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Radiological investigations in neuroanaesthesia and neurocritical care, part 2: magnetic resonance imaging

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Learning objectives

By reading this article, you should be able to:

- Describe the basic physical principles behind the formation of a magnetic resonance image.
- Identify the common contraindications to MRI.
- Discuss some of the more common clinical indications for MRI.
- Explain with clinical cases and accompanying images the advantages of MRI over CT.

Key points

- MRI provides greater anatomical detail than CT scanning, and the range of sequences available to the radiologist allows for greater detection of pathology.
- A basic understanding of the physics behind the creation of a magnetic resonance image is useful in facilitating image interpretation.
- An understanding of MRI safety issues is essential, because strong magnetic fields, radio-frequency pulses, and i.v. contrast agents are used.

After its advent in the late 1970s, MRI has achieved widespread acceptance as an imaging technique that is an alternative to CT and is free from ionising radiation. MRI has other significant advantages over CT, particularly regarding brain imaging. Because of its greater contrast resolution, MRI depicts anatomy in far greater detail than CT, and the range of imaging sequences available allows for greater sensitivity and specificity in identifying pathology. With the increase in the number of MRI examinations performed and the accessibility of images by clinicians via the picture archive and communication system, images are often reviewed before a formal report is issued by a specialist radiologist. Therefore, a basic understanding of the physics behind the creation of a magnetic resonance (MR) image is required to aid in image interpretation by the general clinician. This article also highlights the main indications and contraindications to MRI in the field of neuroscience, and using cases from our institutions, demonstrates the more common pathologies and associated imaging findings.

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Physics of MRI

The MRI physics is complex, and an in-depth explanation of the various techniques used to create the wide range of sequences available is beyond the scope of this article.

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Nevertheless, knowledge of the basic principles behind MRI is essential in image interpretation.

MRI uses magnetic fields and radio waves, and is essentially the imaging of hydrogen atoms, which are abundant in fat and water. The patient is placed within a superconducting magnet, which exposes them to a strong magnetic field (B_0). Gradient coils are used to define the x, y, and z axes. Within these coils lie radio-frequency (RF) coils, which both transmit and receive RF energy to and from the patient. Protons carry a positive charge and act like a mini bar magnet, all pointing in random directions, resulting in a net magnetic effect of zero. When a patient is placed inside the magnet, the external magnetic field causes the protons to either align with (parallel) or against (anti-parallel) the magnetic field. The majority choose the orientation that requires less energy and line up with the magnetic field. However, roughly three out of each million protons line up anti-parallel to the field, and MRI is based on detecting these protons.[1] These protons demonstrate precession, that is, they spin like a spinning top, and the speed of precession is known as the Larmor frequency. Within the magnet, protons spinning parallel to the magnetic field cancel each other out in all directions other than those spinning along the z axis.[2] This is known as longitudinal magnetisation.

In this state, an RF pulse is applied, causing the protons to pick up energy and spin in step with one another (in phase). This is known as transverse magnetisation, in the xy plane. When the pulse is switched off, the protons relax and return to their more relaxed state, losing transverse magnetisation (T_2 relaxation), and returning to their longitudinal magnetisation (T_1 relaxation). The rate of relaxation of a proton is determined by various factors, including the state of neighbouring protons. By changing the time between RF pulses (repetition time) and changing the timing of when the returned signal is detected (time to echo), different types of images can be produced (i.e. T_1-or T_2-weighted imaging).

