A primer in interpretation of head CT scans

ABSTRACT

Over recent years with the development of increasingly efficient scanners, the computed tomography (CT) scan of the head has become one of the most commonly requested initial investigations, used to provide an overview of the brain and its surrounding structures. In particular, the CT head scan has become significant in the trauma setting. With short scanning time, an investigation to confirm or exclude intracranial haemorrhage, skull fracture or stroke can now be performed in a matter of seconds. This article provides physicians with a structure for reading a CT head scan, to help identify key findings that may warrant further specialist neurosurgical or stroke team referral.

Computed tomography (CT) scanning has become one of the most used diagnostic tools in recent years, now very much an integral part of the patient pathway.

With its non-invasive nature and quick scan times, the ability to diagnose a range of pathologies in a short space of time has been a key turning point in increasing the use of CT scans particularly in emergency and acute medical departments. The growth in numbers of CT scans performed has been staggering – between the mid 1980s and mid 1990s, CT scan use grew by 500% (Lee et al, 2004). This trend has continued in more recent times – Bellolio et al (2017) demonstrated that CT use in the emergency department grew by 59% between 2005 and 2013.

Current guidelines issued by the National Institute of Health and Care Excellence (2014) state that a CT scan must be performed on adults with a known or suspected head injury within either 1 or 8 hours of patient admission depending upon the nature of presentation. Any adult over 65 years of age with post-traumatic amnesia or loss of consciousness should receive a CT scan of the head within 8 hours.

With increased demand for scan reporting, particularly in acute settings, reporting times are put under strain, making it harder to meet current recommendations for CT head reports to be completed within 1 hour (National Institute of Health and Care Excellence, 2014). With this in mind, it is important for physicians to be able to recognize key CT signs of acute injury.

This article provides an overview of the basics of CT scanning and recognition of the main findings seen in acute trauma and stroke.

CT basics

The main unit of measurement in CT scanning is the Hounsfield unit (HU). The unit is based upon the principle of attenuation coefficients or, in other words, how easily an X-ray beam can penetrate a material. A highly attenuating material, for example bone, will substantially 'weaken' the X-ray beam and thus little will reach the detector on the other side. This will produce a different signal to one that is poorly attenuating, such as air, where most of the X-ray beam can be transmitted through to the receiver plate (Hounsfield, 1980).

There are two extremes at either end of a HU scale, consisting of air and bone (*Figure 1*).

The HU scale is composed of shades of grey relating to each component of an image (*Figure 1*). The number of shades can be highly variable depending upon the area of the body being imaged. The problem with having 900+ shades of grey is two-fold. First, most computer systems can only display a maximum of 256 shades at any one time, and therefore many values will be grouped together and cause diagnostic overlap. Second the human eye is thought to only be able to accurately distinguish approximately 50 shades of grey at any one time, again causing difficulty where there may not be enough contrast between structures.

A way to manage this is by the concept of windowing, whereby the width of the greyscale is moved in order to discriminate between two tissues (Zatz, 1981) (*Figure 2*).

Approach to a CT head

A systematic approach towards interpreting any type of CT scan is vital for any

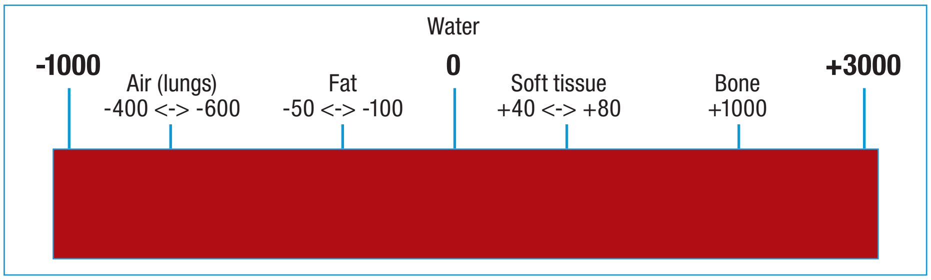

Figure 1. Illustration of the Hounsfield unit scale. Air is poorly attenuating and is therefore is set at -1000, while dense bone, being highly attenuating, is set at +1000. Every other tissue type in the human body including soft tissue, muscle and fat, is invariably in-between these two values, with water set at value zero. All numbers are seen on a scan image as shades of grey, with low values typically 'darker', and higher values 'brighter'.

