NEURODIAGNOSTIC IMAGING

Rapid advances in neuro-imaging techniques have increased its value and interest.

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Neuro-imaging is one of the more interesting fields in radiology, and more so since the rapid technological advances of multislice computed tomography (MSCT), magnetic resonance imaging (MRI), and of course positron emission tomography (PET).

The choice of the imaging modality depends on the cost, availability, expertise, side-effects, sensitivity, specificity and accuracy of a particular test. In general it is more prudent to start with the non-invasive tests and to reserve the more invasive tests for complex cases.

The importance of relevant clinical data in imaging cannot be over-emphasised. Clinical details are extremely important, both in tailoring the examination to obtain the maximum amount of information and in interpreting the study.

PLAIN-FILM RADIOGRAPHY

This would include X-rays of the skull (SXR), focal areas of interest in the skull (i.e. orbits, sinuses, pituitary fossa, temporal bones, etc), the craniocervical junction (CCJ), and the spine.

The skull

The paediatric skull

The paediatric skull differs from the adult skull as it is in a constant state of development and change. A basic approach would start off with the skull size, which has to be correlated with the clinical assessment.

The fontanelle and sutures are especially important in children. Wide sutures are present in metabolic diseases (lead intoxication), malignant suture infiltration (leukaemia), and congenital under-ossification (osteogenesis imperfecta), and occasionally as a normal variant. Craniosynostosis refers to the premature closure of sutures (normally at 30 years of age).

Differential closure of sutures results in different skull shapes.

The adult skull

There is considerable overlap between the paediatric and adult SXR, but the adult skull is no less challenging.

Diffuse thickening of the bone is seen in chronic anaemias and in cerebral atrophy after shunting. Focal hyperostosis is seen in meningiomas, Paget's disease and fibrous dysplasia. Generalised bone thinning is seen in rickets and osteogenesis imperfecta, with focal thinning in neurofibromatosis.

Lytic and sclerotic lesions need to be identified in patients with malignancies, while fractures and sinus air-fluid levels are important in trauma patients. Enlargement of the pituitary fossa is seen in pituitary adenomas and in giant aneurysms with associated calcification. The mastoids can appear sclerotic in chronic infections, and the sinuses opacified in sinus pathology.

The normal bony landmark relationships at the CCJ would probably exclude pathological conditions such as basilar

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invagination (a developmental anomaly with the vertebral column prolapsing into the skull base, associated with Chiari malformations); basilar impression (acquired invagination seen in bone-softening conditions); and platybasia (flattening of the skull base).

The spine

X-rays of the spine are essential in all cases of suspected trauma. In children, vertebral abnormalities and spina bifida are initially assessed on X-ray. In adults with lower-back pain (LBP), X-rays are the first line of investigation. This can help separate spondylosis from possible infection (tuberculous discitis, where initially there is loss of disc space with irregularity of the adjacent vertebral end-plates, and later vertebral body height loss and collapse, and kyphosis) or malignant bony infiltration (sclerosis or lucencies with collapse and/or expansion, usually involving the pedicles, and sparing the discs).

Spinal X-rays are also useful in assessing the neural foramina in patients with radicular pains, and neurofibromatosis where the foramina are enlarged with neurofibromas.

Cervical ribs need to be excluded in patients presenting with vague 'neck' symptomatology.

ULTRASOUND

Paediatric ultrasound

The use of ultrasound is especially helpful in neonates, where the fontanelles are open and provide a good window to image the intracranial contents. It is primarily aimed at identifying haemorrhages and features of hypoxic ischaemic damage in premature neonates.

Ultrasound examination of the spine can be performed in infants less than 6 months of age, as the posterior elements of the spine are not completely ossified, providing an ultrasonic window.

Ultrasound in adults

Ultrasound in adults is used to assess the major vessels of the neck in cases of hypertension, diabetes, transient ischaemic attacks (TIAs) and stroke. In these patients it is important to perform Doppler ultrasound to assess vessel calibre, flow direction, turbulence, flow velocity, plaques and vessel stenosis. Transcranial Doppler is used in the assessment of the intracranial vessels, but it is highly specialised and not widely used.

