Anaesthesia for MRI: ….child's play?

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Overview

This presentation focuses on the technological principles, safety considerations, monitors, equipment, patient issues, and a general overview of the anaesthetic management of patients presenting for magnetic resonance imaging (MRI). Attention will be focused on the paediatric patient and controversies surrounding their anaesthetic management.

Introduction

As a diagnostic imaging modality, MRI remains unparalleled in its diagnostic and clinical value. The clinical applications for MRI continue to evolve, and include its latest use in interventional radiology as well as in the operating room. MRI offers superior soft-tissue contrast and can create images through any body plane. The success of an MRI study partly depends on the ability of the patient to lie motionless. The expertise of the anaesthetist can make the difference between a diagnostic image filled with artifact and one of superior quality. Patients who benefit from anaesthesia include childen, those with impaired cognitive states, claustrophobia or critically ill patients.

The purpose of this article is to focus on the technology, safety concerns, monitors and equipment considerations for MRI. A general overview of the anaesthetic management for MRI focusing on the paediatric patient will be discussed.

Physical principles

Nuclear magnetic resonance(NMR) is a phenomenon that was first described by Bloch and Purcell in 1945, and the technique was widely used as an analytical tool in chemistry and biochemistry in the following decades. MRI then became a practical reality with the simultaneous explosion in computer and superconductor technology. It was in 1977 that Damadian was able to produce the first human images with this technology.

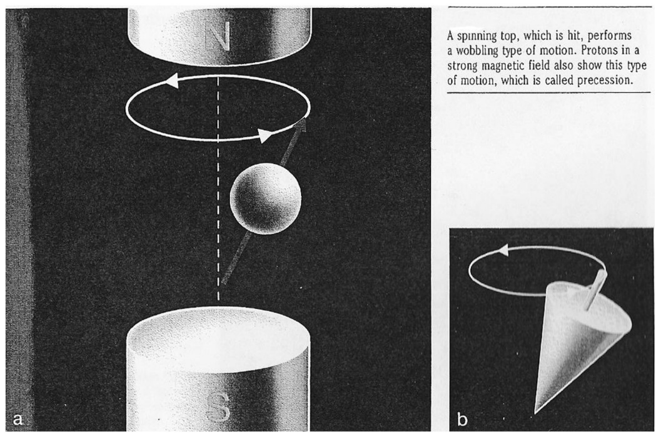
All atomic nuclei possess a charge(due to the presence of protons) and mass(due to the presence of protons and neutrons). In addition, the nuclei of some atoms possess a spin, a property that may be visualized as a rotation of the nucleus about its own axis. As a result the nucleus behaves like a miniature bar magnet.

MRI incorporates the use of static and gradient magnetic fields with radiofrequency pulses to produce precise images of the body. Magnetic field strengths in MRI systems range from 0. 15-3. 0 tesla. The tesla is a measure of the strength of the magnetic field(1T=10000 gauss). The quality of the image depends on the strength of the magnetic field.

The following steps represent a simplified summary of the physical principles involved in the generation of a MRI image.

- Protons are like little magnets.
- In an external magnetic field they align parallel or anti-parallel.
- The lower energy state(parallel) is preferred, so a few more protons align this way.
- The protons perform a motion that resembles the wobbling of a spinning top.
- This motion is called precession.
- The precession frequency is dependent on the strength of the external magnetic field, the stronger the magnetic field the higher the precession frequency.
- As there are more protons aligned parallel to the external magnetic field, there is a net magnetic moment aligned with or longitudinal to the external magnetic field.
- A radiofrequency pulse(RF) that has the same frequency as the processing protons, can cause resonance i. e. transfer of energy to the protons.
- The RF pulse also causes the protons to process in phase. This results in a new magnetic vector.
- Protons recover their original alignment after the RF pulse is switched off. Each proton will emit an RF signal which is proportional to the difference between the energized magnetic resonance state and the original alignment. Tissue contrast develops as a result of the different rates of realignment.
- The signal from the protons is collected by a radiofrequency coil which surrounds the patient, and with Fourier analysis, is transformed by computer into 2 or 3-dimensional images.

