

Anaesthesia in the MRI suite

Reinier Swart^{a*} and William Ian Duncombe Rae^b

^aDepartment of Anaesthesiology, University of the Free State, Bloemfontein, South Africa

^bDiscipline of Medical Radiation Sciences, University of Sydney, Sydney, Australia

*Corresponding author, email: reinier.swart@gmail.com



Anaesthesia in the magnetic resonance imaging (MRI) suite, or when performing surgery that requires MRI guidance, is becoming a more frequent and complex procedure for anaesthetists, as the study modality is increasing in application. MRI is not inert in its ability to do harm and may interfere with the anaesthetist's ability to assess the patient and intervene in the event of emergencies. Strong superconducting magnets can affect the physical environment and present unseen yet pertinent dangers, which may be avoided through awareness and vigilance. A culture of safety and collaboration in the radiology department, an area that is often remote from the usual milieu that anaesthetic providers are comfortable with, is essential to preventing serious injury or death to both patients and staff. It is therefore an important domain of knowledge and expertise for an anaesthetist. This article also describes some of the difficulties occasionally apparent only to the anaesthetic provider, which warrants anaesthetists' involvement in the planning and layout of MRI suites.

Keywords: anaesthesia, emergencies in MRI, magnetic resonance imaging (MRI), MRI safety, radiology

Introduction

General anaesthesia or sedation in a location remote from the theatre or intensive care unit is always a concern for anaesthetists. A full complement of resuscitation equipment is required when these services are provided. However, some of these instruments are not compatible or safe in the extreme physical environment that is intrinsic to the use of strong magnets and radiofrequency coils. Other factors, such as patient access that is limited in the magnetic resonance imaging (MRI) unit, and radiofrequency (RF) interference of magnetic fields with monitors and implantable devices, may pose additional risks. Patients requiring anaesthesia during MRI are usually critically ill and dependent on haemodynamic and ventilatory support. This requires the use of different pieces of equipment that often contain ferromagnetic metals. The aim of this study was to clarify those aspects that are currently pertinent to the safe administration of anaesthetic services in the MRI unit, and provide information on the extraordinary physical environment created by and required for performing MRI.

An overview of the basic physics of magnetic resonance imaging for the anaesthetist

MRI of tissue has been described since 1973. The use of MRI has increased in popularity after becoming the modality of choice to diagnose various conditions. This section does not define the physics of MRI, but rather provides some context when considering the use of anaesthetics in the MRI environment.

The nuclei of some atoms with an unpaired proton or neutron spin in such a manner that a small, local magnetic field is created. This magnetic field acts like any other with a distinct 'north' and 'south' pole. Hydrogen, having a single proton, is such a nucleus with a net magnetisation and, because it has a single electron, the magnetic field is not strongly shielded. Owing to the large amount of water in the human body in soft tissue, water hydrogen is an appropriate investigative target for MRI. Phosphorus, such as in ATP, may also be used, but usually is only applicable in functional MRI.¹

The random alignment of molecules in biological tissue results in no net magnetic field being detectable from the hydrogen protons in the tissue. When a strong external magnetic field is applied, a small fraction of these atoms aligns with the external magnetic field. They will precess with a well-defined frequency because of the interaction of the two magnetic fields, known as Larmor precession, which is the precession of the magnetic moment of an atom in an external magnetic field. An external radiofrequency (RF) stimulus can then be applied to flip these nuclei out of alignment. They exponentially realign with the external magnetic field once the stimulus is removed. This realignment releases a radiofrequency signal that can be measured by means of specially tuned RF coils. If gradient magnetic fields are sequentially activated during this process, it is possible to obtain sufficient information to reconstruct images depicting the spatial distribution and physical characteristics of the environment of hydrogen protons in the body.² RF gradient coils are arranged in three axes perpendicular to each other, allowing gradient directions to be generated in any spatial orientation.

