Imaging for anaesthetists: a review of the methods and anaesthetic implications of diagnostic imaging techniques

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The traditional role of the radiology department has changed dramatically in recent years. Conventional use of *x*-rays has been augmented by the introduction of more powerful methods of diagnostic imaging. Magnetic resonance imaging (MRI), previously called nuclear magnetic resonance (NMR), and increasing use of computerised tomography (*x*-ray CT) scanning, as well as other imaging techniques have involved the anaesthetist in the management of patients undergoing such investigative procedures.

The aim of this review is to outline the principles of operation of MRI, *x*-ray CT, emission computed tomography, digital subtraction angiography and ultrasound and to consider in which areas they are of most use diagnostically. Techniques of anaesthesia and some of the unique problems facing the anaesthetist during these procedures will be considered. In addition methods of patient monitoring and safety aspects will be addressed.

Key words
ANAESTHESIA: general; DIAGNOSIS: computer assisted; *X*-RAY: diagnostic.

Magnetic resonance imaging

At about the time Roentgen was investigating *x*-rays some hundred years ago, Nicolai Tesla was making bold pronouncements about the diagnostic use of electromagnetism. At the time he was dismissed as a charlatan, but, with the recent introduction of MRI it seems that he will be proved right and medicine now has a powerful new diagnostic tool available.

When the nuclei of certain atoms are placed in a magnetic field they can be made to absorb or emit electromagnetic radiation.[1,2] The spectrum of absorbed or emitted radiation is dependent on the nature of the nucleus and its local chemical environment. Only nuclei with an odd number of protons are MRI responsive,[3] the principal ones of biological interest being hydrogen nuclei (protons), ^{31}P, ^{23}Na, and ^{13}C.

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Principles of operation

An MRI imaging system requires a large bore magnet in the form of a tube capable of accepting the human body. Also in the tube system is a radio-frequency transmitter coil surrounding the patient which also acts as a receiver in order to detect the MRI signal. To prevent imaging artefacts caused by movement the patient is required to keep still during the investigation, this may take up to an hour.[4]

In the presence of the magnetic field the protons in the body act like bar magnets and most align themselves with the magnetic field in the long axis of the patient. Additional perpendicular magnetic pulses are now applied by means of the coil surrounding the patient. The nuclear magnetisation now rotates into the transverse plane. When the pulse is discontinued the magnetisation relaxes (recovers) back to the longitudinal axis. During this recovery the component of magnetisation in the long axis of the patient returns to its original value in an exponential way characterised by the time constant T_1. Relaxation of the magnetisation in the transverse direction back to its orginal value of zero is characterised by another time constant T_2.

During this recovery an electrical signal is induced in the receiver coil which surrounds the patient. The signal detected after such a 90° pulse is called the free induction decay (FID) and it is this signal which is used to reconstruct the image.[5]

Both T_1 and T_2 are sensitive indices of local nuclear and molecular environments and these inherent MRI properties of tissues may therefore be used to distinguish between various normal and abnormal tissue types.[6]

The nuclei of a particular MRI sensitive element will respond only to stimulation by a radiofrequency pulse of a specific frequency, this is known as the resonant or Lamor frequency. This is directly proportional to the strength of the static field; thus, if the patient is placed in a gradient magnetic field a certain frequency will define a particular distance along the body. Using three orthogonal gradients spatial labelling can be obtained and the body scanned slice by slice. By adjusting the gradient fields both coronal and sagittal scans can be obtained[7] (Figures 1 and 2).

The equipment associated with MRI (Figure 3) is mainly concerned with the magnet. Most scanners use some form of electromagnet although perma-

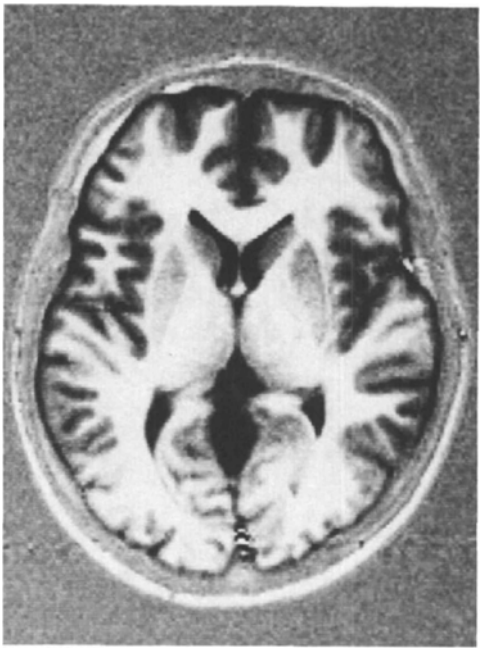

FIGURE 1 Coronal MRI scan of normal brain.