There are a huge number of different types of MRI sequences, including diffusion-weighted imaging (DWI), fluid attenuation inversion recovery, susceptibility-weighted imaging (SWI), and others, which take advantage of the various physical properties of protons exposed to RF pulses in a magnetic field. Any further discussion is beyond the scope of this review, but several good reviews and textbooks are available for further reading, including a recent article in this journal.[3] This includes useful diagrams that may help the reader understand the fundamental concepts of MR physics.[1,4–6]

Contraindications

Given the huge magnetic strength of the magnet in MRI scanners, safety checks must be performed with extreme care on all patients before entering the MR department; this can be a potentially hazardous environment especially for the unwell patient. The mechanical forces on medical devices, such as certain pacemakers, older aneurysm clips, and implantable defibrillators that may contain ferromagnetic material, may cause them to malfunction or dislodge.[7] Ferromagnetic material external to the patient becomes a dangerous projectile within the scan room, and serious injury has been known to occur as a result. Clearly, this applies to all medical and anaesthetic equipment used, including trolleys, oxygen cylinders, and monitoring devices.[8] Particular care is required when a patient becomes unstable whilst in the controlled area, and in the case of a medical emergency, such as cardiac arrest, the patient should be removed from the scanner, rather than the resuscitation team entering the scanning room.

RF pulses can cause heating of body tissues. This is usually negligible and in itself rarely a contraindication to MRI. However, implanted devices may heat to a greater degree, causing local injury and potential malfunction of devices, such as pacemakers. Reaction to i.v. gadolinium-based contrast agents is rare and far less common than reactions to the iodinated contrast media used in CT. However, nephrogenic systemic fibrosis has been reported and can lead to severe renal failure, and can seriously affect other tissues, such as the skin, heart, liver, nerves, and lungs.[9,10] I.V. contrast in MRI is also contraindicated for patients who are pregnant.

MRI is noisy because of alternating currents within gradient coils, causing great force upon the coils.[11] It is also a rather claustrophobic environment. These two factors, along with the fact that examinations often require many sequences and can take up to an hour to complete, can make it an uncomfortable environment for certain patients. Patients must also remain extremely still during the examination to avoid patient-related artefacts affecting the image quality. It is important for any referring clinician to assess whether they feel the patient would be able to tolerate the study before making a request.

Indications

CT remains the 'workhorse' investigation in neurosciences because of its accessibility, speed of acquisition, and relative lack of contraindications. However, in many situations, MRI is far superior to CT, and is often required to solve diagnostic dilemmas and to aid in management decisions. There are no definitive guidelines from the Royal College of Radiologists regarding indications for MRI, but some of the more common indications for brain MRI scan requests are listed in Table 1.

Table 1 Common indications for MRI.

Infarct/ischaemia
Haemorrhage
Tumours/metastases
Infection
Diffuse axonal injury
Trauma and suspected non-accidental injury
Inflammatory conditions
Vascular abnormalities

To highlight some of the conditions where MRI holds a significant advantage over CT, and can more accurately identify pathology and limit the differential diagnoses, several clinical cases are described as follows.

Case 1: Diffuse hypoxic ischaemic brain injury

A 20-yr-old female patient was brought to the emergency department after a suicide attempt by hanging. The patient was unconscious with a Glasgow coma score of 3 on admission. The initial CT scan was reported as being normal (Fig. 1A). A sedation hold performed 3 days later showed that the patient was able to move her legs, but only extending her arms to painful stimuli and she was making no sounds. An MRI was performed 3 days later for further clarification and to assist in prognostication. Figure 1B & C: Symmetrical high signal on T_2 weighted and FLAIR sequences within the basal ganglia (solid arrows) and thalami (dashed arrows). There is evidence of restricted diffusion on the DWI with increased signal intensity (Fig. 1D) with associated low signal on ADC (Fig. 1E), in keeping with cell swelling and cytotoxic oedema. This pattern of symmetrical deep grey structure involvement is typical for severe hypoxic ischaemic injury.

As described in Part 1 of this two-part review of neuroimaging, CT can detect signs of hypoxic ischaemic brain injury, although often, these can be very subtle and may be overlooked, especially if scans are performed within the first 24 h.[12] As MRI is exquisitely sensitive to the detection of cytotoxic oedema, it is more likely to provide diagnostic certainty in this situation. Grey matter structures (i.e. thalamus, basal ganglia, and cerebral cortex), with their increased metabolic demands, are more sensitive to the effects of hypoxia and are therefore more likely to be involved. This is a devastating brain insult that invariably leads to death or lifelong neurological deficits.

