be available for transfer of patients onto the scanning table. Anaesthesia should be induced on tables or trolleys with the facility to tilt the patient head-down. This may require transfer to a MR compatible trolley after the induction of anaesthesia.

It should be possible to observe patients from an area remote from the MR examination room e.g. through a window from the control room, where the radiographers operate the MR system. Once the patient's condition is stable in the scanner, the anaesthetist may choose to observe the patient and monitors from the control room.

There must be immediate access from the MR examination room to the anaesthetic preparation/ resuscitation area as it is essential that, in the event of an emergency, the patient be removed from the magnetic field without delay. Ferromagnetic equipment including oxygen cylinders, defibrillators or laryngoscopes must never enter the MR examination room because of the strong magnetic field.

Piped gases and suction will be required in the anaesthetic room, the MR examination room and the recovery area [4]. Adequate gas scavenging systems will also be necessary. The installation of facilities such as piped gases is easiest and least costly during the initial construction of the unit.

While it is recommended that the MR suite should be an integral part of a radiology department [1], all MR units must be self-sufficient in terms of dealing with emergency situations including cardiopulmonary resuscitation, anaphylaxis and difficult airway management. This has staffing, training and equipment implications. There should be an emergency call system in the MR examination room and telephones in the anaesthetic room and recovery areas.

Function

A meeting between MR staff and potential users of the unit should be convened at an early stage in the operational planning process. While this will indicate the probable case mix of adult and paediatric cases, it should be remembered that this is only accurate at the time of discussion. Experience has shown that there is potential for change after the scanner opens. It will also alert staff to problems associated with specific situations, for example, providing day case anaesthesia or sedation, the management and transfer of critically ill patients from intensive care units or children with difficult cardiorespiratory conditions. Children and their parents attending for a routine examination should be kept separate from critically ill patients.

Costs

The capital cost of MR compatible anaesthetic machines and monitoring equipment should be considered when planning the funding of new units. The revenue consequences of capital investment must be budgeted for and these include staffing costs, day ward facilities, consumables and service contracts for equipment. (see Appendix 1).

Section IV: Equipment

All equipment to be used within the scanning room should be passed and clearly labelled as either 'MR safe' or 'MR compatible'. Equipment is designated as **MR safe** if it presents no safety hazard to patients or personnel when it is taken into the MR scanning room, provided that instructions concerning its use are correctly followed. This does not, however, guarantee that it will function normally and not interfere with the correct operation of the MR imaging equipment, with degradation of image quality. Equipment that is designated as **MR compatible** is MR safe, functions normally in the MR environment, and does not interfere with the correct operation of the MR imaging equipment providing instructions concerning its proper use are correctly followed.

Clearly, all anaesthetic equipment that is used in the inner controlled area should be MR compatible but equipment that is only used in anaesthetic rooms and recovery areas need not be MR compatible.

It is vitally important that MR compatible equipment is easily distinguishable from standard equipment. The hazards associated with using the wrong equipment include the projectile effect [5], burns [6] and malfunction [7] e.g. non-MR compatible syringe drivers may deliver drugs incorrectly with significant effects on patient safety.

The initial designation of MR compatible equipment is the responsibility of the **Responsible Person**, but the day-to-day supervision of equipment entering the inner controlled area is the responsibility of the radiographer in charge of the MR session.

It is the responsibility of the equipment manufacturer to indicate the field strength to which their equipment is compatible. To date, most clinical MR scanners have had a field strength of 1.5Tesla (T) or lower. Recent technological developments mean that 3T MR scanners will become clinically available in the near future. It should not be automatically assumed that equipment that was MR compatible or MR safe at 1.5T, remains compatible or safe at 3T.

Monitors

The monitoring of patients during anaesthesia, sedation and recovery must adhere to previously published standards [8]. Suppliers of MR scanners may provide basic monitoring devices as part of the system. These include ECG and respiration monitors and are provided to facilitate the timing of certain types of image acquisition. It is recommended that separate anaesthetic monitoring equipment is available. Early MR compatible monitors may not include some parameters that are now considered essential e.g. inspired oxygen concentration and anaesthetic agent monitoring. These monitors will require replacement or upgrading to meet current recommended standards.

MR compatible pulse oximeters must use fibreoptic cabling to avoid burns and special ECG electrodes and cables are required. Padding should be placed between cables and the patient's skin and the avoidance of loops in cables within the scanner is essential. The responsibility for safe placement of monitoring devices and leads should be clearly and explicitly allocated.