CT SCANNING

CT has improved tremendously in the last few years with the advent of MSCT. This has shortened scan times to a few seconds. It enables volumetric scanning (minimising movement artefact, thereby improving spatial resolution), reconstructions in multiple planes, and much thinner slices, avoiding the risk of missing smaller lesions. Intravenous contrast enhancement has also been optimised, improving the resolution of CT angiography (CTA), which is now often used as a screening or first-line investigation for suspected subarachnoid haemorrhages or arteriovenous malformations.

Specialised software allows 3-D display of images, measurements of lesions, including lesion volume, and viewing of lesions from any angle and in any plane, be it an oblique plane or a curved one.

The disadvantages of CT versus MRI are the ionising radiation, possible contrast allergy, tissue contrast resolution not approaching that of MRI, that it cannot be used in patients with renal dysfunction (unless patient dialysis is an option), and the high incidence of artefacts from high-density foreign objects in the field of view (e.g. metal teeth fillings, aneurysmal clips, bullet fragments).

The advantages of CT are that it is more accessible, much quicker to perform, gives excellent bony detail, and does not require specialised resuscitation equipment.

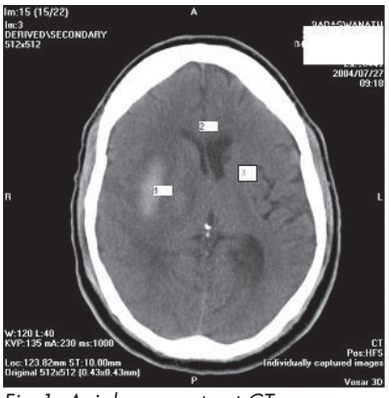
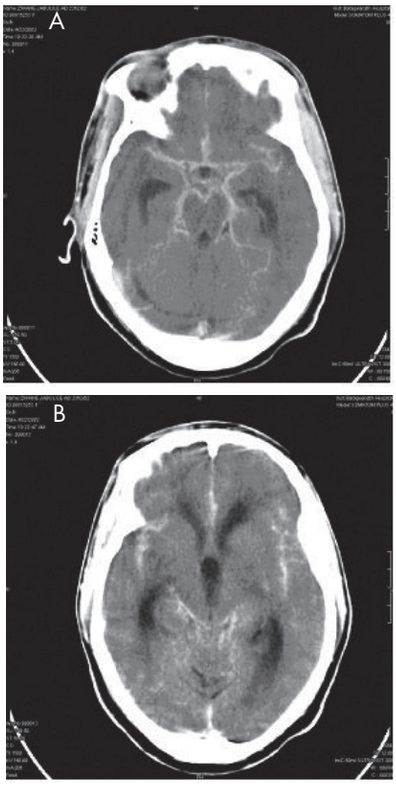


Fig.1. Axial non-contrast CT scan. Adult hypertensive patient with an acute bleed (1 = hyperdense acute blood, 2 = associated mass effect and midline shift, 3 = old lacunar infarct (same density as CSF).



Figs 2a and b. Axial post-contrast CT scans. Adult HIV-positive patient with tuberculous meningitis. Increased meningeal enhancement (due to thick proteinaceous exudates in cisterns and CSF spaces), raised intracranial pressure (usually underestimated owing to associated atrophy), and obstructive hydrocephalus.

In CT we refer to the density of tissues – measured in Hounsfield units. Bone is the densest tissue, appearing white, with fat and then air featuring in the negative (black).

White matter is fattier than grey matter, therefore white matter appears to be darker on CT.

Acute blood is also dense, and presents as a 'white' collection (Fig. 1), while chronic blood is isodense to brain tissue, and is therefore more difficult to diagnose.

Calcifications also appear white. Cysts usually appear hypodense, while fat in masses appears 'dark black'.