The rate at which nuclear realignment takes place depends on the type of molecule and the surrounding molecular environment. Therefore, the RF signal emitted depends on the type of molecule and the tissue being investigated. These rates of relaxation (T1 and T2 – relaxation time constants) can then be separated and interpreted by the MRI software to give differently contrasted images, more commonly known as T1- and T2-weighted images.³

The strength of magnetic fields can be classified according to the units of Tesla (T). MRI magnet strengths commonly range between 0.2 T and 3.0 T, which is approximately 20 000 times greater than the earth's magnetic field. The magnetic field drops quickly with increasing distance from the coils.² To generate such strong magnetic fields, very high current density electromagnets that generate heat due to their resistance are required. It is therefore standard practice to use

superconducting coils that exhibit no resistance at temperatures below 4.2 K when immersed in liquid helium.¹

The RF signals and coils are subject to interference from external RF signals and may also cause substantial electromagnetic interference to external electronic and ferromagnetic devices, and are consequently housed within a radiofrequency shield (Faraday cage) built into the walls of the MRI suite.⁴

Hazards and safe conduct in the MRI unit

Generally, MRI investigations are considered as very safe and manufacturers have taken great care to ensure that all the potentially associated risks are reduced as much as possible. Nevertheless, several hazards, listed in Table 1 and discussed in more detail, are encountered in the extraordinary physical environment created in the MRI suite. It is imperative to be cognisant of these factors, as potential harm to the patient, normally experienced as sensations of pain, noise or heating, may be masked at the time of the imaging by the administration of a general anaesthetic. Furthermore, certain sedatives may also increase the threshold at which patients respond to these stimuli.

(1) Projectile effect

Safety, or warning, lines are theoretical and often not well demarcated according to magnitude of magnetic flux density in MRI suites. Different departments also may have different ways of denoting these zones. As a rule of thumb, most MRI areas should at least demarcate a safe zone, outside of which no adverse effects are experienced.⁴

Within the range where the attractive force is due to a flux density of 5 microT, ferromagnetic objects are at risk of becoming projectiles and all anaesthetic pumps with ferromagnetic mechanical components will become dysfunctional.^{2,4} Case reports have also noted serious injuries related to projectiles in the MRI suite.⁵ Some sources have described dysfunctionality at more than 3 microT. For this reason, waveguides are essential for critically ill individuals who require MR imaging. The pumps may then be situated well out of reach of the attraction forces of the magnet to provide continuity of care.^{1,2,6}

Not enough emphasis can be placed on the dangers of the projectile effect. Anecdotal reports of multiple fractures and internal injuries have been recorded worldwide when incompatible beds and large ferromagnetic objects (such as office chairs) have been brought into the MRI suite when absolute vigilance was not applied (see Figure 1).⁷ The projectile effect has led to injury in



Figure 1: Hospital bed stuck to the inner bore of an MRI magnet – quenching will be the only way to release it

both patients and staff, and is one of the only reasons why an MRI magnet may need to be quenched.

(2) Movement and heating of implantable surgical devices and foreign bodies

Three risks, namely dislodging, malfunctioning and heating up, are associated with implantable ferromagnetic devices in an MRI. In an attempt to prevent the negative effects of the strong magnetic field on patients with electronic devices such as pacemakers, a safety line is usually demarcated at the point at which the magnetic field strength falls to 0.5 microT (5 Gauss), at which pacemakers may malfunction.² All patients and staff must be screened and warned not to enter that area if they may have a pacemaker or implantable cardioverter-defibrillator, or any other attached electronic device such as a hearing aid.

