Anaesthesia for MRI

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<u>Introduction</u>

Magnetic Resonance imaging is the use of extremely high magnetic fields and radiofrequency modulation in order to produce two and three-dimensional scans. It does not produce any ionising radiation and there is no evidence that the strong magnetic field has any deleterious effects on humans.

The safety issues relate to the effects of the strong magnetic field on ferrous objects that might be either in or on the patient, that are in the MRI room, the monitoring and other equipments function and effects on MRI scanning, and the noise that is generated when the scan is being done.

The principle behind intra-operative MRI is that the surgeon can do repeated scans during tumour resection to ensure that the greatest amount of tumour can be resected with the least amount of harm to normal tissue. Macroscopically it is often very hard to tell tumour from normal brain.

The RPAH Intra-operative MRI suite is the first of it's kind in the Southern Hemisphere. The MRI is a Siemens Espree with a 1.5 Tesla magnet. We did our first case on 10 September 2007. It took 14hrs!

How does MRI work (from Wikepedia)

Magnetic resonance imaging was developed from knowledge gained in the study of nuclear magnetic resonance. In its early years MRI was referred to as **nuclear magnetic resonance imaging** (NMRI), but the word nuclear has been associated with ionising radiation exposure, which is not used in an MRI, so to prevent patients from making a negative association between MRI and ionising radiation, the word has been almost universally removed. Scientists still use the term *NMR* when discussing non-medical devices operating on the same principles.

One of the inventors of MRI, Paul Lauterbur, originally named the technique *zeugmatography*, a Greek term meaning "that which is used for joining".[3] The term referred to the interaction between the static and the gradient magnetic fields necessary to create an image, but the nomenclature never caught on.

Principle

Medical MRI most frequently relies on the relaxation properties of excited hydrogen nuclei in water and lipids. When the object to be imaged is placed in a powerful, uniform magnetic field, the spins of atomic nuclei with a resulting non-zero spin have to arrange in a particular manner with the applied magnetic field according to quantum mechanics. Nuclei of hydrogen atoms (protons) have a simple spin 1/2 and therefore align either parallel or antiparallel to the magnetic field.

The spin polarization determines the basic MRI signal strength. For protons, it refers to the population difference of the two energy states that are associated with the parallel and antiparallel alignment of the proton spins in the magnetic field and governed by Boltzmann statistics. In a 1.5 T magnetic field (at room temperature), this difference refers to only about one in a million nuclei since the thermal energy far exceeds the energy difference between the parallel and antiparallel states. Yet the vast quantity of nuclei in a small volume sum to produce a detectable change in field. Most basic explanations of MRI will say that the nuclei align parallel or anti-parallel with the static magnetic field; however, because of quantum mechanical reasons, the individual nuclei are actually set off at an angle from the direction of the static magnetic field. The bulk collection of nuclei can be partitioned into a set whose sum spin are aligned

parallel and a set whose sum spin are anti-parallel.

The magnetic dipole moment of the nuclei then precesses around the axial field. While the proportion is nearly equal, slightly more are oriented at the low energy angle. The frequency with which the dipole moments precess is called the Larmor frequency. The tissue is then briefly exposed to pulses of electromagnetic energy (RF pulses) in a plane perpendicular to the magnetic field, causing some of the magnetically aligned hydrogen nuclei to assume a temporary non-aligned high-energy state. Or in other words, the steady-state equilibrium established in the static magnetic field becomes perturbed and the population difference of the two energy levels is altered. The frequency of the pulses is governed by the Larmor equation to match the required energy difference between the two spin states.

Image formation

In order to selectively image different voxels (volume picture elements) of the subject, orthogonal magnetic gradients are applied. Although it is relatively common to apply gradients in the principal axes of a patient (so that the patient is imaged in x, y, and z from head to toe), MRI allows completely flexible orientations for images. All spatial encoding is obtained by applying magnetic field gradients which encode position within the phase of the signal. In one dimension, a linear phase with respect to position can be obtained by collecting data in the presence of a magnetic field gradient. In three dimensions (3D), a plane can be defined by "slice selection", in which an RF pulse of defined bandwidth is applied in the presence of a magnetic field gradient in order to reduce spatial encoding to two dimensions (2D). Spatial encoding can then be applied in 2D after slice selection, or in 3D without slice selection. Spatially encoded phases are recorded in a 2D or 3D matrix; this data represents the spatial frequencies of the image object. Images can be created from the matrix using the discrete Fourier transform (DFT). Typical medical resolution is about 1 mm^3, while research models can exceed 1 μm^3.