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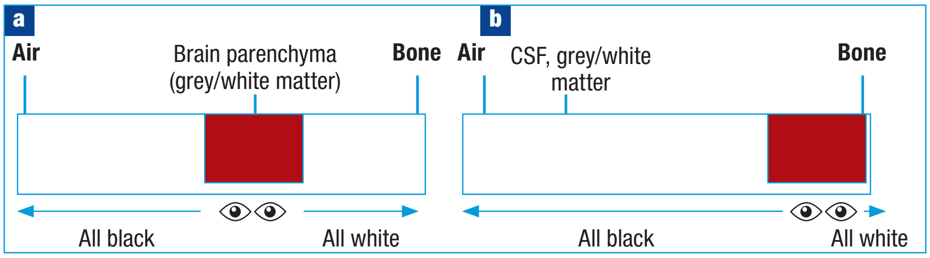

Figure 2. Example windowing to view specific structures. With CT head scans, windowing is used to optimize viewing for brain insult, acute bleeding (subdural window) and skull injury. Windowing allows the reader to focus on specific tissues within the parameters set. All values above and below the window threshold will be completely white or black respectively, allowing the contrast to be prioritised within the range of structures being looked at any specific point in time. The main three windows used in everyday practice are **(a)** soft tissue, air and **(b)** bone.

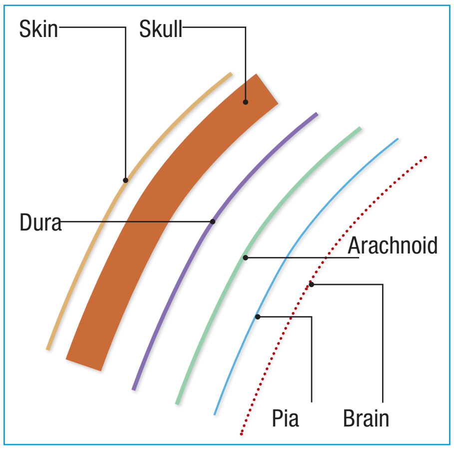

Figure 3. The main three layers overlying the brain from superficial to deep are the dura, arachnoid and pia mater. Blood may accumulate between each of these spaces and because of the nature of their reflections, specific patterns are seen with each.

radiologist; the CT head is no exception. A commonly used mnemonic is ‘blood can be very bad’, standing for: blood, cisterns, brain parenchyma, ventricles and bone. While this is not exhaustive, it will ensure that a majority of pathologies are identified and, particularly for the untrained eye, enable a structured approach to assessing a CT head scan.

Blood

As the Monroe–Kellie doctrine on intracranial pressure states, the brain is situated within a fixed box, the skull (Mokri, 2001).

The cranial vault therefore has a fixed capacity, which is composed of three factors: blood, CSF and brain parenchyma. Any increase in one of these factors will lead to a decrease in the other two to maintain volume–pressure equilibrium. This is particularly important in acute haemorrhage where active bleeding takes up vital space required by the brain. Eventually the only space left for the brain to go through is the foramen magnum leading to coning, risking fatality.

The detection of blood most critically relies upon understanding the effect of age on its CT appearances. The normal evolution of haemorrhage means that it alters its constituent components, which affects its attenuation value and hence appearances on CT. In the hyperacute phase it can be dark, in the acute phase (first 7 days) it can be white, in the subacute phase (1–3 weeks) it can be isointense to grey matter (i.e. the same colour as the cortex) and in the chronic phase (>1 month) it becomes low attenuation (black) (Brant and Helms, 2007). Therefore, acute on chronic events may show a mixture of densities within the region of interest given the mixed ages of blood product. Subacute and chronic haematomas are at risk of re-haemorrhaging, causing an acute-on-chronic subdural haematoma.

In many cases, referring to the patient’s previous imaging can be helpful, as prior CT head scans may highlight longstanding pathology and provide a comparison for new studies.

Layers of the brain

Understanding the layers surrounding the brain can help identify the pattern of bleeding that may be seen on CT (*Figure 3*).

Extradural haemorrhage

Extradural or epidural haemorrhage is blood forming between the inner skull surface and the dura.