It is essential that a remote monitoring facility is available to allow the anaesthetic team to remain outside the scanning room once the patient's condition is stable, should they wish to do so. This will require the provision of **waveguides** between the scanner and control rooms.

The MR environment will cause specific problems with ECG, capnography and temperature monitoring. Aortic blood flow in a magnetic field generates currents that result in significant artefact in the ST-T region of the ECG complex, and monitoring of ischaemia may present significant challenges. There may be a delay of up to 20 seconds in obtaining the capnograph signal due to the length of the sampling tubing. While investigational devices allow temperature monitoring, clinical monitors are only just beginning to provide this facility. The development of improved monitoring modalities will alter the achievable standard of clinical monitoring in MR.

The need for acoustic protection during MR imaging will necessitate the use of ear-plugs or ear defenders, and make audible alarms inappropriate. Clear visible alarms should be provided on all monitors when the attending anaesthetist is in the MR examination room with the patient. Anaesthetists remaining in the control room should have an unobstructed view of the remote monitor, anaesthetic machine and patient.

Anaesthetic machine

A MR compatible anaesthetic machine should be located within the scanning room. Only MR compatible vaporisers and gas cylinders must be used on anaesthetic machines within the scanner room. Any attempt to replace these with standard equipment will be extremely dangerous and is likely to cause a serious accident [9].

Section V: Personnel

A nominated consultant anaesthetist should be responsible for anaesthesia services in MR units. As well as suitably trained anaesthetists, the anaesthetic team will include nurses, operating department practitioners and technical support. The level of assistance for the anaesthetist must be equal to that expected in the operating theatre environment [10]. The potential to encounter unusual cases exists [11] and good communication between anaesthetic and radiological staff is vital.

All staff entering the MR unit must be aware of the local rules of that unit, which may be different to those at other MR installations. It is essential that there is a clear protocol that defines roles and responsibilities of all staff in the event of an anaesthetic emergency or resuscitation. All staff must be fully aware of this protocol e.g. the emergency medical resuscitation team should know not to enter the inner controlled area. Protocols must take account of the possibility of the MR unit being used outside routine working periods. Individual staff should be designated to be responsible for regular checking and maintenance of anaesthetic and resuscitation equipment.

All unauthorised staff entering the controlled area must first be medically screened, and must be under the supervision of an authorised person for the whole time that they remain in the controlled area. If their duties require them to enter the inner controlled area on a regular basis, they should undergo training and be aware of the local rules of that unit appropriate to their duties. Only authorised personnel, who have received specific training and are fully conversant with the local safety rules, are allowed to enter the controlled area unsupervised.

Section VI: Health and safety

Patient safety

Patient safety is a paramount consideration. Screening procedures to determine specific contraindications to MR examination are the responsibility of the radiologist and radiographer. The anaesthesia team should facilitate the adherence to strict protocols to prevent untoward events. This is particularly important in unusual situations e.g. critical care patients. Websites are available that indicate the compatibility of implanted devices [12].

The most commonly used intravenous contrast agent is dimeglumine gadopentetate (gadolinium DTPA). While there is an extremely low incidence of side effects, a severe anaphylactoid reaction has been reported [13]. Other side effects include nausea, vomiting and pain at injection. The recommended dosage is 0.2 ml.kg^{-1} body weight.

Staff safety

All staff entering the controlled area will be subject to the same safety screening procedures as the patients. The occupational hazards to which anaesthetists and their assistants may be subjected include exposure to:

- an intense magnetic field
- acoustic noise
- unscavenged anaesthetic gases
- possible hypoxia if quenching of a superconducting magnet occurs

Magnetic fields

The magnetic fields produced by MR scanners consist of:

- strong static magnetic field
- fast switching magnetic fields - **gradient magnetic fields**
- pulsed radiofrequency fields.

The switched gradient and radiofrequency fields are only present within or in the immediate vicinity of the magnet. The static magnetic field extends well beyond the confines of the magnet. The strength of this stray field depends on the configuration and **shielding** of the magnet, and falls rapidly as the distance from the magnet increases. Actively-shielded magnets are associated with more compact **fringe fields**. However, the sharp fall in magnetic field strength with distance implies a steep field gradient in the immediate vicinity of the magnet, which substantially increases forces on ferromagnetic objects that are inadvertently brought close to the magnet.