Scanner construction and operation

Schematic of construction of a cylindrical superconducting MR scanner
The three systems described above form the major components of an MRI scanner: a static magnetic field, an RF transmitter and receiver, and three orthogonal, controllable magnetic gradients.

Magnet

The magnet is the largest and most expensive component of the scanner, and the remainder of the scanner is built around it. Just as important as the strength of the main magnet is its precision. The straightness of magnet lines within the centre or, as it is known as, the iso-centre of the magnet, need to be almost perfect. This is known as homogeneity. Fluctuations or, non-homogeneities in the field strength, within the scan region, should be less than three parts-per-million (3 PPM). Three types of magnet have been used:

i)   Permanent magnet: Conventional magnets made from ferromagnetic materials (e.g., steel) can be used to provide the static magnetic field. These are extremely bulky (the magnet can weigh in excess of 100 tonnes), but once installed require little costly maintenance. Permanent magnets can only achieve limited field strength (usually < 0.4 T) and have limited stability and precision. There are also potential safety issues, as the magnetic field cannot be removed in case of entrapment.

ii)   Resistive electromagnet: A solenoid wound from copper wire is an alternative to a permanent magnet. The advantages are low cost, but field strength is limited, and stability is poor. The electromagnet requires considerable electrical energy during operation which can make it expensive to operate. This design is essentially obsolete.

iii) Superconducting electromagnet: When a niobium-titanium alloy is cooled by liquid helium at 4K (-269°C, -452°F) it becomes superconducting where it loses all resistance to flow of electrical current. By building an electromagnet from superconducting wire, it is possible to develop extremely high field strengths, with very high stability. The construction of such magnets is extremely costly, and the cryogenic helium is expensive and difficult to handle. However, despite its cost, helium cooled superconducting magnets are the most common type found in MRI scanners today.

Most superconducting magnets have their coils of superconductive wire immersed in liquid helium, inside a vessel called a Cryostat. Despite thermal insulation, ambient heat causes the helium to slowly boil off. Such magnets, therefore, require regular topping-up with helium. Generally, a Cryocooler, also known as a Coldhead, is used to recondense some helium vapour back into the liquid helium bath. Several manufacturers now offer 'cryogenless' scanners, where instead of being immersed in liquid helium the magnet wire is cooled directly by a cryocooler.

Magnets are available in a variety of shapes. However, permanent magnets are most frequently 'C' shaped, and superconducting magnets most frequently cylindrical. However, C-shaped superconducting magnets and box-shaped permanent magnets have also been used.

Magnetic field strength is an important factor determining image quality. Higher magnetic fields increase signal-to-noise ratio, permitting higher resolution or faster scanning. However, higher field strengths require more costly magnets with higher maintenance costs, and have increased safety concerns. 1.0 - 1.5 T field strengths are a good compromise between cost and performance for general medical use. However, for certain specialist uses (e.g., brain imaging), field strengths up to 3.0T may be desirable.

RF system

The RF transmission system consists of a RF synthesizer, power amplifier and transmitting coil. This is usually built into the body of the scanner. The power of the transmitter is variable, but high-end scanners may have a peak output power of up to 35 kW, and be capable of sustaining average power of 1 kW. The receiver consists of the coil, pre-amplifier and signal processing system. While it is possible to scan using the integrated coil for transmitting and receiving, if a small region is being imaged then better image quality is obtained by using a close-fitting smaller coil. A variety of coils are available which fit around parts of the body, e.g., the head, knee, wrist, or internally, e.g., the rectum.