Extradural haemorrhage is associated with head trauma, and significantly correlates with skull fractures. Use of the bone window setting is important if an extradural haemorrhage is seen to interrogate the CT for an associated fracture.

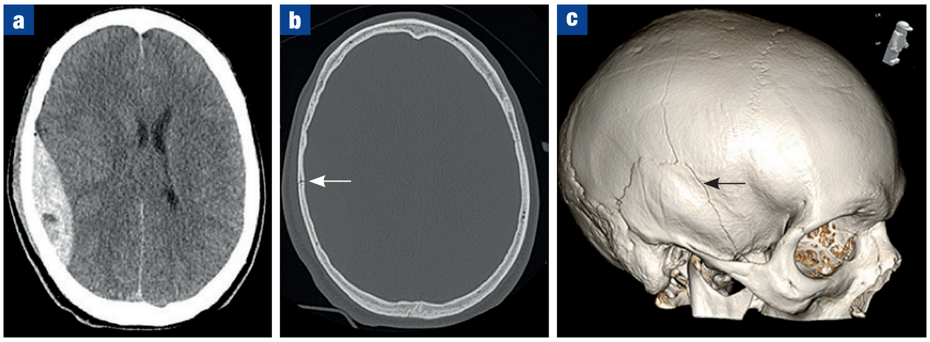

Figure 4. Extradural haemorrhage following a fall down a full flight of stairs. **a.** Unenhanced computed tomography scan of the head showing a large, lentiform extra-axial area of high attenuation consistent with a right extradural haematoma. **b.** A non-displaced fracture involving the right parietal and temporal bones and extending into the skull base (arrow). **c.** Three-dimensional volume-rendered image showing the extent of the fracture (arrow).

Extradural haemorrhages are confined by their sutural margins, so it is uncommon for extradural blood to cross suture lines. An exception to this rule is in the case of skull fractures extending over a suture, where a break in the sutural margin may allow blood to move out of the expected territory (Huisman and Tschirch, 2009) (*Figure 4*).

The classical morphology is that of a convex or lentiform-shaped hyperdensity, as differentiated from the concave, crescent-shaped subdural haemorrhage.

Subdural haemorrhage

Subdural haemorrhage is blood between the arachnoid and dura layers, i.e. within the subdural space. Subdural haemorrhage is often associated with a history of trauma. In young and middle-aged adults, the commonest cause is road traffic accidents while suffering a fall often causes an acute subdural haemorrhage in an elderly patient taking anticoagulants (Jallo and Loftus, 2009).

The pathology of subdural haemorrhage is thought to result from the tearing of bridging cortical veins as they cross the subdural space to drain into their respective dural sinuses.

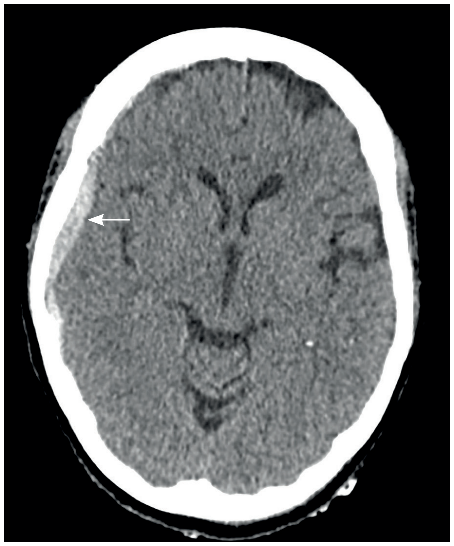

Figure 5. A 69-year-old man presented after a fall, suffering loss of consciousness, amnesia and 'racoon eyes' on clinical examination. Computed tomography scan of the head showed a small right subdural haemorrhage (arrow). The classical teaching on the appearance of an acute subdural haemorrhage on computed tomography is that of a 'crescent-shaped' region of high density, which does not cross the midline. This concave feature is often used to distinguish from the more convex, or lenticular shaped, extradural haemorrhage. Mass effect can invariably be seen and is dependent on the volume of haemorrhage and the severity of underlying atrophy.

