Regular Review

Magnetic resonance imaging—2: clinical uses

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In the first part of this review,¹ we introduced the basic principles of magnetic resonance imaging. We will now summarise the main established clinical uses of the technique.

Magnetic resonance imaging is the most sensitive diagnostic technique for detecting multiple sclerosis (fig 1), being far superior to computed tomography.^{1a,2} A normal magnetic resonance scan of the brain all but excludes the diagnosis of cerebral multiple sclerosis.³ But multiple areas of abnormal signal are non-specific, being seen not only in patients with multiple sclerosis but also in asymptomatic elderly patients⁴ and in a variety of conditions, notably ischaemic disease.

The combination of the clinical features of multiple sclerosis and multifocal, well circumscribed plaques of altered signal with a predilection for the subependymal, periventricular spaces may, however, be very helpful in managing patients suspected of having the disease, though magnetic resonance imaging without the use of gadolinium diethylenetriaminepenta-acetic acid (DTPA) cannot distinguish between active lesions and those that have been present for many years.^{5,6} The use of magnetic resonance imaging enhanced with gadolinium DTPA to assess the activity of multiple sclerosis lesions appears promising.

Another important use for magnetic resonance imaging is in showing parenchymal brain infection. Various types of abscess and infectious encephalitis, particularly herpes, are readily diagnosed in T2 weighted images, such images being more sensitive than computed tomography at showing oedema accompanying inflammation within the brain.⁷ The ability to show the site and extent of various infections in the central nervous system with magnetic resonance imaging is likely to be of particular use in patients with AIDS.⁸

Similarly, cerebral infarction can be diagnosed at an earlier stage than with computed tomography, largely because magnetic resonance imaging can show the extent and shape of focal cerebral oedema. But magnetic resonance imaging, although more sensitive than computed tomography in detecting early infarcts, frequently cannot distinguish bland from haemorrhagic infarction in early infarcts, a distinction that can be achieved with computed tomography. Therefore, computed tomography is preferred to magnetic resonance imaging in those patients who need imaging for stroke in the first 48 hours.

Aneurysms, including those responsible for cerebral haemorrhage, are sometimes demonstrable by virtue of the altered signal of fast flowing blood, and magnetic resonance imaging is particularly good at showing arteriovenous malformations, again based on alteration of signal due to blood flow through the malformation. Magnetic resonance imaging is so good in this particular respect that it can replace arteriography as the method

FIG 1—Magnetic resonance imaging of head showing high signal intensity lesions of multiple sclerosis in the cerebral substance, mainly in the periventricular areas. Two of the larger lesions are indicated by arrows. The scan is an axial T2 weighted image (courtesy of Dr Paul Goddard, Bristol)

of choice for diagnosing or excluding the presence of an arteriovenous malformation (fig 2).

With the notable exception of acute subarachnoid haemorrhage, intracranial haemorrhages are readily shown with magnetic resonance imaging (fig 3). The appearance of collections of blood in magnetic resonance images has attracted considerable attention,^{9,10} and a simplified explanation is given here because the appearances of blood clots over time provide an insight into the complexity of information available from magnetic resonance imaging. Provided that such complexities are understood, they are potentially very useful in reaching diagnostic conclusions.

The signal intensity of haemorrhage varies substantially with time depending on the local chemical environment and the physicochemical state of haemoglobin and its breakdown products in the area of haemorrhage. Within the first 24 hours a blood collection has the characteristics of a protein rich water solution (high proton density, long T1 and long T2 relaxation times) and appears similar to normal brain or oedematous tissue. Thereafter, oxyhaemoglobin

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rounding brain (fig 4). Whether or not this information is clinically useful varies substantially from patient to patient. But magnetic resonance imaging rarely provides less information than computed tomography, whereas computed tomography rarely provides more information than magnetic resonance imaging. Magnetic resonance imaging is therefore an appropriate initial test, obviating the need for computed tomography in most instances.