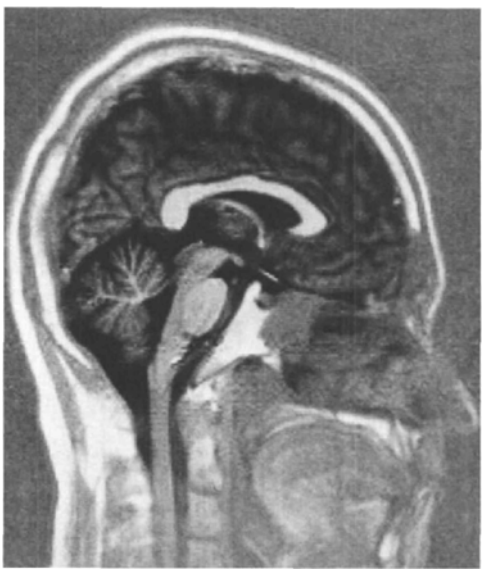

FIGURE 2 Saggital MRI scan of normal brain.

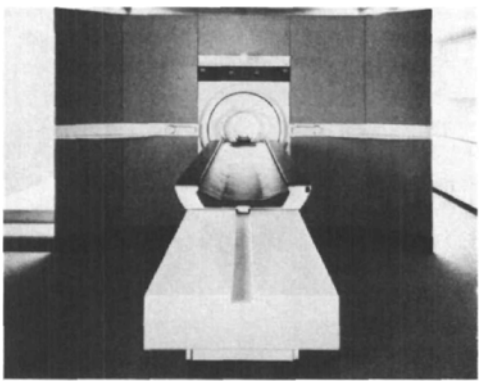

FIGURE 3 Example of an MRI installation, showing the patient feed tube and surrounding magnet enclosed in a cabinet.

nent magnets are available. The field gradients are produced by coils usually mounted on the patient tube. The radiofrequency coils for pulse transmission and signal reception are mounted close to the patient. Two types of electromagnet are currently available, resistive and super-conductive. Site selection for the MRI facility is very important and involves consideration of factors such as the effect of the magnet on the environment and the effect of the environment on the magnet. In some cases a purpose-built structure may be necessary. The magnet is a large device being over 2 metres long, 2 metres wide, 2.5 metres high, and weighing some 5000 kilograms.

Clinical applications

The main focus of clinical interest has been centred on the brain (Figures 1 and 2) where the contrast between grey and white matter gives excellent anatomical detail and has even allowed the process of myelinization to be observed.[8] The posterior fossa can be examined without the bone artifact of *x*-ray CT scans making MRI useful in the study of this area.[9–11] Resolution of brain images is about the same as with CT scans but soft tissue contrast is superior. Disadvantages include poor demonstration of calcification and poor differentiation between tumour and peritumour oedema.[5] MRI has also been evaluated in head injury and has been found to be superior to CT scanning in the diagnosis of subdural and intracerebral haematoma.[12]

Magnetic resonance has been used for imaging the neck and with improvements is likely to become an important technique for the demonstration of the thyroid and parathyroid glands and lymph nodes in this area.[13]

In the thorax, MRI has proved useful in delineating mediastinal and parenchymal masses.[14,15] The heart can also be imaged using ECG gated MRI which can be used to detect diseases of the pericardium,[16] congenital cardiac malformations,[17] and experimentally has been used to display the site of acute myocardial infarction without the use of contrast media.[18]

In the abdomen, images have been produced of the liver showing primary and secondary tumours[19] and chronic liver disease.[20] Imaging the pancreas reveals neoplastic, inflamatory and metabolic disorders[21] whilst MRI of the kidney has been described as the most promising modality in the imaging of renal disease.[22]