Fig. 1. Precession("MRI Workbook by Heyne)



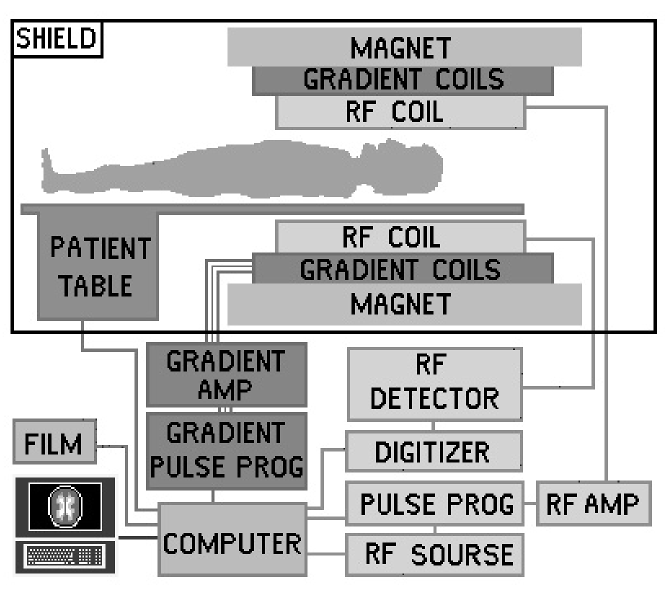
Practical aspects

The MRI suite is a challenging environment for the anaesthetist, and carries inherent risks. Several factors account for this, including the remote location, the unique features of the MRI scanner and patient-related factors. Understanding the implications of the MRI environment will ensure the safety of the patient and personnel.

Special consideration to the following aspects is essential:

- Safety aspects
- Anaesthetic equipment and monitoring
- Patient factors
- Quality of imaging

Fig. 2. Basic setup of MRI scanner(neurocog. psy. tufts. edu/ images/mri-scanner1. gif)



Safety considerations

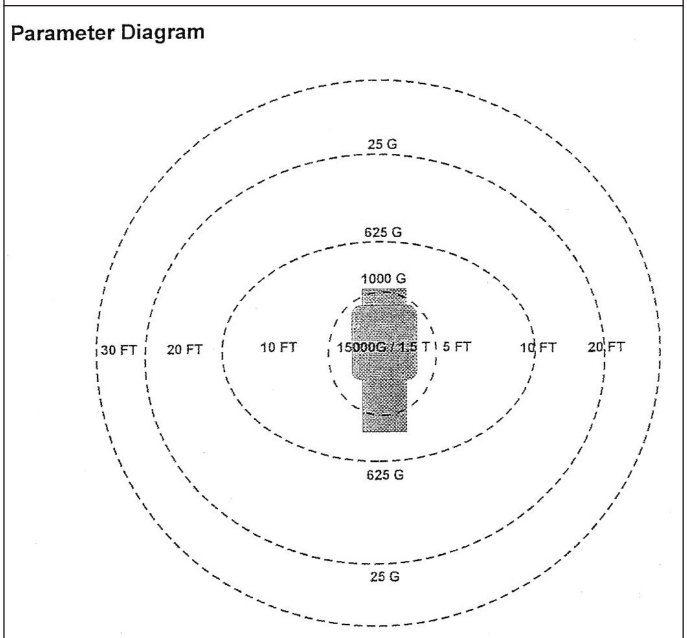
The safety aspects can be considered in terms of the types of interference one encounters in the MRI suite i. e.

- Magnetic interference
- Radiofrequency interference
- Time varied magnetic field interference

Magnetic interference

The attraction of ferromagnetic objects into the magnet is the most obvious hazard of the high static field created by MRI. Early surveys revealed that up to 24% of all MRI centers experienced a projectile-related incident. Even metal jewelry or a ballpoint pen can present a hazard. Precautions need to be taken to isolate the magnetic field but despite these there is always some magnetization of the environment immediately surrounding the magnet.

Fig. 3. Gauss lines(Courtesy Blease Frontline Genius MRI anaesthesia sytems)



Concerning equipment use in the MRI scanner, the following criteria are used for evaluation:

- The effect of the magnetic field on the equipment presents no danger to the patient.
- The equipment functions properly within the magnetic field.
- The equipment has no intrinsic effect on the quality of the image produced.

The influence of the magnet on equipment depends on the strength of the magnet and the proximity to the magnetic bore. Newer MRI machines are shielded, so that the effects of the magnetic field decreases significantly, albeit in a nonlinear fashion.

It is recommended that the 50 gauss line be marked on the floor by a biomedical engineer representing the point in the MRI suite at which the magnetic field falls to 30-50 gauss. At this point, standard ferromagnetic equipment can be used safely.

Anaesthesia equipment for use in the MRI environment has required considerable creativity and flexibility. In general, replacing the machines' ferrous material with stainless steel, brass or aluminium will enable its placement within the imaging room. Another hazard of working in the magnetic field is the erasure of all magnetic media such as credit cards, pass keys, floppy discs, and video tapes. Digital clocks are not affected and most units include one in the control panel. Metal detectors at the entrance to the scanner serve to ensure that no ferromagnetic objects are taken inside the scanner room, are now a standard feature in most units.