A recent development in MRI technology has been the development of sophisticated multi-element phased array coils that are capable of acquiring multiple channels of data in parallel. This 'parallel imaging' technique uses unique acquisition schemes that allow for accelerated imaging, by replacing some of the spatial coding originating from the magnetic gradients with the spatial sensitivity of the different coil elements. However the increased acceleration also reduces SNR and can create residual artifacts in the image reconstruction. Two frequently used parallel acquisition and reconstruction schemes are SENSE[4] and GRAPPA[5]. A detailed review of parallel imaging techniques can be found here: [6]

Gradients

Magnetic gradients are generated by three orthogonal coils, oriented in the x, y and z directions of the

scanner. These are usually resistive electromagnets powered by sophisticated amplifiers which permit rapid and precise adjustments to their field strength and direction. Typical gradient systems are capable of producing gradients from 20 mT/m to 100 mT/m (i.e. in a 1.5 T magnet, when a maximal z-axis gradient is applied the field strength may be 1.45 T at one end of a 1m long bore, and 1.55 T at the other). It is the magnetic gradients that determine the plane of imaging - because the orthogonal gradients can be combined freely, any plane can be selected for imaging.

Scan speed is dependent on performance of the gradient system. Stronger gradients allow for faster imaging, or for higher resolution; similarly, gradients systems capable of faster switching can also permit faster scanning. However, gradient performance is limited by safety concerns over nerve stimulation.

In order to understand MRI contrast, it is important to have some understanding of the time constants involved in relaxation processes that establish equilibrium following RF excitation. As the high-energy nuclei relax and realign they emit energy at rates that are recorded to provide information about the material they are in. The realignment of nuclear spins with the magnetic field is termed *longitudinal relaxation* and the time required for a certain percentage of the tissue's nuclei to realign is termed "Time 1" or **T1**, which is typically about 1 second. T2-weighted imaging relies upon local dephasing of spins following the application of the transverse energy pulse; the *transverse* relaxation time is termed "Time 2" or T2, typically < 100 ms for tissue. A subtle but important variant of the T2 technique is called **T2*** imaging. T2 imaging employs a *spin echo* technique, in which spins are refocused to compensate for local magnetic field inhomogeneities. T2* imaging is performed without refocusing. This sacrifices some image integrity (resolution) but provides additional sensitivity to relaxation processes that cause incoherence of transverse magnetization. Applications of T2* imaging include functional MRI (fMRI) or evaluation of baseline vascular perfusion (e.g. cerebral blood flow (CBF)) and cerebral blood volume (CBV) using injected agents; in these cases, there is an inherent trade-off between image quality and detection sensitivity. Because T2*-weighted sequences are sensitive to magnetic inhomogeneity (as can be caused by deposition of iron-containing blood-degradation products), such sequences are utilized to detect subtle areas of recent or chronic intracranial hemorrhage ("Heme sequence").

Image contrast is created by using a selection of image acquisition parameters that weights signal by T1, T2 or T2*, or no relaxation time ("proton-density images"). In the brain, T1-weighting causes the nerve connections of white matter to appear white, and the congregations of neurons of gray matter to appear gray, while cerebrospinal fluid appears dark. The contrast of "white matter," "gray matter'" and "cerebrospinal fluid" is reversed using T2 or T2* imaging, whereas proton-weighted imaging provides little contrast in normal subjects. Additionally, functional information (CBF, CBV, blood oxygenation) can be encoded within T1, T2, or T2*.

Diffusion weighted imaging (DWI) [7] uses very fast scans with an additional series of gradients (diffusion gradients) rapidly turned on and off. Protons from water diffusing randomly within the brain, via Brownian motion, lose phase coherence and, thus signal during application of diffusion gradients. In a brain with an acute infarction water diffusion is impaired, and signal loss on DWI sequences is less than in normal brain. DWI is the most sensitive method of detecting cerebral infarction (stroke) and works within 30 minutes of the ictus.]

Contrast enhancement

Both T1-weighted and T2-weighted images are acquired for most medical examinations; However they do not always adequately show the anatomy or pathology. The first option is to use a more sophisticated

image acquisition technique such as fat suppression or chemical-shift imaging.[8] The other is to administer a contrast agent to delineate areas of interest.

A contrast agent may be as simple as water, taken orally, for imaging the stomach and small bowel although substances with specific magnetic properties may be used. Most commonly, a paramagnetic contrast agent (usually a gadolinium compound[9][10]) is given. Gadolinium-enhanced tissues and fluids appear extremely bright on T1-weighted images. This provides high sensitivity for detection of vascular tissues (e.g. tumors) and permits assessment of brain perfusion (e.g. in stroke). There have been concerns raised recently regarding the toxicity of gadolinium-based contrast agents and their impact on persons with impaired kidney function. Special actions may be taken, such as hemodialysis following a contrast MRI scan for renally-impaired patients.