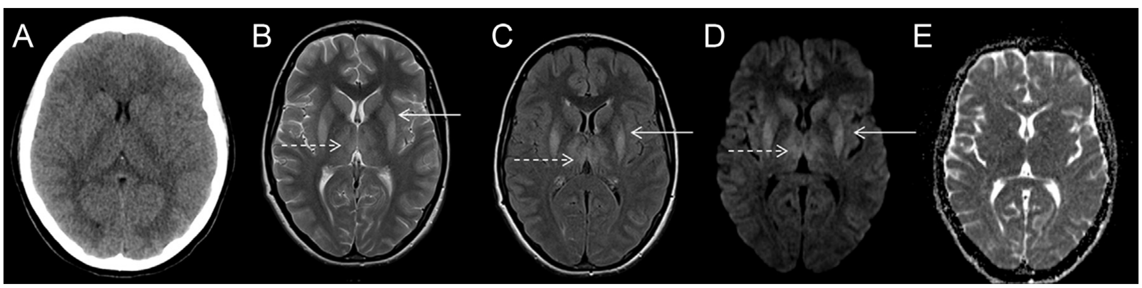

Fig 1 Diffuse hypoxic ischaemic brain injury.

Case 2: Diffuse axonal injury

This image is from a 23-yr-old patient involved in a road traffic collision. The patient was showing abnormal extension movements when sedative drugs were withheld 3 days after the injury. An initial CT head scan as part of a trauma assessment was reported as normal. MRI was performed for further assessment Figure 2A & B: Unenhanced CT does not show any obvious abnormality. Figure 2C & D: gradient echo MRI shows multiple foci of low signal in both superior frontal gyri at the grey-white interface (Fig. 2C − solid arrow) and within the genu of the corpus callosum (Fig. 2D − solid arrow). There is also high T_2 signal within the splenium of the corpus callosum (Fig. 2D − dashed arrow). MR findings are highly suggestive of diffuse axonal injury.

Diffuse axonal injury results from acceleration/deceleration forces resulting in shearing injury to axons. Involvement of the cortex, corpus callosum, and brainstem is seen with progressive severity of force.[13] MRI is much more sensitive in detecting abnormalities compared to CT, and should be considered in any patient with traumatic brain injury where the neurological deficit is out of proportion to CT findings. Blood-sensitive sequences, such as gradient echo recall and SWI, are essential.

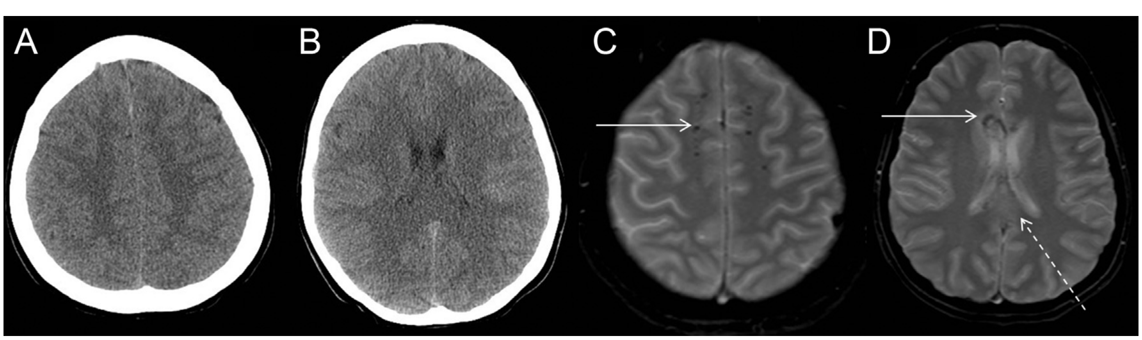

Fig 2 Diffuse axonal injury.