Other areas studied have included the breast where MRI appears to be useful in distinguishing benign and malignant disease,[23] the spine[24] and lumbar discs[25] and bone for the diagnosis of tumours[26] and osteomyelitis.[27]

As can be seen MRI is an immensely valuable tool for providing anatomical information. However, it can also provide physiological data when used in combination with MRI spectroscopy. MRI responsive nuclei include ^{13}C, ^{19}F, ^{23}Na, ^{31}P, and ^{39}K, but the problem with these biologically important nuclei is that they have lower inherent MRI sensitivity and lower physiological concentrations than the hydrogen nuclei used for routine MRI. However, the fact that the other nuclei may be introduced as tracers or have their intrinsic concentrations mapped renders them potentially very useful.[6]

^{13}C spectroscopy is in its infancy at the moment but studies with ^{13}C labelled substrate have been valuable in following the metabolism of the perfused liver and heart.[28] The interest in fluorine imaging is that the physiological concentration of mobile ^{19}F is virtually zero and therefore compounds containing ^{19}F may be introduced as tracers.[6] This has obvious implications for the study of distribution and metabolism of volatile anaesthetic agents, such as halothane, isoflurane and enflurane, as a recent study of the elimination of isoflurane and halothane from the rabbit brain shows.[29] Imaging of ^{23}Na allows regions of hypoperfusion to be identi-

fied and has been used in experimental animals to demonstrate areas of cerebral and myocardial ischaemia.[30] ^{31}P spectroscopy has been used for metabolic studies in a variety of muscle diseases[31–33] and more recently for the study of birth asphyxia, brain atrophy, meningitis and porencephalic cyst.[34] Oxygen in solution is paramagnetic and may be used as a contrast agent,[4] if a patient is given 100 per cent oxygen to breath the T_1 of the left ventricular cavity falls.

Safety aspects

One of the main attractions of MRI is that it does not involve the use of ionizing radiation and seems to be a very safe procedure. Guidelines for the use of MRI have been issued by the National Radiological Protection Board.[35] They noted that some studies have reported changes that may have developmental consequences and it is therefore recommended that women in the first trimester of pregnancy not be scanned. People fitted with cardiac pacemakers should not be exposed to MRI because the time varying magnetic fields can induce electric currents in the pacemaker leads, which in the case of demand pacemakers may be mistaken for the natural electrical activity of the heart and thus may inhibit pacemaker output. Patients with large metallic implants can be exposed but the exposure should be stopped if discomfort from heating of the implant is experienced. Intracranial clips, for example the ones used in the treatment of cerebral aneurysms, may present a hazard if they are made of magnetic material because of the possibility of movement when exposed to the magnetic field. In view of the remote possibility of induced currents affecting myocardial muscle contractility and inducing arrythmias full resuscitation facilites should be available.

Anaesthetic implications

It seems that MRI imaging is destined to become an extremely valuable diagnostic tool and with its more widespread use the services of the anaesthetist are likely to be called upon. Thus far, most of the work has been with co-operative adults and there are few references to general anaesthesia during MRI. However, with more widespread use in children, the critically ill and the unco-operative, anaesthesia will become necessary.

The main problems facing the anaesthetist are airway management, relative inaccessibility of the patient and monitoring. The body cylinder of the scanner totally surrounds the patient and makes manual control of the airway difficult. However, patients can be observed from either end of the tunnel and may be extracted quickly if necessary and as there is no apparent hazard the anaesthetist may approach the patient in safety.

So far studies in children have not involved the use of general anaesthesia. Brash *et al.*[14] scanned ten patients aged four months to 17 years without sedation and all but the four month-old patient remained co-operative for the procedure. Other workers[8] have sedated paediatric patients with chloral hydrate (75 $mg \cdot kg^{-1}$ orally) with satisfactory results, but some have found that both sedation and immobilisation with restraints was necessary to minimise artefacts due to body motion.[17] A recent report of general anaesthesia for MRI describes a technique involving premedication with oral diazepam, induction of anaesthesia with intramuscular methohexitone and maintenance with an intravenous infusion of methohexitone.[36]