More recently, superparamagnetic contrast agents (e.g. iron oxide nanoparticles[11][12]) have become available. These agents appear very dark on T2*-weighted images and may be used for liver imaging - normal liver tissue retains the agent, but abnormal areas (e.g. scars, tumors) do not. They can also be taken orally, to improve visualisation of the gastrointestinal tract, and to prevent water in the gastrointestinal tract from obscuring other organs (e.g. pancreas).

Diamagnetic agents such as barium sulfate have been studied for potential use in the gastrointestinal tract, but are less frequently used.

MRI vs CT

A computed tomography (CT) scanner uses X-rays, a type of ionizing radiation, to acquire its images, making it a good tool for examining tissue composed of elements of a relatively higher atomic number than the tissue surrounding them, such as bone and calcifications (calcium based) within the body (carbon based flesh), or of structures (vessels, bowel). MRI, on the other hand, uses non-ionizing radio frequency (RF) signals to acquire its images and is best suited for non-calcified tissue.

CT may be enhanced by use of contrast agents containing elements of a higher atomic number than the surrounding flesh (iodine, barium). Contrast agents for MRI are those that have paramagnetic properties. One example is gadolinium.

Both CT and MRI scanners can generate multiple two-dimensional cross-sections (slices) of tissue and three-dimensional reconstructions. Unlike CT, which uses only X-ray attenuation to generate image contrast, MRI has a long list of properties that may be used to generate image contrast. By variation of scanning parameters, tissue contrast can be altered and enhanced in various ways to detect different features. (See Application below.)

MRI can generate cross-sectional images in any plane (including oblique planes). CT was limited to acquiring images in the axial (or near axial) plane in the past. The scans used to be called Computed *Axial* Tomography scans (CAT scans). However, the development of multi-detector CT scanners with near-isotropic resolution, allows the CT scanner to produce data that can be retrospectively reconstructed in any plane with minimal loss of image quality.

For purposes of tumour detection and identification, MRI is generally superior.[13][14][15] However, CT usually is more widely available, faster, much less expensive, and may be less likely to require the person to be sedated or anaesthetised.

Magnetic Terminology

Magnetic Induction (**B**): Also called magnetic flux density. The magnetic induction is the net magnetic effect from an externally applied magnetic field and the resulting magnetism.

The symbol **H** is used for the magnetic field (measured in amperes per meter). The distinction if often ignored and both are often referred to as the magnetic field (B is proportional to H. B = μH, μ is the magnetic permeability of the medium).

Flux: Invisible "lines" of force that extend around a magnetic material.

Flux Density: The number of lines of force per unit area of magnetic material. I gauss is defined as 1 line of flux per cm^2. The earth's magnetic field is between 0.5 and 1 gauss depending on location.

The **tesla** (symbol **T**) is the SI derived unit of magnetic field. The tesla is equal to one weber per square metre and was defined in 1960[1] in honor of inventor, scientist and electrical engineer Nikola Tesla. 1 tesla is equivalent to 10,000 gauss (G). The earths magnetic field at the equator is 3.1×10^{-5} T. Typical MRI machines are between 1.5 and 3 teslas. The intra-operative Siemens unit we have in theatres is 1.5 teslas.

The field strength decreases as you move away from the centre of the magnet. The devices include active shielding magnets to reduce the magnetic field outside the bore of the magnet. For this reason, the magnetic fields often have unusual shapes. The field drops more than the square of the distance from the magnet to approximately the third or fourth power but there is no simple mathematical relationship.

The **weber** (symbol: Wb) is the SI unit of magnetic flux. It can be defined in terms of Faraday's law, which relates a changing magnetic flux through a loop to the electric field around the loop. A change in flux of one weber per second will induce an electromotive force of one volt.

Faraday's law of induction (more generally, the **law of electromagnetic induction**) states that the induced emf (electromotive force) in a closed loop equals the negative of the time rate of change of magnetic flux through the loop. This simply means that the induced emf is proportional to the rate of change of the magnetic flux through a coil.

In layman's terms, moving a conductor (such as a metal wire) through a magnetic field produces a voltage. The resulting voltage is directly proportional to the speed of movement: moving the conductor twice as fast produces twice the voltage. The magnetic field, the direction of movement, and the voltage are all at right angles to each other. Whenever movement creates voltage, Fleming's right hand rule describes the direction of the voltage.