Intravenous contrast is often necessary, (except in the trauma patient) as it highlights the pathology (Fig. 2), and there is greater information on site, size and number of lesions.

MAGNETIC RESONANCE IMAGING (MRI)

MRI uses strong magnetic fields and radiofrequency pulses to generate sectional images of the body in any plane.

The major advantages of MRI are that there is no ionising radiation, the paramagnetic contrast is not as toxic to the kidneys, and it has high sensitivity to a wide range of pathologies.

The contrast resolution in MRI is excellent. However, the spatial resolution is not yet as good as it is on CT on available machines.

The disadvantages are the cost, lack of availability, and the fact that it cannot be used on claustrophobic patients unless they are sedated. It is necessary to have MR-compatible resuscitation equipment. The patient also has to be MR compatible; cardiac pacemakers, ferromagnetic valves, ferromagnetic aneurysm clips, and cochlear implants are just a few of a long list of contraindications to MRI.

In MRI we refer to the intensity of the signal that varies according to the sequence used. T1, T2 and fluid attenuated inversion recovery (FLAIR) sequences are commonly used in neuro-imaging. Different sequences are possible with the application of different pulses of varying length. T1 images demonstrate cerebrospinal fluid (CSF) as dark, T2 images demonstrate CSF as white, with white matter being brighter than grey matter, and FLAIR sequences demonstrate all CSF intensity structures as black (Fig. 3).

In a FLAIR sequence the signal from all fluid is attenuated by the application of a special pulse, thereby highlighting white-matter abnormalities.

Improvements in software have resulted in MR angiography having comparable spatial resolution to CTA. It is also possible to perform CSF flow studies where the CSF pathway is highlighted almost in real-time, allowing focal flow restriction or leaks to be identified.

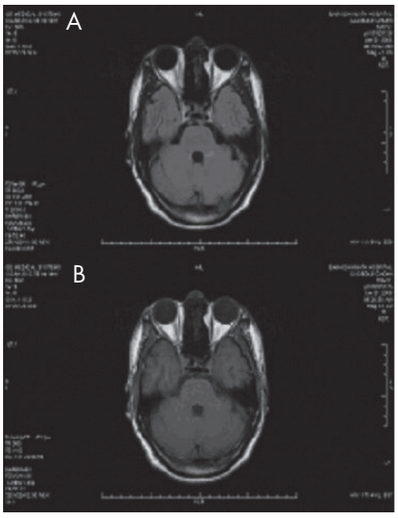
MR diffusion measures random motion of water molecules in the brain. Any limitation to this random motion, i.e. restriction, is picked up as an abnormal signal on specialised sequences. Oedema usually presents with restricted motion. Therefore cytotoxic oedema, as seen in infarcts, is detected within 30 minutes on diffusion scans.

MR perfusion measures rate and volume of blood flow into an area of the brain. It is used in conjunction with MR diffusion, and requires the administration of intravenous contrast.

Functional imaging allows non-invasive mapping of areas such as the sensorimotor and visual cortices.

MR spectroscopy allows detailed regional evaluation of the metabolic functions of the brain, thereby allowing one to differentiate between infection and neoplasia in some cases.

New methods to improve imaging in MR angiography and multiple sclerosis include magnetisation transfer suppression (MTS), where the signal from the brain is suppressed using specialised sequences and the visualisation of abnormally enhancing tissues is increased.



Figs 3 a, b and c. Axial MRI images: T2 FLAIR, T1, T2. Fat is bright on all. CSF is dark on T1, T2 FLAIR and bright on T2. Vessels with normal flow appear as flow voids (see intracranial carotids). Air is black. Dense cortical bone is black. Fatty bone marrow is brighter. Note tiny left lamina papyracea fracture.

However, most of the more specialised MRI techniques are not widely available, and some are only used in overseas academic institutions where 3 tesla and 7 tesla MRI machines are available. Currently 1 - 1.5 tesla machines are being used in South Africa.