The heat generated is sufficient to cause tissue damage and even external monitors are at risk of causing burns severe enough to necessitate amputation.^{8,9} Although most modern surgical implants are non-ferromagnetic, there are several absolute contra-indications to MRI (see Table 2). If, however, the manufacturer specifications of the device accompany the patient, and the devices are certified to be MRI safe, exceptions may be considered. For example, some neurosurgical aneurysm clips are certified to be MRI safe under certain conditions, although this matter is subject to the radiologist's discretion. Older neurosurgical clips have also been noted to be ferromagnetic and have been noted to dislodge and result in death.¹⁰ If doubt exists, the risk is too high and MRI should not be

Table 1: Common hazards in the MRI unit

1. Projectile effect
2. Movement and heating of implantable surgical devices and foreign bodies
3. Effect of metals and other objects on the image quality
4. Thermoregulatory issues: heating and heat loss
5. Monitoring difficulties
6. Minimal patient access
7. MRI chamber pollution by anaesthetic gases
8. Intravenous (IV) contrast agents
9. Noise levels and other physiological effects
10. Quenching of MRI magnets

Table 2: Devices that are absolute contra-indications to MRI^{2,6,13}

1. Cochlear implants
2. Intra-ocular foreign bodies
3. Arterial or aneurysm clips – depending on specification
4. Cardiac pacemakers and implantable cardioverter-defibrillators
5. Spinal cord stimulators and other central nervous stimulators
6. Implanted dental magnet keepers
7. Pulmonary artery catheters and other indwelling cardiac monitoring catheters
8. Other electronic devices not for medical purposes (e.g. cell phones)

considered. A plain film X-ray (or CT investigation) can be performed when in doubt about the placement of such devices.³ Cosmetic and decorative tattoos containing ferromagnetic pigment, i.e. certain red colours, have been found to cause problems from mild skin reactions to second-degree burns. However, the simple fact that a patient has a tattoo should not preclude MR imaging if so indicated.^{6,11,12}

Drug patches, such as glyceryl trinitrate, may also contain ferromagnetic metals that may be hazardous during MRI investigation. The patches may heat up in the presence of the rapidly changing gradient fields, thus having the potential to cause burns. It is therefore also imperative to take a history of and inspect the patient for the presence of such devices or patches and remove them for the duration of the MRI.

Theoretical data suggest that cardiac valve prostheses and especially those which are implanted over atrioventricular low pressure gradients may malfunction significantly in static magnetic fields. Patients with prosthetic cardiac valves should therefore either be excluded from magnetic resonance imaging or additional monitoring may be required to ensure proper physiological functioning of their prostheses (such as non-invasive cardiac output monitors).¹⁴

Not all implanted devices are considered unsafe and it is the radiology personnel's responsibility to ensure MRI safety, and they should therefore always be informed. However, it is important to consider a patient eligible for MRI investigation if indicated and if the implants listed in Table 3 are in situ. Sternal wires, for example, are fixed by fibrous tissue, and the forces exerted by MRI are insignificant in terms of causing harm to the patient. With the advent of stronger MRI superconducting magnets, these recommendations may differ and newer implants are continually tested in vitro with magnets as strong as 7 to 9 T, but each implant must be considered according to its manufacturer's specifications.²

(3) Effect of metals and other objects on MR image quality

The grey value in MRI, simply defined as poor image quality, is dependent on two factors: signal intensity and noise.¹⁶ All images contain a level of background noise. Noise is always present and results from the electromagnetic noise caused by the movement of charged particles in the body, small anomalies in the measurement tools and other magnetic objects in the room.¹⁶ Image quality depends on the homogeneity of the magnetic field and any metal introduced anywhere into the field distorts the static magnetic field, which may cause clip artefact (the enhancement and loss of signal). Even non-magnetic materials may cause artefacts by conducting current, which creates a new local magnetic field.¹⁷

The MRI is also calibrated for each patient and the scan required. When new objects enter the scanning room, they may affect the

Table 3: Implants generally considered/manufactured to be safe in the MRI suite^{2,6,15}

1. General surgical clips
2. Joint prostheses
3. Sternal wires
4. Artificial cardiac valves and annular ring implants
5. Coronary artery stents

settings that have been entered. Especially after intervention, when the surroundings and attachments to the patient have been altered, it is important to note that the calibration may require refinement.¹⁷