It seems likely that the problem of airway management during MRI will be approached in a similar way to that employed in the CT scanner, e.g., endotracheal anaesthesia,[37] the use of ketamine[37,38] or total intravenous anaesthesia.[39,40] There are, however, unique problems presented by MRI. The first of these is the effect of ferromagnetic objects near the scanner producing artefacts and the second is that such objects can be propelled towards the scanner and held against it with amazing tenacity. Of relevance to anaesthetists are things such as intravenous stands, oxygen and nitrous oxide cylinders and monitoring equipment. Interestingly laryngoscopes are not magnetic, but the batteries are, making intubation difficult in the proximity of the scanner. The use of plastic- or paper-coated batteries should resolve this problem,[36] or alternatively blind intubation either nasally or orally using the Airway Intubator[41] could be employed thus avoiding the need for a laryngoscope. These difficulties can be overcome by moving the equipment away from the magnet or by using non-ferromagnetic materials for example pipeline gases rather than cylinders. Cody *et al.*[34] imaged infants in a perspex cylinder connected to a conventional incubator placed three metres away by suitable tubing so that necessary support systems for the infant could be continued. For an intubated

patient a Bain circuit extended to reach the anaesthetic machine would be suitable for both mechanical and spontaneous ventilation, although for spontaneous respiration a shorter circuit is preferable to reduce the work of breathing.

Monitoring also needs to be considered. Conventional ECG monitoring is not possible because the lead wires have to traverse magnetic fields and are subject to distortion by currents induced by changing magnetic gradients or by motion of the leads in a static field. Although it is possible to exclude interference by the use of radiofrequency filters[34] alternative approaches to this problem are to use a finger plethysmograph or monitor the ECG telemetrically.[17] Monitoring of heart beat and respiratory rate can be achieved using an oesophageal[8] or precordial stethoscope,[36] although these sounds may be drowned by the noise of the scanner. Recently Roth *et al.*[42] described a monitoring system consisting of a blood pressure cuff with plastic connectors, an aneroid chest bellows chest wall movement sensor and a doppler pulse detector. Fibreoptic transmission of ECG signals for gated cardiac imaging has been described as has a laser doppler system with fibreoptic signal transmission for measuring ear lobe or lip capillary blood flow during MR imaging.[43]

Since MRI is not a hazard to personnel, the anaesthetist may safely approach the patient during scanning. However, ferromagnetic objects such as analogue wrist watches and magnetically encoded credit cards should be removed and stored away from the magnet to prevent damage or erasure.

X-ray computerised tomography (CT scan)

This has been in use for over ten years and will therefore be more familiar to the anaesthetist.

Principle of operation

The aim of the system is to produce a series of images by tomographic method. The patient is scanned by a narrow beam of *x*-rays and the tube, detectors and collimators are fixed to a common frame so that *x*-rays passing through the patient are detected by two collimated sensing devices which always point towards the *x*-ray source. Both source and detectors scan across the patient's head linearly, taking 160 readings of transmission. At the end of the scan the whole system rotates by 1° and the process is repeated. This continues for 180° when 28,800 (180 × 160) readings of transmission will have been taken. These are stored in disc file for processing by a computer and a picture reconstructed from the data.[44]

The early scanners concentrated on the head but now the newer ones are capable of scanning both the head and the body.[45] The newer machines are also faster and are less affected by image degrading artefacts caused by motion.[46] The majority of pathologic processes imaged are not sufficiently differentiated according to anatomic or density characteristics to allow histologic diagnosis. Thus the accuracy of CT at the moment depends on the precise definition of morphologic characteristics or the capacity for CT guided percutaneous aspiration.[46] Recent advances such as shorter scan time and more rapid image reconstruction have decreased the average examination time to 30 to 40 minutes. A variety of computer manipulations (reconstructions) can be performed after the examination including the production of alternative anatomic displays (sagittal and coronal sections).[46] Although this does involve some loss of image quality. Finally it should be remembered that unlike MRI, CT does involve exposure to ionising radiation both for the patient and the anaesthetist.

