Emerging indications for magnetic resonance imaging in neuroradiology

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Summary

When imaging is needed to investigate a patient's neurological problem, computerised tomography is the initial modality to use. Magnetic resonance imaging is increasingly used, but like the other imaging modalities it has strengths and weaknesses that need to be understood if it is to be used efficiently. The main strength of magnetic resonance imaging is its inherently superior soft tissue contrast because of its ability to image many different tissue characteristics. The emerging indications in neurology are based on imaging additional tissue characteristics.

Key words: angiography, multiple sclerosis, stroke.

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Introduction

The role of medical imaging is to maximise the conspicuousness of a disease process, in contrast to the normal background anatomy. To accomplish this most imaging modalities measure, at most, only one or perhaps two tissue characteristics, for example the reflectivity of sound in ultrasound scans or the absorption of X-rays in radiography or CT scanning. Magnetic resonance imaging (MRI) is unique in its ability to image many different tissue characteristics.

Mechanisms of MRI

Originally, magnetic resonance was developed as a biochemical technique. It was used to differentiate the chemical bonds occurring in pure samples of compounds studied *in vitro*. It was found that it was possible to align the hydrogen nuclei contained in organic compounds in a strong magnetic field. Under these conditions the nuclei would absorb and then retransmit radio waves with the frequencies and time constants of these transmissions depending on the differing elements that the hydrogen was bonded to. In order to scale up this technique to image whole patients, rather than just biochemical samples in test tubes, many technical difficulties had to be overcome, however, the underlying biochemical nature of MRI remains.

The signal from the hydrogen incorporated into long carbon chains and other groups is the basis for T1 imaging. This is effectively a map of the position of fat and protein in an organ so T1 imaging provides information about the structural components of an organ and is used to show structural changes. T2 imaging obtains its signal predominantly from the hydrogen in water. T2 images tend to show pathology to the greatest advantage because most pathological processes (for example trauma, infarction or neoplasia) involve an inflammatory reaction with oedema (increased water content).

The original tissue characteristics have now been expanded. New techniques have the ability to image:

- capillary disruption and leakage using MRI contrast materials
- moving fluids (as used in MRI angiography and flow quantification)
- water diffusion across cell membranes (used in diffusion imaging in acute stroke as well as to define white matter tracts)
- frequency shifts in various metabolites (magnetic resonance spectroscopy and fat saturated imaging)
- oxygen concentration of the haemoglobin molecule (used for brain activation and functional MRI).

Strengths and weaknesses of MRI

The main strength of MRI is its ability to delineate soft tissues throughout the body. Other benefits are the lack of ionising radiation and the multi-planar capabilities of MRI. However, MRI does have some weaknesses. Tissues which have a limited hydrogen content, for example cortical bone, produce no signal and so cortical fractures are better imaged with X-rays. Air and soft tissue interfaces produce artefacts which degrade the signal so the lung parenchyma is also not routinely imaged with MRI.

There are some contraindications to MRI. Strong magnetic fields and rapidly changing magnetic gradients produce movement in ferrous metallic materials and can heat up and induce currents in metallic wires and foreign bodies. Patients with metallic foreign bodies of unknown composition, for example bullet fragments or older iatrogenic implants such as aneurysm clips, heart valves and prostheses, should not have MRI. Newer

prostheses are usually manufactured to be MRI compatible, but pacemakers, implanted defibrillators, cochlear implants and nerve stimulators are all absolute contraindications. Satisfactory images can usually be obtained without contrast media, but if it is considered, there may be a risk of harm in patients with impaired renal function.

Neuroimaging

For many years MRI has been a mainstay of neurological imaging. It is often important to define the site and size of brain lesions which may be very small or subtle on CT. The eloquent* nature and specificity of function of many neural structures means that a 5 mm infarct in the brainstem may be of much more importance than a similar lesion elsewhere in the body.

