New techniques

Summary

This article concentrates on the imaging of intracranial structures and outlines some basic imaging strategies for common clinical presentations.

Keywords: intracranial structures, imaging

Imaging modalities in neuroradiology

- plain X-rays
- computed tomography
- magnetic resonance imaging
- angiography
- nuclear medicine
- ultrasound

Figure 1 MRA of the carotid arteries. There is an area of signal fall out (short straight arrow) in the left carotid bulb indicating a stenosis. The normal right internal carotid artery (long arrow) and left vertebral artery (short curved arrow) are shown

Figure 2 Intra-arterial DSA of left carotid artery, lateral view. There is a collection of abnormal vessels (arrow) typical of an arteriovenous malformation

Department of Radiology, St Mary's Hospital, London W2, UK
M Gibson
A Al-Kutoubi

Department of Nuclear Medicine, Guys Hospital, London, UK
G Cook

Accepted 16 October 1995

Intracranial imaging

M Gibson, G Cook, A Al-Kutoubi

Imaging modalities

The various imaging modalities used in neuroradiology (shown in the box) are discussed below.

PLAIN RADIOGRAPHY

The plain skull X-ray has a much diminished role in neuroradiology. Even in trauma its value is limited and should be restricted to specific indications, such as those outlined in the Harrogate criteria; loss of consciousness, amnesia, neurological signs, cerebrospinal fluid (CSF) from nose to ears, penetrating injury, alcohol intoxication and difficulty in assessing the patient.¹ Even then it should be used in conjunction with computed tomography (CT) scanning.

COMPUTED TOMOGRAPHY

The introduction of CT in the early 1980s revolutionised neuroradiology. Since that time it has become increasingly available and is now almost essential for a district general hospital. The head is usually scanned in contiguous 10-mm slices from vertex to posterior arch of the atlas using a small X-ray source and a rotating detector. This protocol is often modified, depending on the area of interest, with thinner slices or different planes. Intravenous contrast media can be administered to improve visualisation of lesions and blood vessels.

MAGNETIC RESONANCE IMAGING

In many areas of neuroradiology magnetic resonance imaging (MRI) has replaced CT as the cross-sectional imaging modality of choice. At present it is less widely available. The physics of MRI are complex but usually T1-weighted images (useful for delineating anatomy) and T2-weighted images (useful for detecting pathology) are obtained. These can be displayed in any plane although usually orthogonal planes (sagittal, coronal and axial) are used. The signal from different tissues depends on the weighting, for instance, water is low signal (black) on T1 and high signal (white) on T2. Contraindications to MRI include ferromagnetic intracranial aneurysm clips, cochlear implants, ocular foreign bodies and cardiac pacemakers. Contrast media are available for MRI and have the same properties as conventional X-ray contrast media (ie, they are taken up by pathologies that disrupt the blood–brain barrier). The indications for contrast media are not well defined. In general, they do not increase the yield of detected lesions (as the tissue contrast in unenhanced MRI is already good) but do help clarify abnormal or equivocal lesions and outline the vessels. MRI has the advantage over CT that it does not utilise ionising radiation.

Magnetic resonance angiography (MRA) can be performed on the same scanner as MRI, although special software is required. The physical property of the flowing blood, rather than contrast media, is used to generate images. It has been used to evaluate the carotid vessels (figure 1). It is also used to image the intracranial vasculature although, as yet, the resolution is not good enough to replace angiography. Future advances in technology may well achieve this.

At present magnetic resonance spectroscopy (MRS) and functional MRI (fMRI) are little used in clinical practice. MRS offers an insight into neurometabolism and will complement morphological information. fMRI is a technique that correlates function and anatomy and both modalities have great potential.

ANGIOGRAPHY

The use of angiography in neuroradiology has diminished since the advent of CT and MRI. However, it does still have a role. It can be performed by an intravenous injection (poor contrast resolution but very safe) or intra-arterially (with a 1–2% risk of permanent neurological damage but excellent resolution). Digital subtraction angiography (DSA) is useful for evaluating the vessels of the neck and intracerebral arteriovenous malformations (figure 2) or

Figure 3 Intra-arterial DSA of right carotid, lateral view. There is a dense area of contrast that is typical of an aneurysm (arrow)

Figure 4 Doppler ultrasound of the carotid bifurcation. A plaque of atheroma (arrow) projects into the lumen of the internal carotid artery at its origin causing a stenosis

Figure 5 CT scan of the brain. A large low attenuation area in the territory of the middle cerebral artery indicates a infarct (arrow)

aneurysms (figure 3). It is the only approach for therapy, for instance, to embolise arteriovenous malformations. More recently angioplasty and endovascular stenting of carotid stenoses has been developed.

NUCLEAR MEDICINE

Conventional, planar, nuclear medicine brain scans have been replaced by MRI and CT. However, scintigraphic cisternography remains a valuable functional technique in differentiating normal pressure hydrocephalus from other types and is a sensitive method for locating CSF leaks.