All those in close proximity to MR scanners may be at risk of injury from unrestrained objects exposed to intense static magnetic fields, the **projectile effect**. All staff should be fully aware of the implications of the projectile effect so that such items are not taken into the examination room [5]. There is further potential risk from the static magnetic field on any implanted ferromagnetic objects. These devices may move or malfunction if exposed to a magnetic field, with potentially fatal consequences, e.g. pacemakers, some aneurysm clips. The MR unit should have a policy for screening all individuals for the presence of such metallic implants and all anaesthetic staff should ensure that they are fully conversant with these requirements.

Sudden movement of the human body within intense static magnetic fields may cause very weak electrical currents to be induced in tissues causing symptoms such as nausea and vertigo from extraneous excitation of the semicircular canals of the inner ear or flashing lights by effects on the retina. However, there is currently no scientific evidence for a cumulative harmful effect of intense static magnetic field exposure on the human body.

Current recommendations for 'safe' levels of long term exposure to static magnetic fields of healthcare personnel are a time-weighted average of 200mT over any 8-hour period and should not be exceeded. This advice may change therefore personnel should refer to current edition of the MDA recommendations. [14].

Those who work in close proximity to MR scanners should be made aware of these safety levels. Risks may be small, but the current lack of evidence to suggest a harmful effect of cumulative magnetic field exposure does not exclude such a finding being made in the future. Individual workers should be provided with the resources to minimise the risk of personal exposure to magnetic fields as far as is reasonably achievable.

Acoustic noise

Significant levels of acoustic noise are produced during MR imaging due to the vibration of the switched gradient coils. The magnitude of the noise depends on the MR sequence and the strength of the magnet used. The trend towards higher strength magnets and stronger and faster switching gradient fields indicates that noise levels produced within MR scanners are likely to increase.

Noise at work regulations require employers to take actions to reduce noise exposure of employees when it is at or above 85dBA (average daily exposure) [15]. Some MR sequences produce noise levels above these safety levels. Individual MR units must undertake their own measurements and risk assessments. Remaining at a remote location, e.g. in the control room while the scan is taking place, will limit risks from noise exposure. Ear protectors should be provided if staff remain within the examination room during the scan. All patients, anaesthetised or non-anaesthetised, should be given ear protectors.

Scavenging of anaesthetic gases

The use of volatile anaesthetic agents and nitrous oxide in MR units must comply with the Control of Substances Hazardous to Health (COSHH) regulations [16]. MR compatible scavenging systems for use in the MR examination room are available.

Quenching of superconducting magnets

Quenching may occur due to a system fault or as a deliberate action to shutdown the magnetic field. There should be no hazard from this procedure provided that venting of the **cryogen**s to the outside is adequate. There is a potentially lethal hazard due to asphyxiation in oxygen-deficient atmospheres, if there is rapid evaporation and escape of the liquid helium that surrounds and cools the superconducting solenoid. Oxygen sensors should be located in the scanning room and relayed to the control room to warn of the possible hypoxic effect of escaped helium. Anaesthetists working in MR should be familiar with the emergency procedures in the event of a quench being necessary.

Occupational hazards for female staff of childbearing age

For pregnant female staff working within MR scanning rooms, there are the additional concerns of exposure of the fetus to magnetic fields, acoustic noise and unscavenged anaesthetic gases. The current guidelines in the UK from the MDA state that, until further evidence is available, it is prudent not to scan patients in the first trimester of pregnancy [14]. In the case of female staff in the first trimester of pregnancy, the MDA guidelines state that 'it might be prudent to give them the option of whether or not to enter the inner controlled area during the first 3 months of their pregnancy'. Female staff of childbearing age working in the MR environment should be made aware of:

- potentially harmful effects of excessive acoustic noise on the developing fetus
- COSHH regulations in respect to anaesthetic gas exposure
- MDA guidelines in respect to magnetic field exposure.

Section VII: Risk management

The nominated consultant anaesthetist should ensure that anaesthetic staff are familiar with the anaesthetic machine and monitoring equipment which are often of a non-standard configuration. All staff entering the MR unit, including anaesthetic personnel, should have received training from the responsible person or their designated deputy, usually the superintendent radiographer. Participation in such training must be recorded and regular updates should be available annually. Training should involve familiarisation with sections of the local rules of the MR department which are appropriate to the individual role, and should include:

- Access to hazard notices and safety bulletins relating to MR Safety
- Personal safety i.e. removal of all metal objects and credit cards
- Information relating to safety issues of implants both passive and active
- The screening procedure and contraindications to MR
- Safe placement of monitors and radiofrequency (RF) coil leads
- Cardiac arrest procedure, siting of emergency equipment and emergency drugs
- Fire procedure
- Quench procedure

Section VIII: Appendix 1

Planning considerations and cost implications for the inclusion of an anaesthesia service into a new or existing MR installation.