Case 3: Infarction

This scan is from a 79-yr-old patient with acute onset right-sided weakness and numbness. Figure 3A: Unenhanced CT scan showed no obvious abnormality. A subsequent MRI scan demonstrates intense restricted diffusion within the lateral aspect of the left thalamus on DWI and ADC (Fig. 3B & C), with high signal on the T_2 weighted image (Fig. 3D), in keeping with an acute infarct.

Imaging is integral to the diagnosis of acute stroke, and in most cases, an unenhanced CT scan is the initial imaging test, primarily to exclude an acute haemorrhage or a stroke 'mimic'. For larger vascular territory infarcts, the amount of swelling and loss of grey—white differentiation is usually easily detected on CT. However, smaller infarcts in highly eloquent areas of the brain may often be overlooked on CT, and MRI may be required for further assessment. DWI is highly sensitive to cytotoxic oedema, and will demonstrate acute infarcts that are often not visible on CT, even on retrospective review (Fig. 3).

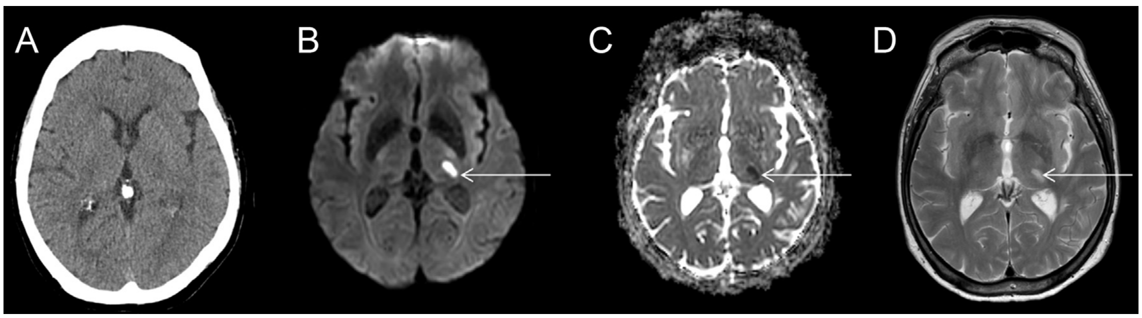

Fig 3 Infarction.

Case 4: Ring-enhancing lesions

A 76-yr-old patient presented with a 2-week history of confusion and word-finding difficulties. MRI demonstrated a large left anterior temporal cystic mass, with minimal surrounding vasogenic oedema (Fig. 4A). After the administration of gadolinium, there was irregular nodular peripheral enhancement with a necrotic centre (Fig. 4B). DWI shows low signal centrally (Fig. 4C), with high signal on the apparent diffusion coefficient (ADC) (Fig. 4D) (i.e. free diffusion of fluid). The DWI characteristics make a high-grade glioma the most likely diagnosis.

There is a wide differential for a ring-enhancing lesion seen on contrast-enhanced CT, including primary or secondary tumour, abscess, and demyelination, just to name a few. The greater soft tissue contrast of MRI, coupled with the properties of DWI, helps differentiate between these different pathologies, which have widely varying treatment options.

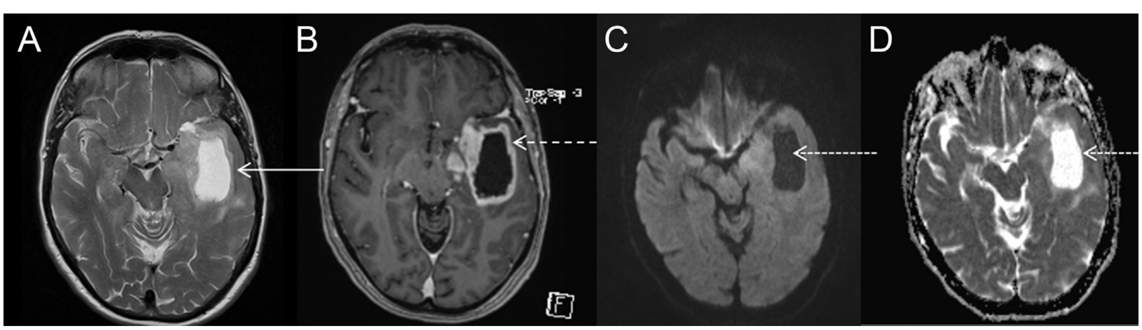

Fig 4 Ring-enhancing lesions.