Magnetic resonance imaging, like computed tomography, only occasionally predicts a specific histological process and may not even permit the distinction between such processes as neoplasm and infection. Also, differentiating the tumour itself from surrounding oedema may be difficult, although using gadolinium DTPA may help in this respect. Diagnosing metastases in asymptomatic patients presents a somewhat different problem. Here the ability of magnetic resonance imaging to detect small lesions—because of greater inherent contrast between

FIG 2—Axial T1 weighted image through mid-cerebellum showing cerebellar arteriovenous malformation with the serpiginous flow void characteristic of fast flowing blood

FIG 3—Haemorrhage within substance of right occipital lobe (solid white arrow) tracking over cerebral hemisphere in occipitoparietal region (open white arrow). Note the high signal intensity in the blood clot due to methaemoglobin shortening T1 and therefore causing increased signal intensity in these T1 weighted images. (a) Parasagittal section, (b) coronal section

changes to deoxyhaemoglobin at a rate that depends on the surrounding oxygen tension.

Deoxyhaemoglobin alters the local magnetic field so that the T2 relaxation value of protons in the area is shortened (reducing signal intensity in T2 weighted images). This effect is seen in the centre of blood clots within the first day or two. Two or three days later the effect of the breakdown of deoxyhaemoglobin into methaemoglobin can be recognised because of its paramagnetic effect, which results in T1 shortening (increasing signal intensity in T1 weighted images). Oedema will be seen surrounding intracranial haematomas for some 5-12 days. With late stage haematomas, haemosiderin in macrophages may cause profound loss of signal at the periphery of the haemorrhage.

Detection of tumours

The most common clinical indication for magnetic resonance imaging is to confirm or exclude intracranial neoplasms. Most intracerebral primary tumours are relatively large when first discovered and are demonstrable by either computed tomography or magnetic resonance imaging. The advantages of magnetic resonance imaging are that extra details about the precise size, shape, and position can be provided because of the ability to image in three planes and the greater inherent contrast between the tumour and the sur-

FIG 4—Large meningioma of right sided posterior fossa compressing cerebellum and brain stem. Imaging in multiple planes provides the precise size, shape, and position of the tumour. (a) Axial T2 weighted image. (b) Coronal T1 weighted image

neoplasm and normal brain, the multiplanar imaging capability that allows optimal projection of complex anatomy, and the fact that magnetic resonance images, unlike computed tomography images, are not degraded by artefact from overlying bone—comes into its own. An appreciable increase in sensitivity compared with contrast enhanced computed tomography can be achieved if gadolinium DTPA is routinely administered in the search for brain metastases.¹¹

Tumours of the pituitary form a discrete group because they may be suspected even when very small owing to their production of hormones. When available, magnetic resonance imaging has become the most widely used technique for showing pituitary tumours.^{12,13} Microadenomas (tumours less than 1 cm in diameter) may be confidently diagnosed, and magnetic resonance imaging seems to be at least as sensitive as thin section computed tomography with dynamic contrast enhancement at showing such tumours.¹⁴ The precise upward and lateral extent of pituitary macroadenomas, particularly their relation to the optic tract, the anterior end of the third ventricle, and the cavernous sinuses, can be clearly shown by magnetic resonance imaging, largely because of its multiplanar imaging capability (fig 5).¹⁵

Acoustic neuromas may also present clinically when small. Here again, magnetic resonance imaging may show tiny neoplasms, well below the threshold for computed tomography detection, partly because of lack of bone artefact and partly because gadolinium DTPA crosses from the bloodstream into such tumours so that they stand out quite clearly in the appropriate imaging sequences.

Spinal magnetic resonance imaging has been used as an all purpose diagnostic technique to show disease in the vertebrae, the spinal cord and surrounding cerebrospinal fluid spaces, and the discs, ligaments, and facet joints. The ability of magnetic resonance imaging to show these various structures is well illustrated in the computer reconstruction, based on signal received from a normal person (fig 6). Such images are not "computer graphics" programmed by a person with a preconceived version of the spinal column, they are reconstructions performed directly from data provided to the computer from the imaging coils within the machine.