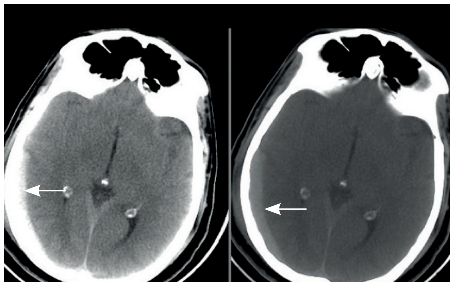

Figure 6. Many cases can be subtle, so it is important to use windowing to optimize subdural blood visualization. A window centre and level of 70–150 is recommended to optimize contrast to look for subdural blood (arrow).

As subdural haemorrhage blood is limited by the dural reflections, the nature of the bleeding limits where the blood may go within the cranial vault. The falx cerebri in the midline and the tentorium cerebelli posteriorly form two key margins which blood from a subdural haemorrhage does not cross (*Figures 5* and *6*).

Spotting high-density material in the subdural space may be relatively straightforward given an appropriate history, but significant difficulty can arise in cases of subacute presentation, where the appearance of blood can be isodense rather than hyperdense (*Figures 7* and *8*).

Figure 7. A subtle left-sided subacute subdural haemorrhage (arrow). It is important to have a high degree of suspicion when patients present with recurrent head trauma to avoid missing occult-evolved blood products.

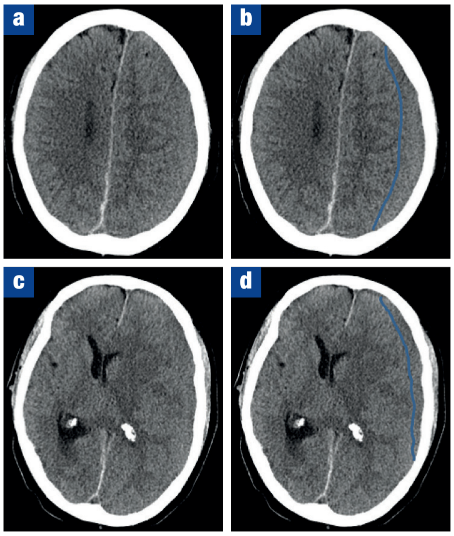

Figure 8. **a.** and **c.** Selected axial slices of an unenhanced computed tomography scan. **b.** and **d.** The same axial slices with the isodense subdural collections outlined. Note the midline shift and that the grey-white matter interface does not extend all the way to the skull vault. These are key features to look for when identifying an isodense subdural haemorrhage.

Subarachnoid haemorrhage

Subarachnoid haemorrhage is defined as the presence of blood between the pia and arachnoid layers of the cranial vault. Patients typically present with a thunderclap headache, photophobia and meningism, and up to half of patients may experience collapse or loss of consciousness (van Gijn and Rinkel, 2001).

There are two main sub-categories of subarachnoid haemorrhage based on their aetiology: traumatic and spontaneous.

Trauma is the commonest cause of subarachnoid haemorrhage, and this is estimated to occur in approximately 35% of traumatic brain injuries (Wu et al, 2010). If there is an associated skull fracture, blood may be seen in the sulci most adjacent to the site of fracture.

The commonest cause of a spontaneous subarachnoid haemorrhage is a ruptured aneurysm, occurring in up to 80% of patients who suffer a spontaneous event. The subarachnoid haemorrhage can be seen throughout the basal cisterns surrounding the brainstem, the sylvian fissures and the parafalcine subarachnoid space. A larger volume of subarachnoid haemorrhage in one of these locations suggests that this is more likely to be the site of a ruptured aneurysm and further radiological investigation and discussion with the local neurosurgical team is advised (*Figure 9*).

It is important to remember that a percentage of patients who present with a thunderclap headache will not have any acute haemorrhage on their CT scans. A normal CT scan does not exclude a subarachnoid haemorrhage and these patients must go on to have a lumbar puncture 12 hours after symptom onset.

Other causes include cerebral vasculitides, anticoagulation therapy and concurrent venous infarction (Brant and Helms, 2007) (*Figure 10*).

The major complications of subarachnoid haemorrhage are reactive vasospasm and communicating hydrocephalus (Brant and Helms, 2007).

Cerebral vasospasm is one of the leading causes of morbidity and mortality following subarachnoid haemorrhage, as a result of

Figure 9. Subarachnoid haemorrhage in a 71-year-old man with a sudden onset headache. The patient had known posterior inferior cerebellar artery and posterior cerebral artery aneurysms. A gyriform pattern of high attenuation is seen in the cerebral sulci (arrows) reflecting acute haemorrhage in the subarachnoid space, which follows the sulcal pattern of the brain. It can also extend into the sylvian fissures, the basal cisterns surrounding the brainstem and into the ventricles. These are all important places to interrogate for areas of high attenuation related to a subarachnoid haemorrhage.