Clinical applications

The most familiar use of CT is in the scanning of the head (Figure 4) for the diagnosis of intracranial neoplasms such as gliomas, meningiomas, pituitary adenomas, craniopharyngiomas and metastatic lesions. Intracerebral, subdural, and extradural haematomas are well shown as are the changes associated with cerebral atrophy, infarction, oedema and contusion. Hydrocephalus is well demonstrated and the presence of cerebral arteriovenous malformations and intracranial aneurysms can be detected.[47]

In the thorax CT has proved useful in the detection of intrapulmonary[48] and mediastinal masses such as thymoma[49] and ectopic parathyroid gland.[50] Both lung abscess and empyemata are well shown by *x*-ray CT.[51] One very important diagnostic area is acute diseases of the thoracic aorta particularly for suspected aortic transection or dissection.[52] CT has been used in the diagnosis of a variety of pericardial abnormalities such as benign and malignant diseases, effusions and congenital defects.[53] Rapid sequence CT following a bolus

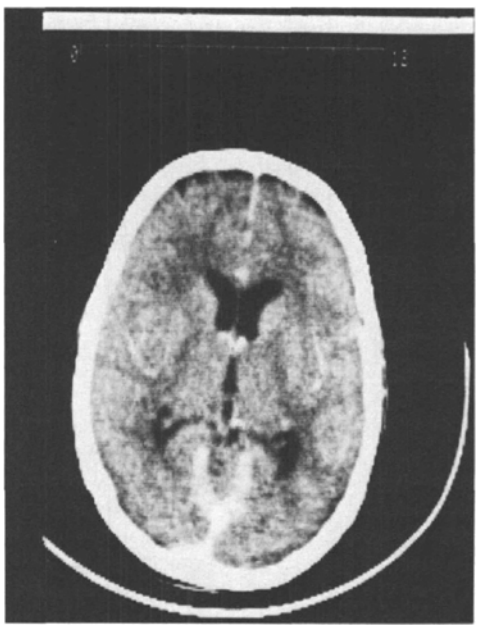

FIGURE 4 *X*-ray CT scan of normal brain at a comparable level to Figure 1.

injection of contrast may be used to evaluate the patency of coronary artery bypass grafts.[54]

In the abdomen CT is excellent for the diagnosis of intra-abdominal abscess,[55] and is an accurate and clinically useful tool in the evaluation of patients with blunt abdominal trauma.[56] It is an excellent technique for staging known malignant disease of the gastrointestinal tract[46] and for demonstrating metastases in the liver, the extent of hepatocellular carcinoma and for non-invasive imaging of the biliary tract.[46] At the moment CT is the most accurate radiological imaging technique for use in patients with suspected acute pancreatitis or one of its complications,[57] and for the diagnosis of pancreatic carcinoma.[58] Imaging artefacts caused by respiratory movements can be a problem in this area[21] and anaesthesia and ventilatory control may become necessary. *X*-ray CT is the preferred screening examination in patients with suspected adrenal tumours.[59] As far as the kidney is concerned CT has found its most common application in the investigation of renal masses but it can also be useful in acute renal diseases such as infection and infarction.[60] CT of the retroperitoneum can be used to diagnose tumours,[61] and retroperitoneal haemorrhage[62] and to detect abnormalities of the abdominal aorta or aortic grafts.[52] In the pelvis CT is unreliable in that carcinoma of the cervix may be understaged and there is no advantage over ultrasound in the diagnosis of ovarian tumours.[63] In the bladder CT is again unreliable in the staging of malignant disease,[64] and has been shown to be incapable of distinguishing between normal and malignant disease of the prostate.[65]

As far as the musculoskeletal system is concerned accurate diagnosis of spinal fractures and dislocations are possible and complex pelvic fractures and prolapsed intervertebral discs are well demonstrated.[66]

In paediatrics CT is particularly useful for the investigation and diagnosis of multiple abscess collections, mediastinal masses, osteomyelitis, myelomeningocoele, and in major multi-organ trauma.[67]