Stroke

In recent years it has been recognised that a stroke is not an 'all or none' phenomenon and that there is some scope for reversing the damage.[1] When a vessel, such as the middle cerebral artery, is acutely occluded, there is cell death in the infarct core within minutes. However, there remains a region of tissue surrounding the core where blood flow from collaterals can maintain the neurons for some time (typically 3–6 hours). These so-called penumbral areas are often of considerable size and it is now known that if the blood flow can be reinstated then this tissue can be saved. The previous nihilism surrounding acute stroke medicine has now changed with the advent of magnetic resonance diffusion/perfusion imaging.

Diffusion imaging is designed to define the infarcted and non-treatable core region. This technique measures the rate of water flow across a cell membrane. Dead cells do not maintain their water and solute pumps and dead tissue can be defined within a few minutes of infarction (it typically takes 1–2 days for infarcted tissue to be defined by CT).[2]

Perfusion imaging uses a bolus of MRI contrast material, which is tracked at one second intervals across the entire brain volume to detect the poorly perfused penumbra surrounding the core. The penumbra has a reduced and delayed perfusion pattern. The relative size of the core and the penumbra is the information required by a neurologist to make a decision as to whether a thrombolytic drug should be given.

Diseases of white matter

Diffusion and perfusion studies are aimed predominantly at grey matter disease, but an offshoot of diffusion imaging also allows a more comprehensive investigation of the white matter.[3]

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*   The term 'eloquent' describes how essential a portion of brain is to normal activities. The eloquent areas of the brain are so specialised that their functions are very difficult to transfer and so damage to these areas leads to permanent loss of function.

Myelin is the lipid insulator surrounding the axons making up the white matter tracts and because water can diffuse along an axon much easier than across the myelin sheath, there is a difference in the diffusion signal along an axonal tract compared to across it. This difference in the diffusion signal along the fibres compared to across them is the so-called fractional anisotropy. Imaging using this technique is beginning to find uses in defining axonal damage in white matter diseases (such as multiple sclerosis) where the changes in the water diffusion are apparent much earlier than with the traditional imaging. It is also sometimes important to know the exact position of a white matter tract, for example a tract adjacent to a brain tumour, as resection of vital tracts, such as the corticospinal tract, can be avoided if they can be visualised despite being displaced or obscured by oedema.

Functional MRI

The scanner has the ability to detect differences in the signal produced by haemoglobin molecules depending on their state of oxygenation. The blood in the capillary bed in areas of the brain which are actively processing information has a different amount of oxygenated versus deoxygenated haemoglobin compared to the background areas.[4] These differences can be detected and maps of brain activation during tasks such as reading, talking or practically any mental activity can be provided. This is a valuable research tool.

Clinical indications are emerging for this technique. These include mapping brain functions (for example where surgery will possibly disrupt an eloquent structure) to minimise functional loss and it has applications in surgery for epilepsy. There is early research to suggest that functional MRI could have a role after a stroke to try and predict the improvement a patient may expect from rehabilitation.

Angiography

Many techniques are available to image the arterial tree. While ultrasound can provide information about superficial arteries, it is very operator dependent and time consuming. Multi-detector CT can quickly image large areas of the vascular tree, but artefacts from calcified plaque in the walls of arteries and the large contrast boluses required remain significant limitations.

MRI has long been able to image arterial or venous structures in a specified region (for example the head or neck) using only the inherent signal changes brought about by the flowing blood. Newer techniques utilising boluses of 10–20 mL of contrast can image much larger regions (even total body angiography is possible with this technique). The practical uses in neuroradiology of this technique, however, are to provide a review of the entire arterial tree supplying the brain from the aortic arch to the cortical branches, as part of a comprehensive