(4) Thermoregulatory issues

Internal thermoregulation is affected under anaesthesia, and radiant heat loss and decreased thermogenic mechanisms lead to hypothermia under most conditions. Recent studies, however, have suggested that RF radiation produced by the scanner may actually lead to heating and is more pronounced in stronger MR magnets and noted more often in 3 T than 1.5 T scanners. Active heating may cause hyperthermia under these circumstances. The prevention of passive heat loss should therefore be adequate to maintain body temperature. Indwelling thermistors in the bladder should be disconnected from their circuitry, but may remain in situ during investigation, on the condition that they will not cause artefact if the area of investigation is close to the bladder.²

RF energy is absorbed by bodily tissue and dissipated to the environment as heat.¹⁸ To combat this effect, air conditioners are often left to blow air continuously into the MRI chamber. This may be a problem for patients with a relatively larger body surface area, for example children and infants.

(5) Monitoring difficulties

It is important to note that there is a distinction between 'MR safe' and 'MR compatible'. These concepts are outdated terminology and may cause confusion. Therefore, the United States Food and Drug Administration (FDA) has revised the terminology to include 'MR conditional' and 'MR unsafe', as the first two terms were often used interchangeably. 'MR safe' implies that the equipment poses no known risk to the patient and environment under MR conditions, but functionality is either not guaranteed or not tested, and 'MR compatible' implies that the equipment is both safe and functions adequately under such conditions.¹⁹

Previously, ferromagnetic anaesthetic machines were used to ventilate patients with long Mapleson-type circuits that were passed through waveguides. Currently, MR compatible anaesthetic machines, vaporisers and ventilators are available. Piped gases and back-up cylinders are also available in aluminium vessels. These systems are not as readily available as other ferromagnetic systems and are more costly, but minimal monitoring requirements must still be met.³

All leads and wires may have a current induced by the changing magnetic fields and therefore pose a risk of causing burns to the patient. It is imperative that the anaesthetist be aware of this risk. It should also be ensured that the wires and leads are made of a braided material with minimal contact with the patient's skin. The shortest leads possible must be used, keeping in mind that the scanner bed moves in and out of the scanner portal. The wires can also be placed on top of linen to minimise skin contact, as any type of ECG lead may still cause burns.¹³ Where possible, fibre-optic or carbon fibre wiring should be used, and it is also important to ensure that no equipment emits RF waves. Mains power supply may also interfere with image quality and should therefore be isolated, filtered or avoided by making use of battery power supply, which should be firmly secured away from the MRI magnets.^{2,3,20}

Monitoring screens should be available where the anaesthetist is seated, preferably in the control room. If situated within the MRI chamber, visual alarms should be activated to compensate for high noise levels.²

Electrocardiographic (ECG) monitoring is not possible with normal ECG leads. Short MR-compatible leads, preferably < 15 cm, and electrodes should be used and placed in a narrow triangle on the patient's chest. ECG monitoring may become affected by the magnetic field and mimic the changes seen in hyperkalaemia during periods of activation due to Faraday's law.^{2,3,8,9} Burns related to pulse oximeters have been noted, therefore MR compatible oximeters should be used and cables should be placed as far away from the scanner as possible.¹ Blood pressure monitoring with compatible pressure transducers and plastic connectors will make non-invasive monitoring possible. Longer lines are needed for capnography, and therefore longer delays of 20 seconds or more should be expected.²

(6) Minimal patient access

The 2009 American Society of Anesthesiologists (ASA) *Practice Advisory on Anesthetic Care for Magnetic Resonance Imaging* noted that the MRI suite is a hazardous location due to various factors, to such an extent that 70% of all radiology-related claims originated in the MRI suite (see Table 4 for contributing factors). Newer C-shaped magnets are now also available to improve patient access and minimise patient anxiety and claustrophobia. Surgery under MRI guidance is also becoming more prominent, although these magnets are often weaker with lower resolution, and are therefore not always applicable for the investigation that may be required.^{4,6}