Advances in single photon emission computed tomography (SPECT) and positron emission tomography (PET) have lead to these becoming important modalities in neuro-imaging. SPECT uses compounds labelled with conventional radioisotopes such as Technetium-99m (99mTc) or Idoine-123 (¹²³I). The gamma camera rotates around the patient. Axial, sagittal and coronal images can be produced from the reconstructed data. The commonest agent used is 99mTc-hexamethyl propyleneamine oxime (HMPAO). This lipophilic substance is taken up and trapped in the brain in proportion to blood flow and so images produced with this radiopharmaceutical represent regional cerebral blood flow, ie, a functional map rather than an anatomical image.

PET scanning makes use of short-lived, cyclotron-produced radionuclides (eg, ¹⁸F, ¹¹C, ¹⁵O). The PET scanner detects paired annihilation photons emitted at 180 degrees to each other, to form tomographic images in any plane. As with SPECT, functional images can be produced, such as glucose metabolism (¹⁸F deoxyglucose), amino acid metabolism (¹¹C methionine) and blood flow (H₂ ¹⁵O). The advantages of PET over SPECT include better spatial resolution, its use of organic substances rather than analogues and its ability to quantitate function accurately. There is limited availability, however, due to the high capital costs in setting up a cyclotron unit.

ULTRASOUND

Ultrasound can be used to image the brains of neonates with patent fontanelles to detect hydrocephalus, haemorrhage or other structural abnormalities. In the older child or adult the skull prevents the ultrasound beam from reaching the brain. However, it can be used to image the arteries of the neck, particularly to detect stenoses of the carotid arteries (figure 4). This technique is operator dependent but when quality control is sufficiently high, some surgeons will operate on ultrasound findings alone. Alternatively it is combined with angiography or used as a screening tool.

Figure 6 Intra-arterial DSA of the carotid bifurcation. There is a very tight stenosis at the origin of the internal carotid artery (arrow)

Figure 7 Intravenous DSA of the origin of the great vessels. The normal great vessels are seen in the upper chest and neck

Figure 8 MRI of the brain, T1-weighted images post contrast. There are large areas of abnormal enhancement (arrows) in the left cerebral hemisphere due to herpes encephalitis

Figure 9 CT scan of the brain. The scan shows fresh subarachnoid blood in the Sylvian fissures (arrows) in a patient presenting with sudden onset of severe occipital headache

Figure 10 CT scan of the brain. A patient presents with increasing confusion several weeks after a minor head trauma. The scan shows an acute on chronic subdural haematoma. Fresh blood is shown as hyperdense (curved arrow) and the chronic collection is shown as isodense (straight arrow)

Imaging strategies

The basic strategies set out below are designed to encompass some common clinical presentations. They represent our opinion and are not intended to be dogmatic. Obviously their use depends on local availability and local clinical opinion. Clinical presentations can be divided into chronic and acute.

ACUTE PRESENTATIONS

Established neurological deficit (ie, stroke persisting longer than 24 h)

CT or MRI are the modalities of choice. In early infarction MRI is more sensitive than CT. However CT does exclude most other important, particularly surgical, causes. Three days after the infarction CT reveals the diagnosis in 80% of cases (figure 5). Both CT and MRI can accurately detect intracerebral haemorrhage. This is important as the management of haemorrhage is different to that of nonhaemorrhagic infarction where aspirin or heparin may be used. For suspected cerebellar or brainstem lesions MRI is preferred to CT as the latter suffers from artefact due to the adjacent petrous bone which obscures much of this region.

Transient neurological deficit

Transient neurological deficits include transient ischaemic attacks (TIAs) lasting less than 24 h or reversible ischaemic neurological disability. Usually CT or MRI is performed to identify any infarction, although in TIAs they are often normal. Assessment of the arteries of the neck is undertaken to identify carotid stenoses which, if treated surgically, will improve the prognosis.² This can be done with duplex ultrasound scanning (dependent on operator skill and often as a complimentary or screening procedure rather than a definitive investigation). Intra-arterial angiography provides high resolution images but carries a 1–2% risk of permanent neurological deficit (figure 6). Intravenous angiography is safer and in most patients adequate diagnostic images are obtained (figure 7). Some patients however will need intra-arterial studies.³ MRA can provide clear images of the neck vessels. It has drawbacks such as overestimation of stenoses, artefacts and long imaging times. However, technical advances make this a promising noninvasive investigation for the near future.

Acute loss of consciousness

Again neither CT or MRI are usually used. CT can be (and usually is) negative in encephalitis or early infarction. MRI is more sensitive than CT but less

Figure 11 99mTc-HMPAO-SPECT transaxial images. An elderly woman with dementia. The cortex is generally thinned in keeping with generalised atrophy and there are additional focal areas of reduced uptake bilaterally and nonsymmetrically, consistent with a multi-infarct aetiology

Figure 12 MRI of the brain. T2-weighted axial images. Multiple high signal areas in the deep white matter typical of demyelination. A typical lesion is indicated by the arrow

accessible (figure 8). It also takes longer, makes monitoring the patient difficult and is more dependent on the patient lying still.