Magnetic resonance imaging can replace computed tomography and myelography for diagnosing such intraspinal conditions as neoplasm, cyst, haemorrhage, syrinx or hydromyelia, and epidural abscess. Magnetic resonance imaging is more sensitive than computed tomography for detecting myelopathy and is better at excluding cord compression. Abnormal signal within a spinal cord of normal diameter may be seen in

FIG 5—Large growth hormone secreting pituitary adenoma. The size of the tumour, particularly its upward extent, is well shown in this mid-line sagittal T1 weighted scan. The tumour extends only slightly above the pituitary fossa and is still well below the level of the optic nerves

FIG 6—Computer reconstruction of spine using data derived from magnetic resonance imaging. This three dimensional colour display shows the anatomical definition achievable with state of the art imaging. The intervertebral discs are displayed in red and the spinal nerves in yellow (courtesy of ISG Technologies, Toronto, Canada)

myelitis, demyelination, or oedema, but unfortunately the altered signal intensity is not specific in that infective, demyelinating, and degenerative myelopathies may all appear similar.¹⁶ Any expansion of the cord is readily detected without the need for contrast agents, and the abnormal signal intensity of the responsible tumour, cyst, or haemorrhage may be characteristic. For instance, fat in a lipoma, cerebrospinal fluid in a syrinx or hydromyelia, and blood in a haematoma may all give characteristic combinations of signal intensity.

With advanced equipment magnetic resonance imaging is as good as if not better than computed tomography or myelography for showing herniation of lumbar discs,¹⁷ though changes in the facet joints are better displayed with computed tomography. The multiplanar capability of magnetic resonance imaging makes it an excellent method of displaying congenital abnormalities such as diastematomyelia, Chiari malformations, myelomeningoceles, and the details of spinal dysraphism. Magnetic resonance imaging seems to be a promising technique for distinguishing post-operative scarring from residual or recurrent disc herniations in patients who have had a previous laminectomy.¹⁸

Magnetic resonance imaging can show arteriovenous malformations in the spinal cord as it can in the brain, but, until its sensitivity for detecting vascular malformations has been determined, myelography and spinal angiography will be needed to exclude such lesions definitively.¹⁶

Magnetic resonance imaging of the musculoskeletal system

Musculoskeletal imaging has become the second most important application of magnetic resonance imaging after imaging of the central nervous system. At first sight this seems surprising as there is no signal from bone itself, but the fact that bone marrow and intra-articular and extra-articular soft tissues are so plainly shown means that musculoskeletal magnetic resonance imaging has found clinically useful applications in showing the size and extent of both primary

(fig 7) and secondary tumours; in showing injuries such as torn menisci in the knee joint; and in diagnosing avascular necrosis with precision at an earlier stage than is possible with other methods.¹⁹ In many parts of the body magnetic resonance produces images with lower spatial resolution and requires longer examination times than computed tomography, but this is not true for most skeletal applications. The lack of motion artefact, the use of surface coils, and the high inherent contrast of the relevant tissues mean that high quality images in any desired plane may be quickly and consistently obtained. At present magnetic resonance imaging has little advantage over plain films or computed tomography scanning for predicting the histological diagnosis of a bone or soft tissue tumour; that aspect remains the province of biopsy, but certain tissues may give rise to characteristic magnetic resonance signals—for example, flowing blood, haematoma, cyst, fibrosis, and fat. A disadvantage is that calcification does not give rise to signal, and tumour matrix calcification is often not visible. Similarly, destruction of cortical bone is often difficult or impossible to recognise even when clearly shown by computed tomography or plain film radiography.

FIG 7—Osteosarcoma of lower femur. The normal bone marrow has high signal in this T1 weighted image owing to its high fat content. The tumour has a lower signal intensity than the marrow but a much higher signal intensity than the normal cortical bone, which shows no signal. The full extent of the tumour is well shown; that the osteosarcoma has broken through into the soft tissues posteriorly is clearly seen (courtesy of Dr Paul Goddard, Bristol)

One widely used application of skeletal magnetic resonance imaging is diagnosing meniscal and ligamentous tears in joints, notably the knee.²⁰ The fibrocartilaginous menisci are seen as low signal structures in all conventional sequences. The diagnostic accuracy of magnetic resonance imaging in detecting torn menisci seems similar to that of arthrography, and it is hoped that many patients may be spared arthrography and unnecessary arthroscopy. Diagnosis depends on showing an abnormal signal within the meniscus (fig 8). An abnormal signal that extends to the meniscal surface indicates a tear, whereas an abnormal signal wholly within the meniscus without reaching the surface is believed to represent one of the stages of intrameniscal degeneration.