Current MRI production standards require an inner bore of 70 cm, compared with the previous standard of 55–60 cm. This new standard may alleviate claustrophobia and allow for larger patients to be scanned, although it does not warrant optimal image quality.²¹

Owing to the inherent dangers of radiation and strong superconducting magnets, radiology suites are often isolated from the rest of the hospital and the assistance of adequately trained staff may often be more remote. This is also a point for consideration when transporting a patient for investigation.²

(7) MRI chamber pollution by anaesthetic gases

MR compatible scavenging systems are available and examination room pollution is therefore avoidable and imperative to control. Pollution levels may also rise quickly if older ventilation circuits are used and higher gas flows are implemented for carbon dioxide clearance. Older circuits, which need to be longer in the MRI suite, may also contribute to a higher cost of anaesthetic delivery due to the higher volumes of anaesthetic vapours used.³

(8) IV contrast agents

Table 4: Contributing factors to litigation claims in the MRI suite according to the 2009 ASA practice advisory

<ul style="list-style-type: none"> - Obstructed view of the patient - Risk for over-sedation - Non-MRI compatible equipment
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The most commonly used intravenous MR contrast agent is gadolinium dimeglumine. It is used to alter signal intensity, which is increased on T1-weighted images and decreased on T2-weighted images. It does not cross the blood–brain barrier (BBB) and may therefore be used to indicate breakdown in the BBB.² The dose commonly used is 0.2 ml/kg and is considered to be mostly safe. Commonly occurring side effects are minor, except for nephrogenic systemic fibrosis (NSF), which is an irreversible, progressive systemic fibrotic disorder affecting the skin and internal organs, with an incidence of < 1 per 10 000 if eGFR is <30 ml/min/1.73 m². The risk for this rare disorder is higher in individuals with pre-existing kidney dysfunction and patients should be screened accordingly.²² A recent FDA recommendation for the addition of the warning of gadolinium retention in tissue stated that although no adverse effects have been clearly identified with this phenomenon, it is important to note, especially in pregnancy. This accumulation has been observed very prominently in the brain and is the primary cause for concern.²³

(9) Noise levels and other physiological effects

Harmful noise levels in excess of the safe 85 decibel level are often produced by the activation of RF coils. Depending on the sequence of images required, these noise levels may persist for extended periods of time. The damage caused by these noise levels may be masked in the patient due to the administration of sedation or general anaesthesia, and the patient, and also caregivers in the MRI suite, should always wear protective earplugs or earmuffs. Auditory alarms and upper airway obstruction may be masked by high noise levels.^{2,3,6}

Faraday's law states that a current is induced in a column of conducting fluid in an external changing magnetic field. In the patient in an MRI scanner, especially in field scanners greater than 4 Tesla, this effect is maximal in the transverse aorta. This can affect monitoring due to ECG changes resembling hyperkalaemia, and cause direct, immediate physiological effects. Symptoms (see Table 5) are, however, of short duration and no known long-term effects have been described. As such, MRI investigations are generally regarded as safe. Symptoms may be multifactorial, but may arise due to the effect of current propagation in conducting fluids in specialised organs of the body.^{1,24}

With regard to MRI safety in pregnancy, limited evidence is available and randomised controlled trials are difficult to conduct in this population group. However, concerns have been raised pertaining to the noise levels, scavenging of anaesthetic gases and the unknown effect of strong magnetic fields on the developing foetus. It is therefore recommended in the UK that female patients and staff in their first trimester of pregnancy should avoid the MRI chamber.³