POSITRON EMISSION TOMOGRAPHY

PET involves the acquisition of physiological images based on positron emission detection. Currently it is used more for oncology – to detect cancers as well as to assess the effects of therapy. In neuro-imaging PET is also used to evaluate undetermined causes of memory disorders, to investigate refractory seizure disorders, and of course experimentally. PET is not widely used owing to the lack of availability, exorbitant cost and lack of experience in interpreting studies. It is certainly not a modality to entertain lightly.

INTERVENTIONAL RADIOLOGY

Interventional radiology has also kept pace with the general advances in radiology. Neuro-interventional radiology for obvious reasons lags behind general interventional radiology owing to the associated morbidity and mortality. Cranial aneurysms, fistulas, and arteriovenous malformations can be managed percutaneously using coils, detachable balloons, or embolic materials. These treatments can be definitive, or an adjunct to surgery, helping to reduce the morbidity and mortality associated with long and complex surgeries.

SELECTING IMAGING MODALITY

Trauma

CT is often the second line of investigation after plain-film radiography in the trauma setting. The bony detail, hyperdensity of acute blood, and speed of CT make it ideal. Patients at highest risk of significant intracranial injury include those with altered levels of consciousness, penetrating head injury, clinical evidence of depressed fracture, or focal neurological signs. However, medicolegal considerations may influence the decision to scan patients with a normal Glasgow Coma Scale and minor head injury.

Stroke

CT is still the first line of call in patients with stroke. The aim of CT imaging in stroke is to exclude other pathologies that present clinically as a stroke, i.e. intra- or extracerebral haemorrhage, tumour, and infection. CT is preferable to MRI for the demonstration of acute haemorrhage as well as demonstrating a haemorrhagic infarct.

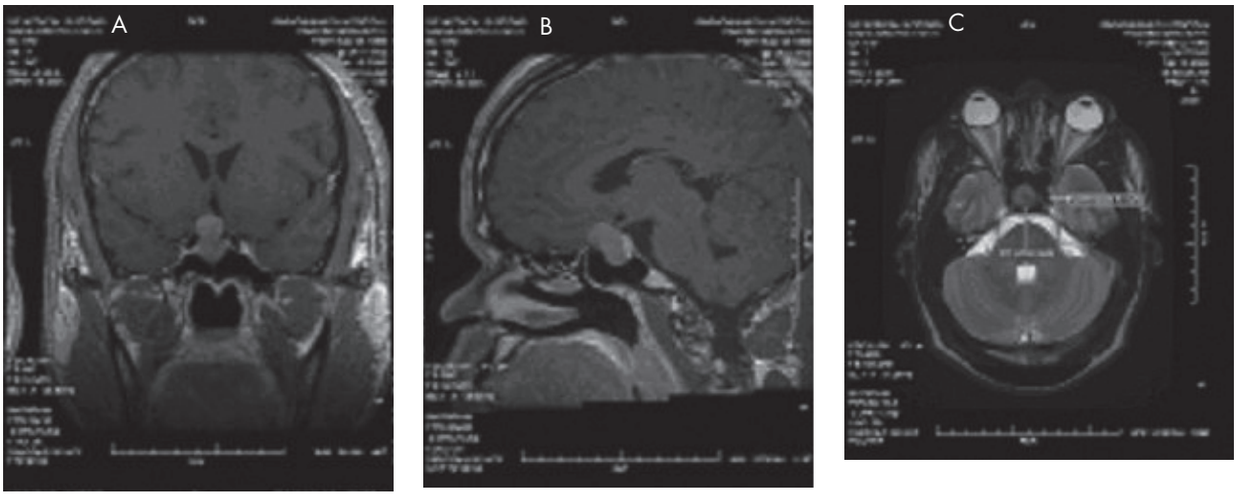
Patients with an acute stroke may be unstable or unco-operative, thus requiring monitoring, which is easier using CT than MRI. However, if the patient is a candidate for acute thrombolysis, MRI is helpful, where MR diffusion and perfusion studies are necessary.