Case 5: Ring-enhancing lesions

A 48-yr-old patient presented after a seizure and had reported a 1-week history of headache. MRI demonstrated a right frontal lobe cystic lesion with moderate surrounding oedema (Fig. 5A). Post-gadolinium images show a thin, uniform, peripheral enhancement (Fig. 5B). The DWI (Fig. 5C) demonstrated high signal with low ADC values (Fig. 5D). This is typical for an abscess with thick purulent contents that show restricted diffusion. This was confirmed on aspiration. This demonstrates once again the importance of DWI. In the case of intracranial abscess, it is important to interrogate the paranasal sinuses, mastoid air cells, and middle ear cavities as potential sources of infection.

Other clinical scenarios involving infection where MRI is superior to CT are the detections of empyema and ventricular debris. This material has high protein content, and may contain necrotic material and inflammatory cells and bacteria, and on DWI shows as high signal on DWI and low signal on ADC, which are the MR characteristics of restricted diffusion. This is eloquently demonstrated in Figure 5(E–H), respectively. Figure 5(E and F) shows a thin subdural collection to the right of the posterior falx (arrows), which is of high signal on DWI (Fig. 5E and low signal on ADC (Fig. 5F), in keeping with restricting material (i.e. with restricted diffusion), compatible with a subdural empyema. Figure 5(G and H) shows the material within the trigones of both lateral ventricles (arrows), which is in keeping with intraventricular debris, also showing restricted diffusion. Whilst these may be detectable on CT, MRI is again more sensitive.