Fig. 1

A contrast-enhanced magnetic resonance angiogram of the arterial supply to the brain
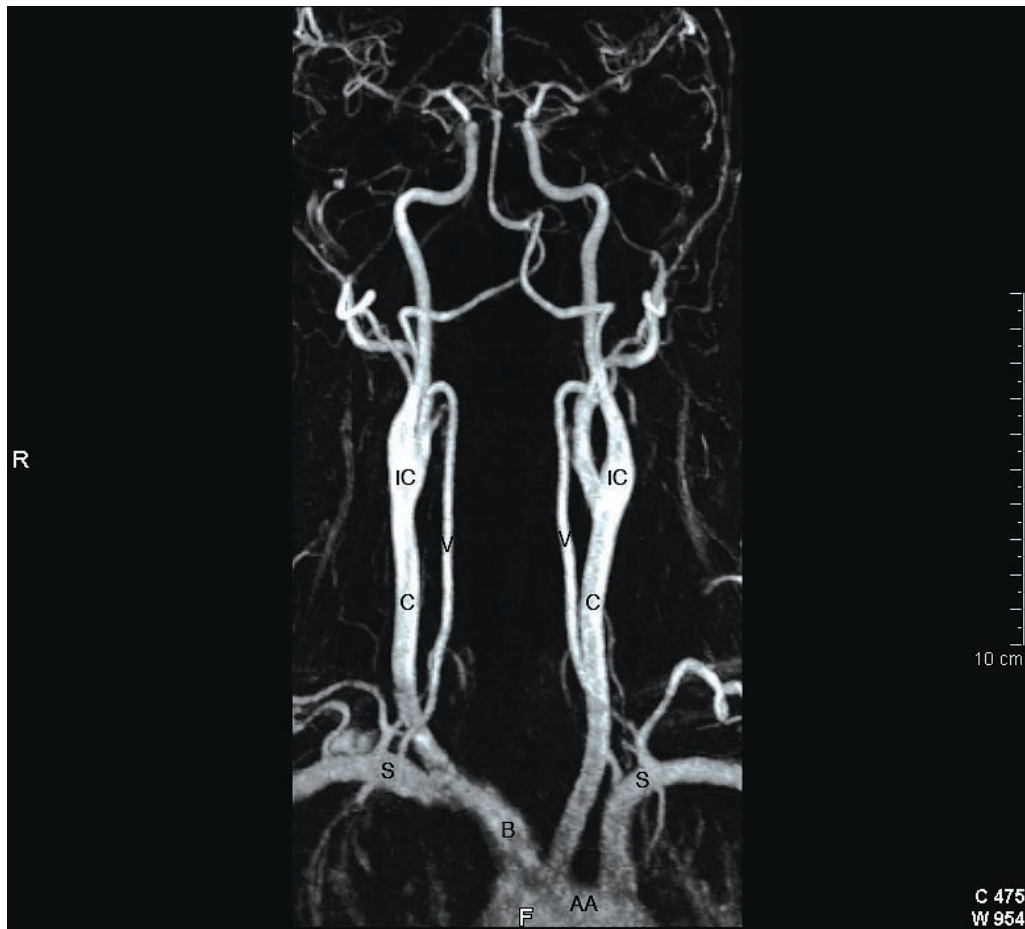
AA	aortic arch	IC	internal carotid arteries
B	brachiocephalic artery	S	subclavian arteries
C	common carotid arteries	V	vertebral arteries

The internal carotid arteries branch within the brain (at the top of the figure) to supply blood to the anterior and middle cerebral arteries. The two vertebral arteries join to form the basilar artery in the midline.

investigation which replaces several separate tests with a single examination (Fig. 1).

Conclusion

The role of MRI in neuroimaging continues to expand. The ability of MRI to image many differing tissue characteristics and the continued research into new applications means that MRI will continue to evolve at a rapid rate.

References

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Conflict of interest: none declared

Self-test questions

The following statements are either true or false (answers on page 27)

5. Following a stroke it takes 1–2 days for the lesion to be detected by MRI.

6. Cochlear implants are a contraindication to MRI.