Radiofrequency interference

Some of the more significant challenges to monitoring in the MRI suite are presented by the two large radiofrequency(RF) coils which surrounds the patient. The outer coil transmits the RF while the inner one receives the RF emitted from the patient. The scanning room must be shielded from outside RF interference, such television transmitters, beeper paging systems, two-way radios, and commercial radio stations, which may affect RF transmission and reception. In addition, any cables or leads can behave as antennae for the RF.

The MRI suite can be shielded by lining the walls and the windows with thin continuous sheets of copper. Monitors and cables must be shielded because RF pulses are also capable of inducing electrical eddy currents and short circuiting electrical equipment. For passive shielding, cables can be wrapped with a thin layer of aluminium foil, and small copper boxes can be used to house electrical equipment.

Time varied magnetic field(TVMF)

TVMF enables the computer to spatially encode the RF emitted from the patient to construct 2- or 3-dimensional images. TVMF can induce electrical eddy currents in both biological tissue and electrical wiring. Although the biological effects are usually minimal, very large TVMF (>10, 000T/sec) have the potential to interfere with nerve conduction, induce seizures, or cause ventricular fibrillation. For this reason, coils in any cables or leads should be avoided.

An innocuous, albeit annoying effect of TVMF to personnel is the presence of flickering illuminations known as magnetophosphenes. These are caused by the torque from the magnetic field gradients on the retinal cones. This effect has been completely reversible thus far, and no long term effects have been reported.

Anaesthesia equipment and monitoring

Basic set-up includes:

- Systems for central wall gases should be installed after consultation with biomedical engineers.
- Electrical power consists of isolated circuits with filtered 120V (AC) to prevent electrical noise artifacts from interfering with images.
- Wave guides are copper shielded pipes fitted into the walls to shield cables and wires from RF interference.
- Anaesthetic machines require modification by replacing the machine's ferromagnetic components with brass, aluminium and plastic. The back bars and vertical supports are among the largest components to be replaced.
- Medical gas cylinders constructed from aluminium should be used.
- Vaporizers, however, are affected little by the powerful magnetic field, and function accurately in this environment.
- Plastic, battery-operated laryngoscopes may be used.
- Breathing circuits may require additional lengths of tubing.
- Infusion pumps contain ferromagnetic circuitry which can malfunction in the presence of the magnetic field.

Monitoring

- Electrocardiography is always problematic within a static magnetic field. Current is induced in any conducting fluid when the fluid flow is 90° to the field. Spike artifacts that mimic R waves are often produced even in filtered systems and make it impossible to reliably monitor for ischaemia and arrythmias. MRI compatible ECG systems utilize electrodes made of carbon graphite to lower resistance, eliminate ferromagnetism, and minimize RF interference. In order to optimize the ECG signal, the skin must be dried or abraded. Cables are coaxialized to avoid any coils and subsequent burning of the skin. Manufacturers recommend the use of impedance monitors to prevent skin burns. A small towel is placed on the patients chest to prevent cables from touching the skin as an extra precaution.
- Automated oscillometric blood pressure monitoring eliminates the problems of electromagnetic interference, because it is based on pneumatic principles. Conventional noninvasive blood pressure units are not RF shielded, consequently, blood pressures may be recorded using the manual mode between RF pulses.
- Invasive blood pressure monitoring has certain limitations. The accuracy of conventional transducers needs to be determined by biomedical engineer. Moving the transducers away from the patient with the addition of tubing may cause damping.
- MR-specific pulse oximeters use heavy fibreoptic cables which do not overheat and cannot be looped. These cables are expensive and easily damaged.
- Main stream capnography is not recommended as the sensor is within the magnet bore and will likely interfere with imaging even if it's not ferromagnetic.
- The magnet superconductors are kept cool in liquid nitrogen. Should the coolant evaporate due to leaky housing the ambient oxygen supply of the room can drop precipitously causing hypoxia and the potential for cryo injury.
- Temperature monitoring is necessary during MRI because RF raises body temperature. Thermistors are not practical because of ferromagnetic content. Liquid crystal thermometers are employed, although their accuracy is limited. Recently, temperature probes using RF filters, have been introduced.

Patient considerations

As mentioned previously indication for general anaesthesia or sedation include the following:

- Reduce patient movement e. g. infants, impaired cognition etc.
- Airway protection e. g. unconscious pt. , critically ill on IPPV.
- Control of ventilation e. g. head injuries, pt's with raised ICP.
- Anxiety and claustrophobia.