Fleming's right hand rule (for generators) shows the direction of induced current flow when a conductor moves in a magnetic field.
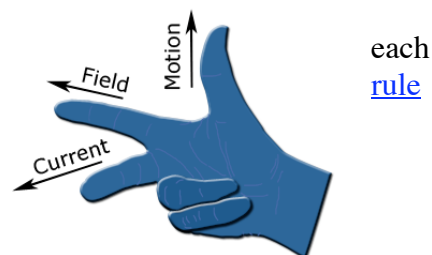
Ferromagnetism

Iron, nickel, cobalt and some of the rare earths (gadolinium, dysprosium) exhibit a unique magnetic behavior which is called ferromagnetism because iron (ferrum in Latin) is the most common and most dramatic example. Samarium and neodymium in alloys with cobalt have been used to fabricate very strong rare-earth magnets.

Ferromagnetic materials exhibit a long-range ordering phenomenon at the atomic level which causes the unpaired electron spins to line up parallel with each other in a region called a domain. Within the domain, the magnetic field is intense, but in a bulk sample the material will usually be unmagnetized because the many domains will themselves be randomly oriented with respect to one another. Ferromagnetism manifests itself in the fact that a small externally imposed magnetic field, say from a solenoid, can cause

the magnetic domains to line up with each other and the material is said to be magnetized. The driving magnetic field will then be increased by a large factor which is usually expressed as a relative permeability for the material. There are many practical applications of ferromagnetic materials, such as the electromagnet.

Ferromagnets will tend to stay magnetized to some extent after being subjected to an external magnetic field. This tendency to "remember their magnetic history" is called hysteresis. The fraction of the saturation magnetization which is retained when the driving field is removed is called the remanence of the material, and is an important factor in permanent magnets.

All ferromagnets have a maximum temperature where the ferromagnetic property disappears as a result of thermal agitation. This temperature is called the Curie temperature.

Ferromagntic materials will respond mechanically to an impressed magnetic field, changing length slightly in the direction of the applied field. This property, called magnetostriction, leads to the familiar hum of transformers as they respond mechanically to 60 Hz AC voltages.

Equipment Classification

In 2006, a new classification system for implants and ancillary clinical devices has been developed by ASTM International and is now the standard supported by the US Food and Drug Administration:

MR-Safe: The device or implant is completely non-magnetic, non-electrically conductive, and non-RF reactive, eliminating all of the primary potential threats during an MRI procedure.

MR-Conditional: A device or implant that may contain magnetic, electrically conductive or RF-reactive components that is safe for operations in proximity to the MRI, provided the conditions for safe operation are defined and observed (such as 'tested safe to 1.5 Teslas' or 'safe in magnetic fields below 500 gauss in strength').

MR-Unsafe: Nearly self-explanatory, this category is reserved for objects that are significantly ferromagnetic and pose a clear and direct threat to persons and equipment within the magnet room.

Magnet Extinction

If one removes the current circulating in the supper conductor then the magnet field will be extinguished. This can not be done quickly and a special device is needed to dissipate the energy contained. The only way to turn off the magnetic field suddenly is to vent the liquid helium to the atmosphere. The helium vessel is contained within another vessel which is vented to the outside world (usually the roof). If the helium vessel ruptures (or the helium is vented) then it will escape into the outside atmosphere. The coils will cease to become superconducting as the temperature rises and the magnetic field disappears. This is not something that will be done lightly as our MRI contains 1700litres at a cost of about $5-10/litre.

Patient & Patient Exclusions

It is not just patients we have to consider, anyone who might enter the MRI theatre must have completed a screening question to exclude them if they have ferrous or electronic objects in them eg: prosthesis, implants, foreign bodies, aneurysm clips, spinal cord stimulators, pacemakers, AICDs, Dentures, ferro-magnetic fillings and any type of Ferro magnetic implants.

Pregnancy; no guidelines have been established for pregnancy

In order to prevent unauthorised access to the theatre all the entrances have keypad security (the PIN is changed monthly) and warning signs at each entrance. Each staff member must also have completed an MRI safety course. This is not the place for the locum anaesthetist or ASEPs staff.