(10) Quenching of MRI magnets

Table 5: Symptoms commonly experienced during MRI investigation

<ol style="list-style-type: none"> 1. Nausea 2. Vertigo 3. Scotomata 4. Claustrophobia (unrelated to magnetic field) 5. Tingling and/or a burning sensation in nerves
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The superconducting magnets are cooled to below 4.2 Kelvin by super-cooled liquids or cryogenes, with liquid helium being the most commonly used agent.¹ Quenching is the process through which the liquid is rapidly boiled off and large volumes of gas are produced, which are generally vented into the atmosphere outside the building. Subsequently, the magnets lose their superconducting ability and the magnetic field is deactivated. This process may be initiated manually by means of an emergency switch generally located in the chamber, or may occur because of an error of installation or service.³ This process rapidly cools the gases in the MRI chamber if the vent is exposed to the environment and may lead to condensation of liquid oxygen. The descending vapour cloud may be harmful to the patient and staff, as it may create a hypoxic environment in the MRI suite. As a result of this possibility, oxygen sensors should be present in the MRI suite to alert the operators when a hypoxic environment develops.⁶ The implications of this process should also caution the anaesthetic care provider not to view quenching as a first-line option in the event of an emergency. It is, however, imperative that quenching be reserved for dire emergencies only, for example, in the case of impingement of a person to the magnet by another object. Each unit should have a quenching policy that is readily available.

Anaesthetic conduct

The greatest challenge in MRI investigation is getting the patient to lie as motionless as possible in a noisy, confined environment. The majority of patients should be able to do this without the need for anaesthetic care, but certain population groups (see Table 6) are more predisposed to requiring assistance, of which the largest portion is children. Each case should, however, be evaluated on merit for anaesthesia and often conservative techniques will succeed in preparing the patient for MRI investigation. These techniques include behavioural methods (reassurance, advice), natural sleep methods (e.g. the 'feed and wrap' method), and sedation.^{25,26} Apart from careful patient selection, very few data exist to support specific anaesthetic techniques.²⁷ One study suggested the addition of dexmedetomidine to propofol for sedation, which resulted in lower propofol requirements and airway complications.²⁸

Although sedation for MRI is commonly and successfully undertaken, the 2009 ASA *Practice Advisory on Anesthetic Care for Magnetic Resonance Imaging* indicated that sedation and light anaesthesia are associated with respiratory depression, oxygen desaturation, bronchospasm, drowsiness, agitation and vomiting.^{2,4,29}

General anaesthesia for MRI

Every patient should receive a pre-anaesthetic assessment as per usual recommendations and general starvation guidelines should be followed. Patients should be screened for metallic implants or other devices. There is no superiority of one

anaesthetic technique over another for MRI per se, but the choice of technique rather depends on individual factors, such as intubation and controlled ventilation, which may be preferable for exceptionally small infants or neonates.^{2,26,28}

Ideally, a dedicated induction room should be available as not all resuscitation equipment is MR safe. This induction room can double as a resuscitation room in the event of an emergency during MRI. Another metal check can be performed after induction and before entering the MRI room to ensure no metal objects are present. When using a laryngeal mask airway (LMA), some of these devices may have metal coils in the pilot balloons. These metal coils, which may cause artefacts, can be taped out of the way onto the receiver coil, although MR-compatible LMAs with no metal coils are available. It is important to ensure that the airway is secure at this stage of the procedure, as access to the airway will be limited from this point onwards. The patient should be secured by ascertaining that no wiring is in direct contact with the patient and providing ear protection, and it should be ensured that monitoring is visible and all necessary lines and infusion lines are safely passed through the waveguides where available. Generally, no analgesia is required, unless when provided for the sore throat resulting from airway placement, and the patient can be safely awakened in the induction room.^{3,6}

Consent for MRI

The consent for anaesthesia for MRI remains a troublesome issue, as it is generally implied with most surgical procedures and especially under emergency circumstances. However, the responsible anaesthetist has to inform the patient of anaesthetic conduct and risks, especially because anaesthesia is more complicated in the MRI environment. Ideally, the referring clinician should also provide input, especially with regard to the indications for investigation.²