Building

The building plans should include the following (in addition to what is considered as standard for an MR installation):

1. Adequate access to the MR unit (including ITU beds) may require modification of corridors and doorways. Alternative access may be required for beds to avoid passing through the waiting area.
2. Anaesthetic induction and recovery area(s) of sufficient size to accommodate predicted patient throughput. Consideration of whether more than one patient is likely to be in induction and/or recovery at any one time. Induction and recovery should be separate areas.
3. Provision of sufficient storage (including drug fridge) for consumables and anaesthetic machine when not in use.
4. Installation of piped gases, suction and scavenging units in each of MR examination room, induction and recovery areas.
5. Provision of RF waveguides for piped gases, suction and monitoring equipment. This normally needs to be specified at the time of MR equipment specification as the RF screened room is often included in the tender process for the MR equipment.
6. Provision of emergency call system and telephone in induction and recovery areas.

Purchase of Capital Equipment

The following additional capital equipment must be purchased:

1. MR compatible monitoring equipment to comply with minimum monitoring standards.
2. MR compatible anaesthetic machine, vaporisers and ventilator.
3. Standard anaesthetic machine, suction and monitoring equipment for induction/recovery area.

Revenue Cost Implications

1. Staffing - anaesthetist, anaesthetic assistant, technician, nurses.
2. Provision of day-case recovery facilities.
3. Consumables.
4. Service contract for anaesthetic and monitoring equipment - usually 8-10% of purchase price per annum.

Section IX: Appendix 2

Glossary of Terms

Authorised Personnel/Person. In the context of the MR safety guidelines, authorised personnel are able to access the controlled area without supervision. They must have received appropriate training in MR safety and should be conversant with the local safety rules of the MR unit appropriate to their duties. In particular, they should be able to implement the emergency procedures contained within the local rules. All authorised personnel should have been medically screened prior to first being given access to the MR unit. They should be sufficiently competent to supervise non-authorised personnel, patients and visitors who may require access to the controlled area.

Controlled Area. The controlled area wholly contains the 0.5mT magnetic field contour. Self-locking doors with coded locks control access to the controlled area. Only authorised personnel have unsupervised access to the Controlled Area. All patients, visitors and non-authorised staff should be medically screened before entering the controlled area.

Cryogenes. Cryogenes are liquid coolants that are used by superconducting magnets to keep the magnet coil windings at a superconducting temperature. Liquid helium is the cryogen used in modern superconducting MR systems, although older systems also used liquid nitrogen as a secondary coolant to help reduce the rate at which liquid helium boils off. Rapid boil-off of the cryogen is accompanied by a loss of superconductivity and is known as a quench.

Fringe field. The fringe field is the magnetic field that exists outside the external housing of the MR system's magnet. It decreases with distance from the centre of the magnet. There are two important safety considerations. First is the position at which the fringe field decreases to a value below 0.5mT. Persons fitted with cardiac pacemakers should not be allowed to enter fields above this value. Second is the rate at which the fringe field increases in close proximity to the magnet as this determines the force on ferromagnetic objects which causes the projectile effect. Magnetic shielding is used to make the fringe more compact. In addition to presenting a safety hazard, the fringe field may also damage items such as wrist watches, mobile phones and will erase the information stored on credit cards.

Gadolinium DTPA (dimeglumine gadopentetate). This is the most commonly used MR contrast agent. It reduces the T1 and T2 of tissues (see MRI) with which it comes in contact. This produces an increase in signal of T1-weighted images, and a reduction in signal on T2-weighted images. It is most commonly used as a contrast medium to identify tumours and also in Contrast-enhanced MR angiography.

Gauss (G) see Tesla. Gauss is a unit of magnetic field strength (the correct term is magnetic flux density). It has been mostly superseded by the SI Unit, Tesla. 1 Gauss = 0.1 milliTesla (mT). 1 Tesla = 10,000 Gauss. The cardiac pacemaker field contour is often referred to as the 5 Gauss line.