Paediatric considerations

Focusing on the paediatric patient, there are a few considerations that have been highlighted in the literature.

Children up to the age of 7 years normally require pharmacological immobilization for successful MRI examination. These techniques are not without complications or side-effects. A few of the controversies regarding these techniques include:

- Sedation failures in children undergoing MRI.
- General anaesthesia with spontaneous breathing.
- Side-effects after inhalational anaesthesia for cerebral MRI.
- Noise in the MRI scanner.
- Iatrogenic hyperthermia following MRI.

Sedation versus General Anaesthesia

The need for immobility is essential for successful MRI imaging. A variety of sedative agents, including chloral hydrate, benzodiazepines and pentobarbital, have been used. These agents fail to produce the depth of sedation necessary to complete the diagnostic test. Sedation failure increases cost and potentially delays diagnosis. Unfortunately, it remains difficult to predict whether sedation is likely to succeed or fail for any given child.

A study examining the relationship between temperament and sedation failure during MRI and computer tomography(CT) revealed that children who were less adaptable, and tended to be less positive in mood according to a Behavioural Style Questionare, and who were difficult to manage according to their parents, were likely to fail sedation.[1]

Spontaneous breathing versus controlled ventilation

Controlled ventilation requires tracheal intubation which significantly increases induction time.[2] However, spontaneous breathing is associated with higher $ETCO_2$ which can be a concern in patients with raised ICP. Recovery times appear to be similar between the two techniques.

Side-effects of Inhalational anaesthesia for cerebral MRI

A problematic number of side-effects has been reported in paediatric out-patients following General Anaesthesia(GA) for cerebral MRI in a recent study.[3]

Cerebral MRI is one of the commonest investigations in the MRI suite. Indications include, suspected tumours, cerebral malformation, epilepsy/seizures and mental retardation. Side-effects include the following, with their relative incidence in brackets:

Agitation	(22%)
Nausea	(12%)
Vomiting	(11%)
Hiccough	(11%)
Conjunctival injection	(8%)
Rhinitis	(8%)
Rash	(7%)
Fatigue	(7%)
Vertigo	(5%)

Diarrhoea	(5%)
Headache	(2%)
Fever	(2%)
Laryngitis	(2%)
Bronchospasm	(2%)

There appears to be no association between the side-effects and specific inhalational agents. A significant association for the appearance of any neurological side-effect and the site of cerebral tumours seems apparent.

A clear association between existing infratentorial pathology and the occurrence of neurological side-effects such as agitation, headache, hiccough, fatigue or vertigo in children aged ≥5 years exists.[3] These side-effects may persist for up to 72hrs after the MRI. Side-effects in children under 5yrs of age may be under-reported due to inability to communicate these symptoms.

The contrast agent gadolinium, which substantially improves the imaging quality of MRI, could potentially induce side-effects. After intravenous administration, it has an elimination half-life of 90 min. This substance is cleared by renal elimination. Severe anaphylaxis is rare, but nausea and vomiting has been reported.[3]

It is therefore mandatory that physicians provide parents with adequate advance information about the types of side-effects after diagnostic MRI procedures.

Noise in the MRI scanner

Acoustic noise in the MRI scanner can be a tapping, knocking or chirping noise produced by rapid alteration of currents within the gradient coils. Studies indicate that without protection, the noise can lead to temporary hearing loss.[4] The measured noise ranged from 82 to 92decibel. It is worth noting that average daily exposure of 90decibel only protects 85% of the exposed population from significant hearing loss.

The following active and passive noise reduction techniques may be employed:

Active: computer-generated low-frequency pulsatile sound waves that 180° out of phase with the anticipated noise. This offers a reduction of approximately 10 decibel through headsets.

Passive: foam earplugs, if sited correctly, may reduce a continuous non-impulsive noise of 92-63 decibel.

Iatrogenic hyperthermia during MRI[5]

Radiofrequency energy absorbed during MRI increases the patients body temperature. This is particularly prevalent during long scans with high-energy sequences. Although hypothermia is more common during MRI, this case report stresses the importance of temperature monitoring during MRI.

Radiofrequency shielded temperature probes are currently in use to monitor temperature in the USA only!

Finally, although not studied, there is some general debate about high intensity magnetic field exposure and neurophysiological function. These electromagnetic fields may potentially cause health symptoms in everyday life.

Conclusion

Magnetic resonance imaging provides a new and challenging field for the anaesthetist. Cardiac MRI, which falls beyond the scope of this review, presents a unique set of challenges and requires constant modification of our anaesthetic technique. So, watch this space!

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