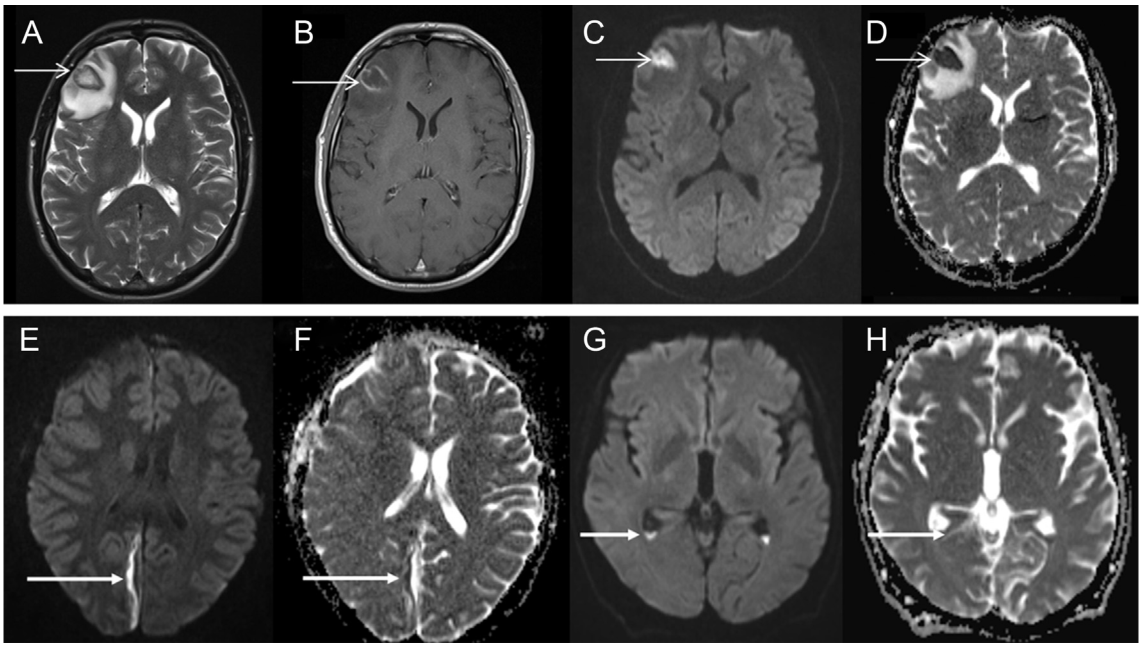

Fig 5 Ring-enhancing lesions.

Case 6: intracranial hypotension

A 54-yr-old patient presented with known nerve root sheath cysts and headaches. Coronal and axial post-contrast T_1-weighted MRI (Fig. 6A and C) shows thick uniform pachymeningeal enhancement and thin high T_2 signal intensity bilateral subdural fluid collections (Fig. 6B). Sagittal T_1-weighted image shows brainstem sagging (dashed arrow) and tonsillar descent (solid arrow). These image findings are the most common, but there are several other features of low pressure, including pituitary gland enlargement, dural venous sinus enlargement, and reduced fluid in optic nerve sheaths.

Intracranial hypotension is defined as CSF pressure less than 7 cm H_2O, and can either be spontaneous (primary) or secondary to lumbar puncture, over shunting or trauma. Patients experience headache relieved on lying down, visual and hearing disturbances, nausea and vomiting, and vertigo. MR brain and spine imaging is useful in suggesting a diagnosis of intracranial hypotension and potentially identifying an underlying cause. Given that underlying causes of spontaneous hypotension include dural tears and dehiscence of perineural cysts, MR myelography may identify the site of potential CSF leak. Referral to anaesthesia is often made for a non-targeted blood patch, the most frequent treatment option.[14]

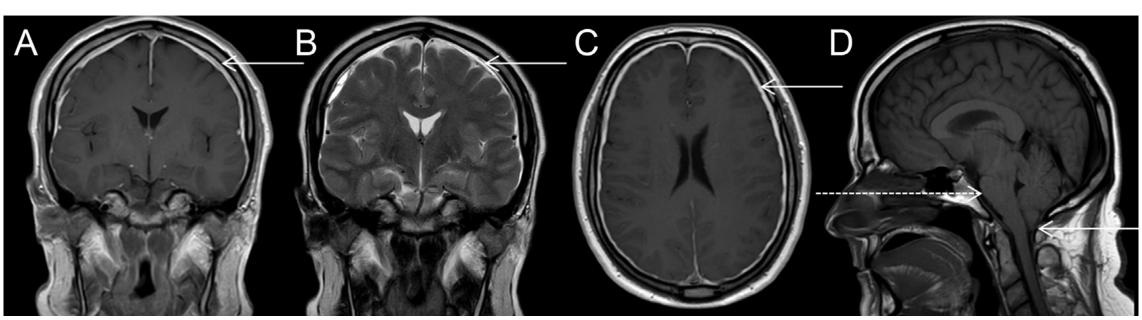

Fig 6 Intracranial hypotension.

Case 7: Leptomeningeal disease

A 40-yr-old patient with chest X-ray changes consistent with military tuberculosis (TB) presented after a 2-week history of headache and increasing agitation. T_2-weighted sequence (Fig. 7A) shows no obvious abnormality. However, contrast-enhanced T_1-weighted sequence (Fig. 7B) shows thick leptomeningeal enhancement around the brainstem and in the interpeduncular fossa (arrow). There was also cranial nerve enhancement (not shown). Appearances are typical for TB meningitis.