Staff must then remove all potentially ferrous material and place them in a locker in the scrub bay. Credit Cards, mobile phones, PDAs, Pagers, watches, coins etc are removed. Glass Frames are usually safe but should be checked with a strong magnet. There are no phones in the theatre but we have one in the anaesthetic room.

With the layout of our theatre, we can leave pagers just inside the scrub bay and the door to the scrub bay can be left open to hear if they go off.

Anaesthetic Considerations

The major equipment issues revolve around having equipment whose function will not be affected by the strong magnetic field, ensuring that no currents are generated in the equipment that is attached to the patient and minimising the interference with the MRI during imaging.

The need to be physically more remote than usual from the patient means that patient access is limited and one must ensure that all the monitoring and vascular access one needs is placed before the patient is draped.

Our theatre has yellow floor markings to indicate the 0.5 mT line (within which pacemakers will malfunction) and the 5mT line is marked in red.

Every piece of equipment bought into the MRI theatre must be checked before this to ensure to what extent it is ferromagnetic. Any unique important piece of equipment must have a spare in case of breakages during a long case. As the manufacturers do not sell much MRI compatible equipment getting it repaired or replaced may take weeks or even months. Having to stop doing intra-operative MRIs for such a length of time easily justifies the expense of duplicate equipment.

Anaesthetic Machines

Currently Drager, Datex and Ulco make anaesthetic machines. Ulco provides a conventional "boyles" machine with a fairly simple ventilator. It is quite a bit cheaper than the other two. Datex makes an MRI compatible version of the Aesteva workstation. It also has an MRI compatible version of their 7900 ventilator (that includes pressure support). Drager make an MRI compatible version of the Fabius workstation and it includes an MRI compatible ventilator that provides pressure support. Both machines have mechanical flowmeters and vaporizers. Apparently, standard Blease vaporizers are MRI compatible. The Datex workstation has an alarm when the machine is exposed to a greater than 300 Gauss.

The anaesthetic circuit needs to be very long (6m) to allow for rotation of the table into the MRI coil. All the connections to the machine and monitor must be kept neatly together to prevent accidental disconnection.

Gas Cylinders

It seems that standard BOC Oxygen and Nitrous Cylinders are (at present) non-ferrous. They have an aluminium body with brass fittings. Each cylinder should be checked with a strong hand magnet before being bought into the theatre. Ideally, they should be fitted to the machine when the machine is outside the theatre for additional safety. One should not assume that this is so. There are case reports from overseas of gas cylinders flying into MRI magnets and at least one death has occurred from this.

Monitoring

All the monitoring equipment must be appropriately shielded and rated to work within defined magnetic fields. We use the Datex iMMR MRI Monitor that has the usual monitoring functions of the S/5 monitor except for Temperature monitoring. Currently however, there is no way to print trend records however unless one has a Datex central server (which we do not have).

Conductive leads need to be kept as straight as possible to minimise current generation. They should be kept off the patient's skin to prevent burns if they become hot.

Temperature

All our usual temperature probes are conductive and therefore my act as an antenna and can potential heat up and cause harm. We use a Luxtron One temperature system that uses a fiberoptic temperature probe (with a 10m extension).

Fluoroptic® optical sensor technology is based on the fluorescence decay time of a special thermo-sensitive phosphorescent (phosphor) sensor, located at the end of a fibre optic cable (see Figure 1). Light generated by an excitation LED is routed through a probe extension and connectors, where it falls on the phosphor sensor located at the probe tip. Older Fluoroptic® temperature systems used xenon flash lamps that need to be replaced over time, but current systems use LEDs that never need to be replaced. When stimulated with red light from the LED, the Luxtron phosphor sensor emits light over a broad spectrum in the near infrared region (see Figure 2). The time required for the fluorescence to decay is dependent upon the sensor's temperature. After the LED is turned off, the decaying fluorescent signal continues to transmit through the fibre to the instrument, where it is focused onto a detector. The signal from the detector is amplified and sampled after the LED is turned off. The measured decay time is then converted to temperature by the instruments software using a calibrated conversion table. Different calibration tables are used depending on the temperature range and application, but the overall temperature range capability of this optical sensor technology is currently –200C to 330C. The fact that the excitation light signal and the fluorescent decay signal pass along the same optical path means that the fibre optic probes can be relatively small. This is particularly important in medical research applications. Fibre optic probes as small as 0.5mm diameter (STB probe) are available.