The place of magnetic resonance in imaging joints

FIG 8—Magnetic resonance scan of knee showing normal lateral meniscus (white arrow) and torn medial meniscus (black arrow). Note that in this coronal T2 weighted image there is a horizontal band of high signal within the torn medial meniscus, which connects with the high signal synovial fluid. The normal lateral meniscus does not show any intrameniscal high signal

other than the knee and for various other arthropathies remains to be established. Particularly hopeful areas include the shoulder and temporomandibular joints, with magnetic resonance imaging likely to replace arthrography of the temporomandibular joint by providing accurate information about meniscal motion and function.

Other uses of magnetic resonance imaging

The use of magnetic resonance imaging other than for neurological and musculoskeletal applications varies considerably from institution to institution, depending largely on the equipment available and the interests of various specialists. The cardiovascular system, the pelvis, and the liver have all proved fruitful regions of the body for magnetic resonance imaging.

The use of cardiac magnetic resonance imaging varies greatly (fig 9).²¹ Its most widely accepted uses include defining anatomy in complex congenital heart disease—for example, showing details of the pulmonary outflow tract in transposition of the great vessels; showing details of aortic dissection, coarctation, or other anatomically deforming conditions of the aorta; diagnosing intracardiac tumours; and providing details of pericardial processes, particu-

FIG 9—Axial, relatively T1 weighted axial image through transplanted heart at level of left atrium and left ventricle (courtesy of Dr John Bingham, Guy's Hospital, London)

FIG 10—Magnetic resonance imaging of upper abdomen showing large phaeochromocytoma (arrow) of left adrenal gland. The mass shows the very high signal in a T2 weighted image typical of a phaeochromocytoma. K=Kidney. S=Spleen

larly neoplasms affecting the pericardium. The ability to determine the direction and rate of blood flow in the heart and great vessels opens up the possibility of deriving important physiological variables non-invasively.²²

Pelvic magnetic resonance imaging is a potentially useful technique because of the high inherent difference in contrast between the various pelvic organs and their investing fat and the ability to image in any plane. The multiplanar capability is of particular advantage compared with computed tomography, which is limited to the transaxial plane. Magnetic resonance imaging of the liver is potentially both more sensitive and more specific than any other imaging technique for diagnosing metastatic disease or showing the size and extent of a primary tumour, but appreciable technical problems exist in realising this potential.^{23 24} The main problem is the substantial movement that takes place with each breath. Fast imaging methods and algorithms to suppress motion artefact are likely to overcome these difficulties. Similar problems beset imaging the pancreas, kidneys, and spleen, and for the time being computed tomography remains the more informative technique for imaging these organs. The role of magnetic resonance imaging in evaluating adrenal tumours is promising, particularly for patients with phaeochromocytoma (fig 10).²³

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ANY QUESTIONS

What alternatives are there to quinine in treating nocturnal leg cramps in elderly people?

Muscle cramps at night are difficult to study because they occur away from the hospital clinic or laboratory. Explanations for muscle cramps in the literature are therefore based on common sense and speculation as to underlying physiological mechanisms. Quinine has long been prescribed, but if possible treatments other than drugs should be tried. In elderly people a check for possible electrolyte disturbance is an important initial assessment as diuretic treatment is common. A possibility is that the cramp is related to hypovolaemia. Patients may be short of fluid because they restrict intake to avoid having to get up at night to empty their bladder. Simple analgesics such as paracetamol are not usually successful in bringing relief.

The advice based on what is known of the physiology of cramp should be: (a) check the sleeping posture to avoid undue pressure on nerves; (b) check for hypovolaemia

(dehydration) or electrolyte disturbance due to diuretic treatment or disease; (c) check for disturbances of sleep pattern, especially depression; and (d) try to take measures to improve the warmth of the hands and feet, such as wearing bedsocks, and to avoid excessive shortening of muscles caused by the weight of bedclothes—a cradle or small stool in bed can take the weight off the feet.

Cramps may also be due to overexcitability of spinal motor neurones and this may be a consequence or a cause of disturbed sleep. There is room for a trial of drugs to improve sleep patterns—for example, compounds of the benzodiazepine group or an antidepressant, such as amitriptyline or lofepramine—provided there are no contraindications, particularly in elderly patients. Muscle cramps can of course be relieved by stretching, but this too disturbs sleep. In summary, cramps should if possible be managed by local physiological means rather than by resorting to pharmacological agents.—R H T EDWARDS, professor of medicine, Liverpool