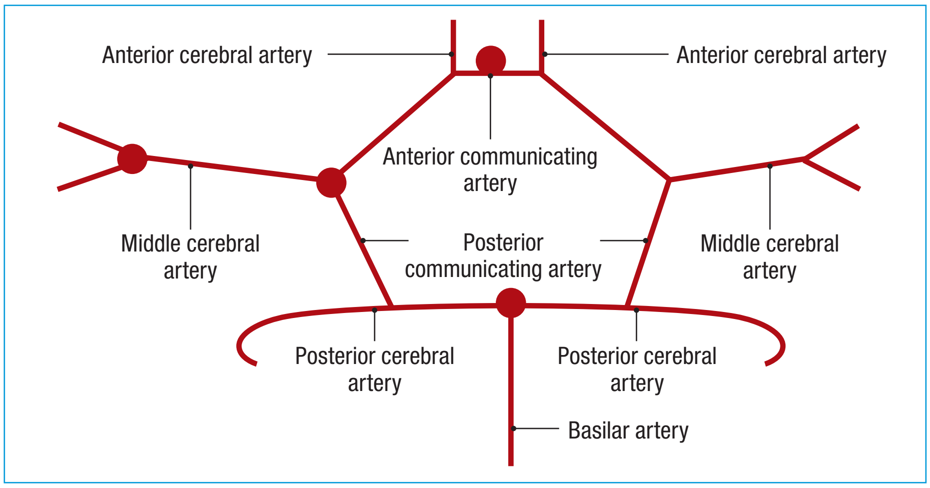

Figure 10. Common locations of cerebral aneurysm formation (red circles). The most common site for aneurysm rupture is the anterior communicating artery, followed by the junction of the internal carotid artery and posterior communicating artery.

significant cerebral ischaemia manifested through newfound neurological symptoms and reduced consciousness (Frontera et al, 2009).

Cisterns

The basal cisterns are CSF-filled cavities formed by openings in the subarachnoid space. The major cisterns that can be easily assessed on a CT head scan are shown in *Table 1*, divided by their anatomical surroundings. Significant mass effect can efface the cisterns and therefore they are a key area to review when assessing for herniation (*Figure 11*).

Table 1. The major intracranial basal cisterns and surrounding anatomy

Cistern	Anatomy
Ambient	Surrounding the midbrain posterior to the thalamus
Suprasellar	Superior to the sella turcica and inferior to the hypothalamus
Quadrigeminal	Between the splenium of corpus callosum and superior surface of the cerebellum
Sylvian	Across the insular surface within the Sylvian fissure

Brain

The brain parenchyma can be assessed looking for midline shift and sulcal effacement.

A simple way to measure for midline shift is to draw a line from the internal occipital condyle to the anterior midline falx looking for any significant asymmetry of the brain either side of this line, which may represent focal mass effect. Midline shift adjacent to the falx is commonly referred to as subfalcine herniation (Tu et al, 2012) (*Table 2*, *Figures 12* and *13*).

In cases of high volume bleeding or oedema, cortical sulci will become effaced; this may often only be seen unilaterally akin to the side of bleeding. Therefore it is always important to compare one side to the other.

In stroke, the grey–white matter interface can be evaluated. The interface of grey and white matter is a key region involved in stroke, and loss of this interface can be seen in acute infarction, affecting the distribution territory of the occluded cerebral artery. In the hyperacute setting this is often unreliable and repeat imaging may be necessary at a later stage.