Gradient magnetic fields. The technique of magnetic resonance imaging uses magnetic field gradients to localise and encode the MR signals with spatial information to generate an image. The gradient fields are superimposed onto the static field but are only switched on for short periods (typically just a few milliseconds). The fast switching of the gradient fields generates rapidly varying magnetic fields. This may cause interference on the patient's electrocardiogram and, on higher performance MR systems, may cause peripheral nerve stimulation. The electromagnet coils that generate the switched gradient fields vibrate, generating acoustic noise, which is often in excess of 100dB. Hearing protection should always be provided to patients whether conscious or unconscious.

Inner Controlled Area. The Inner Controlled Area is a term which is often used to describe the MR Examination room which contains the MR system magnet. The attractive force of the fringe field is at its greatest in this room presenting a significant projectile hazard. The Inner Controlled Area is always contained within the Controlled Area.

Magnetic shielding. Magnetic shielding is used to reduce the extent and strength of the fringe field. There are two main types of magnetic shielding. Passive shielding uses several tons of steel to constrict the magnetic field. It can be immediately surrounding the magnet or distributed around the walls of the room. Active Shielding uses a secondary set of superconducting magnet coils that reduce the fringe field outside the magnet housing. For active shielding and passive self-shielding, the attractive forces increase rapidly close to the magnet. For room shielding (or if no shielding is used), attractive forces are significant throughout the MR examination room.

MR Examination Room. The MR examination room contains the MR system's magnet and is where the fringe field is at its strongest, thus presenting a projectile hazard. It is often referred to in safety guidelines and local safety rules as the Inner Controlled Area.

MRI. Magnetic Resonance Imaging (MRI) is the process of acquiring images using the principle of Nuclear Magnetic Resonance (NMR). Hydrogen nuclei are caused to resonate by applying a radiofrequency magnetic field in the presence of a strong static magnetic field. The hydrogen nuclei emit a radiofrequency signal which is spatially encoded by using magnetic field gradients to form images

which represent anatomical slices within the body. The signals mainly emanate from both lipid and water-based tissue, and depend on both NMR properties of the tissue and the acquisition parameters of the MR system set by the operator. MRI is able to generate a wide range of soft tissue contrast, making it suitable for a wide range of conditions and diseases. Two common parameters that dictate the properties of signal evoked from different tissues are the T1 and T2 time constants, which describe the characteristics of MR signal obtained. MRI sequence parameters can be chosen to elicit T1 or T2 contrast.

MRS. Magnetic Resonance Spectroscopy (MRS) is the process of acquiring spectroscopic data using the principle of Nuclear Magnetic Resonance. The MR spectra obtained reveals the proportion in which many important chemical species are present in tissue. Localised MR Spectroscopy allows MR spectra to be obtained from small volumes of tissue in vivo. It can be combined with MRI to provide both anatomical and metabolic information and is developing as an important diagnostic tool.

MR safe. Equipment is designated as MR safe if it presents no safety hazard to patients or personnel when it is taken into the MR examination room, provided that instructions concerning its use are correctly followed. This does not, however, guarantee that it will function normally and not interfere with the correct operation of the MR imaging equipment, with degradation of image quality.

MR compatible. Equipment that is designated as MR compatible is MR safe, functions normally in the MR environment, and does not interfere with the correct operation of the MR imaging equipment providing instructions concerning its proper use are correctly followed.

mT (milliTesla). See Tesla.

Projectile hazard/effect. The magnetic fringe field exerts an attractive force on any ferromagnetic object that is brought into the vicinity of the magnet. Massive objects, such as gas cylinders and patient trolleys, and smaller objects with sharp edges, such as scissors or tools, will accelerate rapidly towards the magnet and may cause serious injury to staff or patients. The MR system itself may also be damaged. All personnel entering the Inner Controlled Area must first be screened for such objects.

Quenching. Quenching refers to the rapid, almost explosive, boil-off of liquid helium and the accompanying loss of superconductivity. The magnetic field is lost and a large volume of helium gas is generated and should normally be vented to the outside atmosphere through a quench pipe. If this pipe were to fracture it would present a potentially lethal hazard caused by the rapid build-up of helium gas in the MR examination room, leading to asphyxiation. Quenches can be

spontaneous, usually occurring when the magnet is being powered up or down during installation or services, or can be deliberately activated in an emergency, such as fire.