Intracranial masses

Imaging intracranial masses depends on the suspected location and the clinical presentation of the mass.

CT is the first choice of investigation when there is skull-base pathology and sinonasal masses, or if there is confusion as to the nature of the pathology.

MRI is often an adjunct study in patients with brain tumours as the size and extent of the lesion can be better characterised with multiplanar imaging. It gives much better contrast resolution and, as such, is more sensitive to the presence of concomitant lesions.



Figs 4 a, b and c. Coronal and sagittal T1 post contrast, axial T2. Pituitary macroadenoma. There is a soft-tissue mass arising from the pituitary fossa, iso-intense to grey matter on T2, and enhances post contrast. The position, dimensions and extent of this adenoma are well demonstrated.

Lesions arising from the pitutary fossa (Fig. 4), the inner auditory meatus (e.g. nerve-sheath tumours), or the posterior fossa (e.g. haemangioblastoma) are also visualised with greater accuracy on MRI than on CT.

Demyelinating conditions

MRI is undoubtedly the gold standard in evaluating demyelinating conditions such as multiple sclerosis (MS), progressive multifocal leucoencephalopathy (PML), and acute disseminated encephalomyelitis (ADEM) associated with HIV/AIDS.

Infections

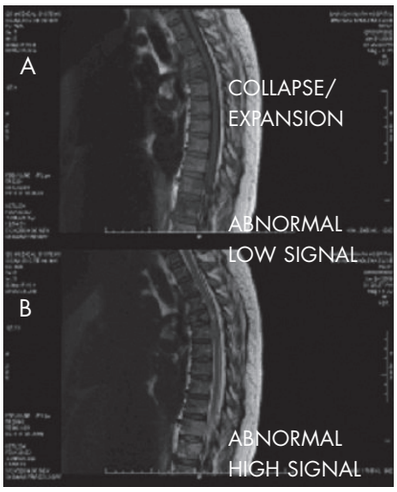
MRI is also superior to CT in the imaging of central nervous system (CNS) infections, regarding number and extent of lesions, and to visualise very early cerebritis, where the associated vasogenic oedema may not be appreciated on CT.

Spinal pathology

Patients with spinal pathology require plain-film imaging, followed by CT scanning if there is a history of trauma.

CT is indicated if there are positive findings on plain films, or if the film is negative and there is a strong suspicion of bony injury, as CT demonstrates bony detail better than MR.

In the acute phase MRI can demonstrate injuries to the spinal cord, disc and ligaments. MRI will also reveal chronic complications such as syringomyelia, arachnoid cyst formation or cord atrophy.



Figs 5 a and b. Sagital T1, T2 thoracic spine. Malignant bony metastatic disease. Fat is bright. CSF is dark on T1, and bright on T2. CSF is dark on T1, T2 FLAIR, and bright on T2. Normal fatty bone marrow is brighter. Abnormal marrow is dark on T1 and bright on T2 D/T. Malignant infiltration in this patient.

Low-back pain

Low-back pain is very common, and initially most patients may only require plain films, which could possibly be the only examination necessary.

Plain films are useful for screening of more sinister pathologies, to evaluate mechanical alignment, and to assess the degree of osteoarthritis.

CT myelography following the introduction of MSCT is used often, especially when MRI is unavailable or if the patient is not MR compatible. It offers direct visualisation of the disc margin, theca, nerve roots, facet joints, and pars interarticularis. CT can clearly demonstrate the level and severity of stenosis.

MRI is the investigation of choice when there are neurological signs and symptoms (Fig. 5). There is no need to administer intrathecal contrast, and the excellent contrast resolution means much more information can be gathered. MRI is the most sensitive technique available to evaluate disc disease, disc herniation, and infection. Cord pathology is also easily identified, as well as early marrow infiltration in malignancies.

This article gives a short overview of neuro-imaging. It by no means covers all aspects of neuroradiology, which is beyond its scope.

Further reading

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IN A NUTSHELL

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