The probe is not suitable for insertion to a body cavity so we place it in the axilla.

Pulse Oximetry

The pulse oximetry has use a fibre-optic cable and they are quite fragile. Unfortunately, they also cost several thousand dollars each so you need to be very careful with them and ensure you have a spare. We usually put it on a finger but if they were scanning lower down than the head, you would need to put it on the toe.

Carbon Dioxide and Agents

We use long (6m) gas sampling tubing to an analyser in the Datex iMMR. Good waveforms can be achieved.

Blood Pressure

Whilst it is said that none of the commercial transducers are MRI compatible the ones we use from Surgicare perform perfectly provided they are kept at the end of the table (near the patient's feet) so they do not get particularly close to the magnetic field. A standard arterial line is placed and we have been placing an internal jugular line for secure venous access. Our transducers have 180cm manometer tubing.

As a safety backup an NIBP cuff is also placed on the arm with a 6m hose. This works well but is infrequently used.

ECG

The EKG uses four leads attached to non ferro-magnetic ECG Electrodes. The ECG electrodes are only placed about 20cm apart and can only give approximations of leads I, II and III. The leads are braided together and must not be placed directly on the patients skin in case they heat up. ST segments can not be analysed. When the patient is being scanned, there is often the appearance of ST segment elevation on the ECG. This is apparently due to the ejection of blood (itself a conducting substance) into the aorta during systole inducing a very small current flow.

EEG and Evoked Potentials

These are not practical inside the MRI theatre. We have been using a standalone BIS monitor during the induction (which is done in the anaesthetic room as there are no truly MRI compatible laryngoscopes - in fact the blade, bulb and handle are ok but the batteries are quite ferromagnetic). We use the BIS to gauge how much anaesthetic agent that particular patient needs and then remove the electrodes before the MRI head box is put on the table.

Nerve Stimulator

We place the electrodes over the common peroneal nerve as it winds around the neck of the fibula. The stimulator box is kept at the end of the bed (or fixed to the anaesthetic machine) and disconnected for scanning.

Acoustic Noise

When the MRI is actually scanning, the noise levels are very high, in the range of 110-130db. This is potentially harmful to the patient so foam earplugs are put into each ear to minimise the risk. The staff usually leaves the theatre whilst scanning occurs but provided they have ear protection there is no other reason they have to leave. The noise is due to the rising electrical current in the wires of the gradient magnets being opposed by the main magnetic field. The stronger the main field, the louder the gradient noise.

Patient Warming

Warm air blowers cannot be used in the theatre due to the electrical interference they would create during scanning and the risk of magnetic attraction. There are some very expensive heated water blankets available. What we do is to make sure the patient is wrapped in warm blankets after they have been changed into theatre clothes and when they are in the anaesthetic room, we place a full body warming blanket on them. This is disconnected when the patient is transferred into the theatre. Practically we have not had a problem with patients getting cold. We also use warmed IV fluids (from a warming cupboard in the anaesthetic room. Fluid warmers should also not be used in the theatre unless absolutely needed.

Patient Positioning

Usually these cases are done Supine but they may also be done in the Prone or Lateral Positions. Due to the long duration of these cases (up to 15hrs), the patient must be carefully padded to avoid pressure areas. We use compression stockings and active below knee calf compressors (the compressor is secured and kept well outside the 5mT line

Syringe Pumps

Alaris Infusion syringe pumps have been found to work within acceptable parameters at a static field of 10 mT. We have tested both the newer PK pumps (for TCI) and the older Alaris TIVA pumps and both perform normally.

Endotracheal Tubes/LMAs

Whilst the tubes/LMAs themselves are ok the valves often contain a ferrous spring. As this is very lightweight spring this is not usually an issue (as it can not generate a great amount of force). The valve of the ETT should be taped to the ETT to keep it as far away from the head as possible.

Other Equipment

Wherever possible MRI safe equipment should be used. Trolleys, IV Poles, Chairs etc must all be carefully checked. Equipment should be labelled as to their MRI suitability (as above). Some equipment however is only available in non-MRI compatible form, eg Diathermy machines. In this case great care must be taken to avoid them coming close to the magnet and all such devices must be tethered to the wall or pendant to ensure that they can not get to close to the magnet.