Severe headache

Subarachnoid haemorrhage needs to be confirmed or refuted. CT will usually show subarachnoid blood (figure 9), although if the clinical suspicion is high and the CT scan negative then a lumbar puncture should be performed. The timing of the CT depends on whether the local neurosurgeon requires urgent investigations to precede urgent operation. Angiography is essential before surgery for subarachnoid haemorrhage to identify aneurysms and arteriovenous malformations. It is important to localise the site of the bleeding and to detect any synchronous intracranial aneurysms. Spiral CT and MRA are also being used to detect intracranial aneurysms.

Head injury

The indications for skull X-rays are given above. A cervical spine X-ray can be difficult to obtain but can be vital in trauma to detect associated spine fractures. Further imaging is required if the level of consciousness or neurological deficits does not improve after resuscitation. CT is often used as it is available and easy, when the patient is uncooperative, or in need of close observation. Although it is less sensitive than MRI it detects the majority of lesions that require urgent surgical intervention (ie, subdural and extradural haematomas) (figure 10).

CHRONIC PRESENTATIONS

Chronic headache

This is a common clinical problem and most causes do not require imaging (ie, migraine). However, the presence of atypical or other suspicious features can warrant imaging. The choice between MRI and CT depends on local availability.

Epilepsy

Imaging in epilepsy is often negative. However, recently interest has focused on the use of MRI in intractable temporal lobe epilepsy. The coronal images through the temporal lobes allow inspection of the hippocampus. Lesions such as small gliomas can be detected. Alteration in signal or size of the hippocampus may indicate mesial temporal sclerosis. Both conditions are amenable to surgery. This can lead to improvement or even cure of the epilepsy.⁴ PET scanning with ¹⁸fluorodeoxyglucose (FDG) is the most sensitive method of detecting epileptogenic foci. These cause hypometabolic defects on the interictal scans or hypermetabolic foci during an ictus. Concurrent electroencephalographic monitoring is therefore useful. SPECT is also able to locate these foci due to their reduced blood flow interictally.

Dementia

Imaging seldom contributes to the investigation of dementia. If clinical features are suggestive of a chronic subdural haematoma then this can be detected by either CT or MRI. Both ^{99m}Tc-HMPAO-SPECT and ¹⁸FDG-PET can differentiate between the various types of dementia (figure 11).

Neurological impairment from a cerebral cause

Both CT and MRI can reveal the conditions that may require surgical

Figure 13 Study 1: ¹¹C-methionine. Study 2: ¹⁸FDG-PET brain scans. A patient with a history of astrocytoma of the right frontal lobe resected surgically with possible recurrence. CT was unable to differentiate postsurgical and radiotherapy changes from recurrence. Both ¹¹C-methionine and ¹⁸FDG scans show increased uptake into an area of concurrent tumour (bright areas). High ¹⁸FDG uptake probably means that this is a high-grade tumour. Some low-grade tumours show reduced ¹⁸FDG metabolism in comparison to normal cortex. A right frontal defect is seen, consistent with previous surgery

Figure 14 MRI of the brain, sagittal T1-weighted scan. The scans shows a large tumour occupying and expanding the pons (arrow). The size and position of this tumour made it unresectable. Treatment was with palliative radiotherapy

Figure 15 MRI of the brain. Sagittal T1-weighted image post-contrast. There is a large pituitary adenoma (arrow) expanding the pituitary fossa

intervention (ie, primary or secondary tumours, abscesses or chronic subdural haematomas). Other nonsurgical lesions such as old infarctions or demyelination can also be detected. MRI is more sensitive than CT in detecting demyelination in both the brain and spinal cord (figure 12). The functional nature of PET allows differentiation of recurrent or residual tumour from reactive gliosis secondary to radiotherapy (figure 13). It is the most sensitive modality in this situation.

Visual disturbance

Usually the site of the abnormality can be determined clinically. MRI is useful for imaging the visual pathway from the orbit to the visual cortex.

Cranial nerve palsies

MRI is used to image the brainstem (figure 14) and exit regions of most cranial nerves. The more peripheral lesions are difficult to detect. Investigation of tinnitus, vertigo or sensorineural hearing loss is usually directed towards the detection of acoustic neuromas. This can be done with contrast-enhanced CT but many centres are switching to MRI due to its higher sensitivity.

Endocrine abnormalities

These are usually investigated with blood tests. However, detection of a pituitary adenoma is important, especially if surgery is a possibility. This can be achieved with either MRI or CT (figure 15). The former is preferred, especially for follow-up to avoid exposure to ionising radiation.

1 Harrogate seminar report. *The management of acute head injury* London: Department of Health and Social Security, 1983; no 8.

2 North American Symptomatic Endarterectomy Trial collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high grade carotid stenosis. *N Engl J Med* 1991; 325: 445–53.

3 Stevens JM, Barter S, Kerslake R, Schneidau A, Barber C, Thomas DJ. Relative safety of IV DSA over other methods of carotid angiography and impact on clinical management of cerebrovascular disease. *Br J Radiol* 1989; 62: 813–6.

4 Jack CR. Epilepsy - surgery and imaging. *Radiology* 1993; 189: 635–46.