Anaesthetic implications

Neither sedation nor anaesthesia are required for most adult patients. However, children and uncooperative adults may need general anaesthesia to prevent image degrading movement. The main problem facing the anaesthetist is airway management. Ferrer-Brechner *et al.*[37] found that ketamine anaesthesia and heavy sedation was unsatisfactory because of movement and airway problems. They noted that general endotracheal anaesthesia with either halothane or enflurane in nitrous oxide and oxygen was the most satisfactory technique because of better airway control and prevention of motion. They advised caution, however, in checking that the tube did not kink or become misplaced due to movements associated with the scanning process. In their series, 8 out of 60 cases suffered laryngospasm following extubation. However, other workers noted that in infants and small children, who were normotensive and showed no evidence of raised intracranial pressure, ketamine was a safe and effective means of producing immobilisation for CT scanning.[38] Recently total intravenous anaesthesia with etomidate[40] has been used for CT scanning. Unfortunately the high incidence of involuntary movements with this drug leads to an unacceptable number of technically unsatisfactory scans. Landen and White[68] were able to reduce the

number of general anaesthetics given to children for CT scans by employing a system of sedation using meperidine, promethazine, chloropromazine and trimeprazine.

Monitoring also needs to be considered. Scanning rooms are often cramped and are not conducive to the support of high-risk patients. Facilities should be available for the monitoring of neurologic status, blood pressure, ECG and temperature. One group of workers found that a portable battery-operated unit with temperature probe, ECG, and attachments for connecting intracranial and blood pressure transducers was suitable.[69]

The radiation exposure during *x*-ray CT of the patient is similar to that of a conventional skull *x*-ray. Therefore although the exposure values for personnel attending the patient are minimal they should wear lead aprons as a precaution.[37]

Other imaging methods

Other methods of diagnostic imaging the anaesthetist may encounter include emission computed tomography, ultrasound and digital subtraction angiography.

Emission computed tomography

Emission tomography measures physiologic function. Radiopharmaceuticals can be selected to go specifically to various regions of the body (e.g., ^{123}iodine accumulates in the thyroid). The photons emitted from these radionuclides are detected by scintillation crystals or arrays of solid state detector material which move around the patient, or surround the patient, in order to collect data from multiple angles in a similar way to *x*-ray CT.

There are two types of emmission CT commonly used, single photon emmission and positron emission. Single photon tomography uses gamma ray emitters such as ^{123} iodine, ^{201}thallium and ^{99m}technicium. Positron emission tomography involves the use of radionuclides that emit two gamma rays after the annihilation of a positron with an electron, these travel in exactly opposite directions and are picked up by detectors on opposite sides of the patient. Events are only registered when two detectors are excited simultaneously. Positron emission tomography has been used in the study of regional myocardial metabolism and can be used to noninvasively demonstrate alteration in myocardial metabolism associated with ischaemia,[70] and in the evaluation of coronary artery disease.[71] Brain acid base balance and regional cerebral blood flow have been studied in stroke patients using ^{11}carbon and ^{15}oxygen;[72] ^{11}carbon being made artificially in a cyclotron.[73]

Emission computed tomography is useful in measuring regional blood flow, perfusion, metabolic distribution and tissue metabolism. In this latter application ^{18}F-2-deoxy-D-glucose (^{18}F2-DG), which is taken up by tissues at a rate related to their metabolic activity,[74] has been used to demonstrate liver metastases based on their increased accumulation of ^{18}F2-DG.[75]

Digital subtraction angiography

Using this technique, patency and flow through large vessels such as the femoral, carotid and renal arteries, the aorta and major vessels of the brain can be ascertained by a simple intravenous injection of contrast material. Basically an image taken just before injection is subtracted from one taken when the contrast is in the vascular system. This technique is very sensitive for the detection of carotid artery disease and renal artery stenosis, and avoids the need for arterial infusion of contrast material.[73] It has also been used to assess aneurysms of ventricular and atrial septa,[76] and in the diagnosis of pulmonary embolism.[77]

Ultrasound

This will be familiar to all anaesthetists and has numerous clinical applications. The two basic variables measured are tissue acoustic impedence differences and sound frequency shifts due to motion.[73] Of particular interest to anaesthetists is the fact that ultrasound has recently been used to measure stroke volume and cardiac output noninvasively.[78]

Anaesthetic implications

These techniques pose no special anaesthetic problems but do have relevance because of their application in the intensive care unit. For example, digital subtraction angiography may be used to assess continued patency of carotid vessels or in the evaluation of continued blood supply to compromised limbs. Ultrasound can be used to measure heart ejection fractions and ventricular dimensions. Emission tomography may be useful for assess-

ment of the extent of myocardial infarction or for measuring renal function non-invasively.[73]

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