Wheeled devices should have brakes as well (eg, instrument trolleys) but this is not always possible.

If such unshielded electrical equipment is used it will need to be unplugged from power during scanning otherwise the MRI images will be degraded.

Cardiac Arrest

We cannot bring a defibrillator into the theatre. The patient will have to be moved out of the theatre into the anaesthetic room should a defibrillator be needed.

Conduct of the Anaesthetic

The anaesthetic technique chosen is not determined by the fact that the patient is having an MRI. We use the same types of anaesthetic techniques used for non-MRI intracranial surgery, ie Oxygen/Nitrous or Oxygen/Air/Sevoflurane supplemented with Propofol/Remifentanil. Occasionally TIVA will be used. Patients are paralysed with a Cis-atracurium infusion.

The MRI table cannot be tilted so we induce the patient in the anaesthetic room on a trolley that can be tilted. The fact that we are inducing in the anaesthetic room means we are not limited in the equipment we can use BUT we must be very careful that equipment that is not safe to use in the MRI suite is not accidentally bought into the theatre, eg by being left on the patients body/blankets.

IV and infusion lines all need to be very long (5 meters). They must be bundled together neatly to avoid accidental damage.

The patient's are catheterised after induction.

At this stage, we have been placing an Internal Jugular central line to provide secure venous access with multiple lumens. We may revert to our usual practice of placing an ante-cubital fossa peripheral central line instead as we gain more experience.

Once all this is done, we slide the patient onto the MRI table (still in the Anaesthetic room) and then the patient's head is fixed with non-magnetic pin fixation. In order to optimise the image a "head box" containing an RF antenna is put over the patient's head and the patient is then carefully moved into theatre for the initial scan. The head box is removed for surgery and replaced before each scan.

The MRI table fixes onto a pedestal that rotates about an axis. At one extreme, it clips onto the MRI base on which it can slide into the magnet for the scans. The table is then rotated back to the blue position where the surgery occurs.

The Anaesthetic machine is located at the end of the table, next to the magnet. Once the case has started we can not easily enter the anaesthetic room and our access is via the scrub bay (which also has locked doors, these are not shown on the diagram on the right.

The Anaesthetic machine remains in place during rotation of the patient into the MRI machine, which is why long tubing is needed.

At the end of the case the MRI table is disconnected from the pedestal and the patient is moved into the anaesthetic room, transferred onto their bed (tilting) and then woken up and extubated.
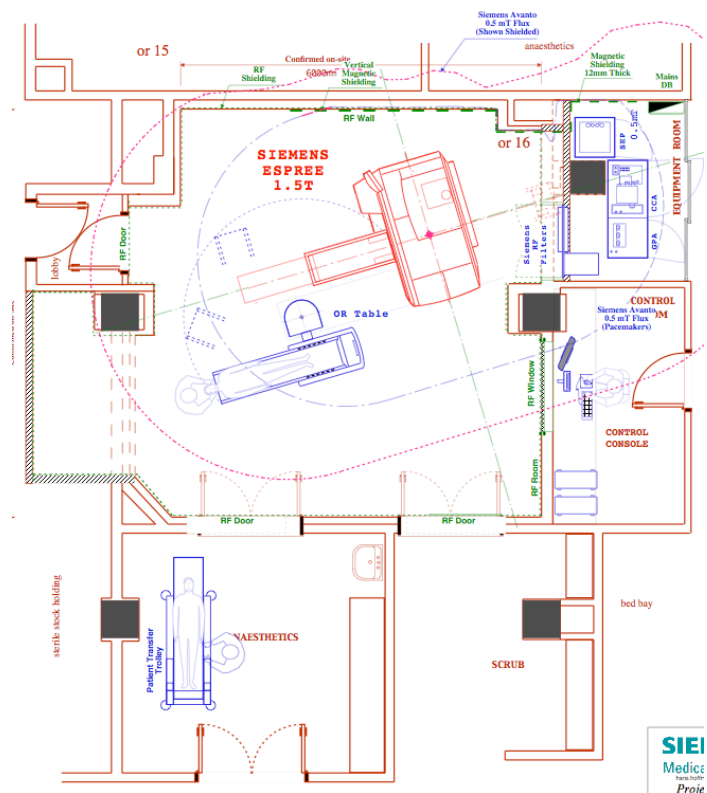
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