Enhancement of the leptomeninges, the arachnoid and pia mater, is seen in a wide range of conditions, and whilst thick enhancement can sometimes be identified on contrast-enhanced CT, contrast-enhanced MRI is the modality of choice to detect it. Some of the many causes include leptomeningeal carcinomatosis, infection (pyogenic, viral, tuberculous, or fungal), granulomatous (sarcoidosis), or vasculitis. Enhancement can either be diffuse and uniform, or in the case of TB, for example, more focal around the basal cisterns. Leptomeningeal carcinomatosis may often be nodular in appearance.

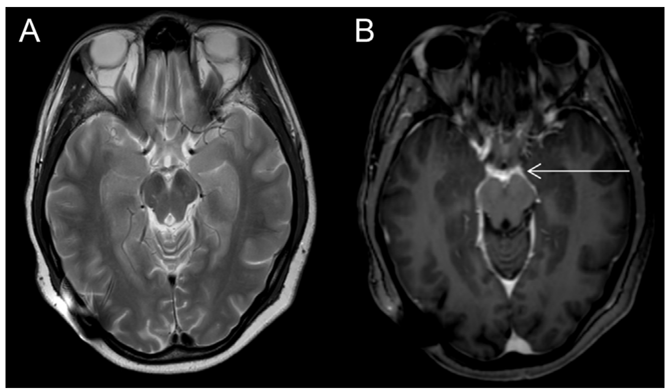

Fig 7 Leptomeningeal disease.

Case 8: Encephalitis

A 72-yr-old man presented with a week history of increasing confusion. An initial CT scan (not shown) demonstrated ill-defined low attenuation in the right temporal lobe. An MRI scan was performed for further assessment. This shows high signal on the axial T_2-weighted sequence (Fig. 8A) in the right temporal and insula lobes with gyral swelling and white matter oedema. This is also shown as low signal on the sagittal T_1-weighted sequence (Fig. 8B). DWI and ADC (Fig. 8C and D) show cortical restricted diffusion. The distribution of these changes is consistent with herpes simplex encephalitis.

Infection, including encephalitis, has been briefly touched on in Part 1 of this article.[12] Whilst CT may often demonstrate the swelling, loss of sulci, and low attenuation changes typical of parenchymal infection, these can often be very subtle, especially in the early stages, and MRI may be required to help make the diagnosis.

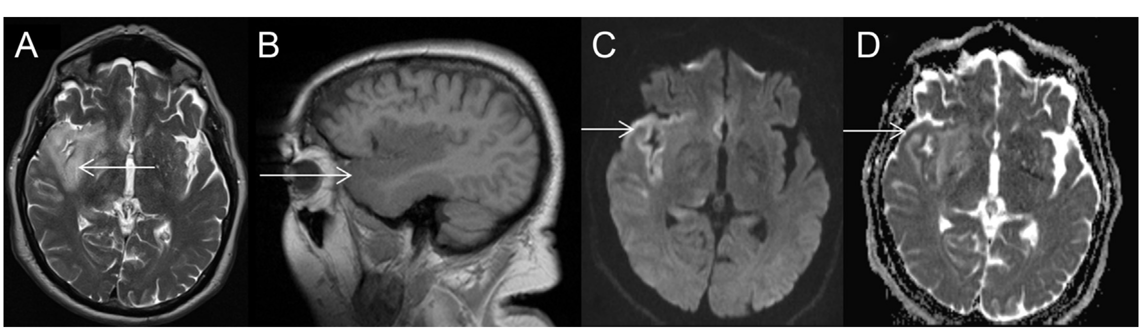

Fig 8 Encephalitis.

Conclusion

MR brain imaging is an invaluable tool in the diagnosis and assessment of a wide range of neurological conditions, and is often required in diagnostic dilemmas or where an initial CT scan is normal despite severely altered neurological signs. We have presented a range of clinical cases to help demonstrate the diagnostic power of MRI, to help clinicians better understand the modality, and to aid in image interpretation.

Declaration of interest

The authors declare that they have no conflicts of interest.

MCQs

The associated MCQs (to support CME/CPD activity) will be accessible at www.bjaed.org/cme/home by subscribers to *BJA Education*.

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