Emergencies and MRI room design

All but minor emergencies are nearly impossible to manage within the 0.5 microT line, and minimal access to the patient also precludes rapid intervention. Items such as pens and stethoscopes should not be allowed near the MRI magnets, and therefore to perform an accurate clinical assessment is difficult and should be done with awareness and caution. It is necessary to remove the patient from the magnetic field as soon as practically possible and evacuate to the induction room or post-anaesthetic care area to have access to emergency resuscitation equipment. The resuscitation team should also know not to enter the 0.5 microT line and await arrival of the patient in the resuscitation area.³

Clear warning signs should always be available at or near the entrance of the MRI room to alert inexperienced staff to the potential dangers. It is also clear that, moving forward, anaesthesiologists should be consulted regarding the design and layout of MRI suites, as they are an intricate part of the safe performance of these investigations. Because critically ill patients are increasingly becoming part of the patient population presenting for these scans, it is important that all anaesthetists acquaint themselves with the risks and environment inherent to magnetic resonance imaging, in order to assist in the planning of these units when approached for input. Resuscitation and preparation areas should be an indispensable part of the planning of MRI suites, and anaesthetists have an intimate knowledge of the peri-anaesthetic needs of the critically ill. This will allow for a continuous culture of safety in the MRI environment.^{2,3}

Table 6: Patient groups or conditions predisposed to requiring anaesthetic care²

- Infants and children
- Patients with learning difficulties
- Movement disorders
- Claustrophobia
- The critically ill
- Where sedation may be dangerous (e.g. raised intracranial pressure)

A recent search of the Anaesthesia (formerly ASA) Closed Claims Project for the period 2000–2014 showed that while the paediatric population represented only 5% of the total anaesthesia, procedure and critical care-related malpractice claims, 75% of the eight MRI-related claims during this period involved paediatric patients, with seven (88%) of these claims being related to respiratory problems.³⁰ These problems occurred mostly in patients with pre-existing cardiorespiratory impairment. It is crucial that the anaesthetist does not waste any time when respiratory difficulties are identified, especially because children and infants are particularly vulnerable to even short periods of hypoxaemia.^{25,31}

Critically ill patients

Critically ill patients frequently require MRI investigation, which can become a complicated matter for the reasons listed below. Interdisciplinary communication and planning for MR imaging in these patients are therefore essential.

- Invasive monitoring is often essential.
- Haemodynamic support with infusion-controlled drugs is regularly needed.
- Ventilatory support is often essential.
- During surgical interventions, ferromagnetic objects may have been left behind in the patient.
- Transport of these patients is often complicated by several monitoring and therapeutic attachments.

With regard to invasive monitoring, all external electronic connections to indwelling catheters or wires need to be removed. Pulmonary artery catheters and epicardial pacing wires have to be detached, as they pose a risk of micro-shock and melting of pulmonary artery catheters within a patient has been reported.¹³ Central venous catheters are safe to remain in situ.²

All unnecessary infusions need to be terminated. However, if MR-compatible infusion pumps are available these may be used within the 0.5 microT line, which may require the anaesthetist to remain in the MRI suite. Other pumps can be connected from the control room through the waveguides to infusion lines in the patient.²

All necessary transport arrangements must be made before moving the critically ill, bearing in mind that most transport ventilators are not MR-compatible. It is important to do a final metal check before entering the MRI suite to ensure that no oxygen cylinders used during transport approach the MRI magnets, as it may result in the catastrophic consequence of creating a highly combustible, heavy projectile.^{5,31} This final metal check may also take into account any metal surgical implants left in place during intervention, which is important to report to radiology before transport.

In summary

Newer techniques for MR imaging may result in this investigation becoming a more commonplace encounter for the anaesthetist. It is therefore important for anaesthetists to be comfortable with the limitations posed by this imaging modality. Stronger magnets are being implemented in the clinical environment, and even stronger magnets are used for research purposes. Therefore, it is important for anaesthetists to be involved in the planning and development of these spaces, as most of the important resuscitation equipment is not compatible with these environments. The physical

environment and spatial orientation of the superconducting magnets and their cooling systems complicate access and intervention but, with careful planning and vigilance, many pitfalls can be avoided in this challenging environment.

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