Radiofrequency (RF) Coil. Radiofrequency (RF) coils are used to detect the RF signals emitted from the patient. The main RF coil of the system is known as the Body Coil and is typically located inside the covers within the bore of the magnet. This coil is also used to transmit the pulsed radiofrequency field. Additional specialised coils (often known as Surface Coils) may be used to improve the sensitivity of signal detection from a particular body area. The cables from these coils must be carefully placed so that they are not in contact with either the patient or monitoring cables as this can cause RF heating.

Responsible Person. In the context of MRI services, the chief executive or general manager of the organisation has the ultimate responsibility to ensure that the MR safety guidelines are implemented. This responsibility is normally delegated to a specified responsible person who may be the clinical director or superintendent radiographer in charge of the department in which the MR equipment is located.

RF heating. The radiofrequency pulses used in MRI deposit energy into the patient's tissues, and therefore have a heating effect. The level of power deposition is strictly controlled, and is calculated per kilogram of tissue for each scan (see SAR). Metal implants, monitoring transducers and cables may preferentially take up the RF power, resulting in excessive RF heating, causing burns to the patients skin. To avoid this risk, only MR compatible monitoring equipment should be used in the MR environment. Care should be taken when placing RF coil cables and monitoring cables to ensure that no loops are formed and that they are not in close contact with each other or the patient's skin.

RF shielding. Radiofrequency (RF) shielding has a two-fold purpose. Firstly, the radiofrequency pulses used by the MR system should not interfere with equipment outside the MR examination room. Secondly, radio signals and other electromagnetic interference in the external environment should be prevented from interfering with the MR signal detection. RF shielding is achieved by making the MR Examination room an RF screened room.

RF screened room. The radiofrequency (RF) screened room (also known as an RF cabin) provides RF shielding for the MR system. It consists of cladding made of thin copper or aluminium sheet that forms the inner surface of the walls, ceiling and floor of the MR examination room. The door (copper clad with leaf spring edges) and window (copper gauze sheet) of this room form an integral part

of the RF screen. The door must therefore be closed when the MR system is operating and the screen must not be broken by passing electrical conducting materials through it. Medical gas supplies and sample tubes for monitoring equipment must be made of non-conducting material and must be passed through specially-designed **waveguides** supplied with the RF screened room to maintain the integrity of the screen. Cables that carry signals or power must either be fibreoptic, or must pass through special electrical low pass filters supplied with the RF screened room.

SAR. The Specific Absorption Rate (SAR) is a measure of the RF power deposited into the patient, calculated per kilogram of tissue. The patient's body weight is entered into the MR system at the start of the examination, and the SAR is calculated before each scan is commenced. The SAR is strictly limited by the MR system manufacturer according to national or international guidelines. Higher values of SAR may lead to core body temperature rises of up to 1 °C, and there is an increased likelihood of RF heating of transducer cables.

T1-weighted image and T2-weighted image. The MR signal emitted by biological tissue has an amplitude, which depends both on the properties of the tissue and upon the timing parameters of the particular MR acquisition pulse sequence used. The two most important properties are the T1-relaxation and T2-relaxation. The pulse sequence parameters can be chosen either to emphasise signal differences which are primarily dependent upon either T1 relaxation, or T2 relaxation, resulting in images which have soft tissue contrast which is described as either T1-weighted or T2-weighted respectively. Both types of image are normally acquired as they provide complimentary diagnostic information.

Tesla (T). Tesla is the SI unit of magnetic field strength (the correct term for field strength is magnetic flux density). The cardiac pacemaker field contour is often referred to as the 0.5 milliTesla (mT) line. Typical nominal field strengths of commercial MR systems are 0.5, 1.0 and 1.5 Tesla. More recently, higher field strength (e.g. 3.0T) systems are becoming commercially available. MR spectroscopy is normally performed at higher field strengths up to 7.0 Tesla.

Waveguide. A waveguide is a hollow tube made of brass that forms a conduit through the wall of the RF screened room without breaking its integrity. Waveguides are typically 2.5-5.0cm in diameter with the length, dependent on the diameter, calculated to prevent the passage of radiofrequency interference. It allows non-electrically conducting pipes, sample tubes and fibreoptic cables to be passed into the MR examination room for patient monitoring, and gas and drug delivery purposes.

Section X: References

1. *Health Building Note 6 Supplement 1. Accommodation for magnetic resonance imaging.* NHS Estates 1994, London, HMSO. ISBN 0113217307
2. *Health Guidance Note Magnetic Resonance Imaging.* NHS Estates, London, HMSO. ISBN 0113220510.
3. *Facilities for Diagnostic Imaging and Interventional Radiology.* NHS Estates 2001, London, HMSO. ISBN 0-11-322000-0.
4. *Immediate Postoperative Care.* Association of Anaesthetists of Great Britain and Ireland, 1993.
5. MDA Publication. 'MRI static magnetic field safety considerations – the projectile effect caused by the influence of the static magnetic field of magnetic imaging systems' 1998.
6. Dempsey MF, Condon B. Thermal injuries associated with MRI. *Clinical Radiology* 2001; **56**: 457-65.
7. MacIntyre PA, Sury MR. Is propofol infusion better than inhalational anaesthesia for paediatric MRI? *Anaesthesia* 1996; **51**: 517.
8. *Recommendations for Standards of Monitoring during Anaesthesia and Recovery.* Association of Anaesthetists of Great Britain and Ireland, 2000.
9. Chaljub G *et al.* Projectile cylinder accidents resulting from the presence of ferromagnetic nitrous oxide or oxygen tanks in the MR suite. *American Journal of Radiology* 2001; **177**: 27-30.
10. *The Anaesthesia Team.* Association of Anaesthetists of Great Britain and Ireland, 1998
11. Andrzejowski J, Mundy J. Anaesthesia for MRI angiography in a patient with Williams syndrome. *Anaesthesia* 2000; **55**: 97-8.
12. <http://www.mrisafety.com>
13. Weiss KL. Severe anaphylactoid reaction after i.v. Gd-DTPA. *Magnetic Resonance Imaging.* 1990; **8**: 817-8.
14. The Medical Devices Agency. *Guidelines for Magnetic Resonance Diagnostic Equipment in Clinical Use with Particular References to Safety.* London: HMSO, 1993. To be revised 2002
15. Health and Safety Executive. *Noise at Work Regulations.* London: HMSO, 1990.
16. Health Service Advisory Committee. *Anaesthetic Agents: Controlling Exposure Under COSHH* London: HMSO, 1995.

Section XI: Further Reading

- Keengwe IN, Hegde S, Dearlove O, Wilson B, Yates RW, Sharples A. Structured sedation programme for magnetic resonance imaging examination in children. *Anaesthesia* 1999; **54**: 1069-72.
- Laurence AS. Sedation, safety and MRI. *The British Journal of Radiology* 2000; **73**: 575-7.
- McBrien ME, Winder J, Smyth L. Anaesthesia for magnetic resonance imaging: a survey of current practice in the UK and Ireland. *Anaesthesia* 2000; **55**: 737-43.
- Menon DK, Peden CJ, Hall AS, Sargentoni J, Whitwam JG. Magnetic resonance for the anaesthetist. Part 1: physical principles, applications, safety aspects. *Anaesthesia* 1992; **47**: 240-55.
- Morton G, Gildersleve C. Noise in the MRI scanner. *Anaesthesia* 2000; **55**: 1213.
- NRPB Board statement on restrictions on human exposure to static and time varying electromagnetic fields and radiation. Documents NRPB 1993; **4**: (5) ISBN 0859513661.
- Peden CJ, Menon DK, Hall AS, Sargentoni J, Whitwam JG. Magnetic resonance for the anaesthetist. Part II: anaesthesia and monitoring in MR units. *Anaesthesia* 1992; **47**: 508-17.
- Practical MR Safety Considerations for Physicians, Physicists and Technologists.* Editor Emanuel Kanal. 2001 RSNA Course Syllabus.
- Rafferty C, Burke AM, Cossar DF, Farling PA. Laryngeal mask and magnetic resonance imaging. *Anaesthesia* 1990; **45**: 590-1.
- Sury MRJ, Hatch DJ, Deeley T, Dicks-Mireaux C, Chong WK. Development of a nurse-led sedation service for paediatric magnetic resonance imaging. *Lancet* 1999; **353**: 311-12.
- Zorab JSM. A general anaesthesia service for magnetic resonance imaging. *European Journal of Anaesthesiology* 1995; **12**: 387-95.
- Zorab JSM, Young AER, Brown PN. Anaesthesia for children and infants undergoing magnetic resonance imaging: a prospective study. *European Journal of Anaesthesiology* 1996; **13**: 400-3.



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