A 'hyperdense' vessel is an early sign of ischaemia, representing acute clot in the affected cerebral vessel and so the

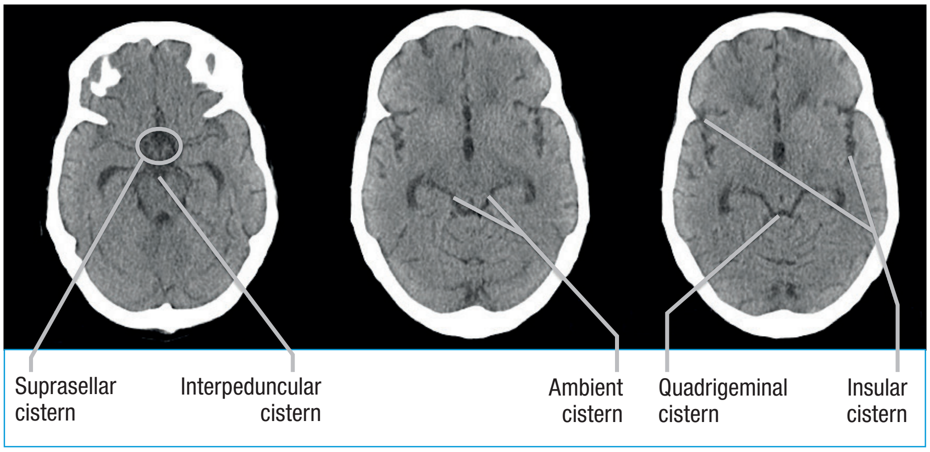

Figure 11. Normal appearances of the major cerebral cisterns. The significance of the major cerebral cisterns is that in cases of subarachnoid haemorrhage these spaces may fill with blood, and in some cases, might be the only sighting of blood on computed tomography. This is the case with the so-called 'perimesencephalic subarachnoid haemorrhage' where blood may only be seen within the midbrain cisterns.

Table 2. The major intracranial basal cisterns and surrounding anatomy

Herniation	Anatomy
Subfalcine	Beneath the falx cerebri
Uncal	Inferomedial displacement of the uncus
Transcalvarial	Brain shift through the calvarium
Transtentorial	Superior or inferior displacement in relation to the tentorium cerebelli
Tonsillar	Downward displacement of the cerebellar tonsils into the foramen magnum leading to coning

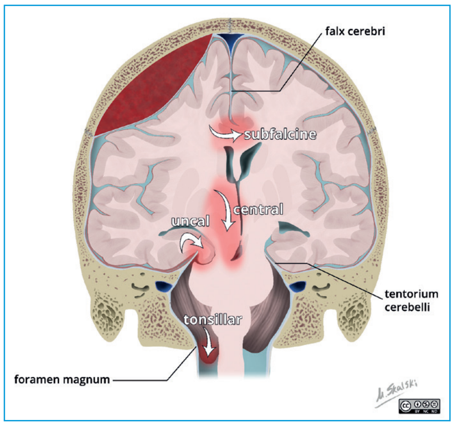

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Figure 12. Types of herniation. The type of herniation associated with the greatest mortality, and therefore of most clinical importance, is tonsillar herniation (coning), which can lead to brainstem death in severe cases.

territory that is supplied is susceptible to suffer ischaemia and infarction unless prompt management is undertaken, either thrombolysis or increasingly thrombectomy (*Figure 14*).

Ischaemic stroke accounts for approximately 85% of all strokes, and the remaining 15% are haemorrhagic stroke.

The two commonest causes of haemorrhagic stroke are hypertension in the younger to middle-aged patient, and amyloid angiopathy in the older population (*Figure 15*). Hypertensive haemorrhages are usually located within the basal ganglia, and less often the cerebellum and pons. Haemorrhage associated with amyloid angiopathy are usually more peripheral lobar haemorrhages.

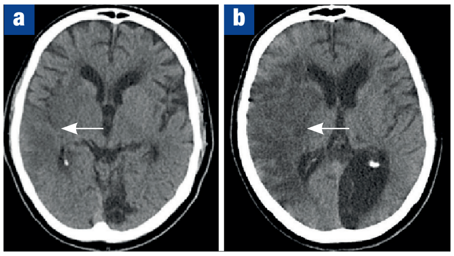

Figure 13. Early and late middle cerebral artery infarction. **a.** Acute stroke with loss of grey–white differentiation and effacement of sulci over the right middle cerebral artery territory (arrow). **b.** A later stage right middle cerebral artery infarct in a different patient. Note the increased prominence of cytotoxic oedema, which is now causing a subtle degree of midline shift (arrow) and effacing the frontal horn of the right lateral ventricle. Persistent ventricular effacement can cause a non-communicating hydrocephalus, a commonly encountered complication of pathologies causing mass effect.

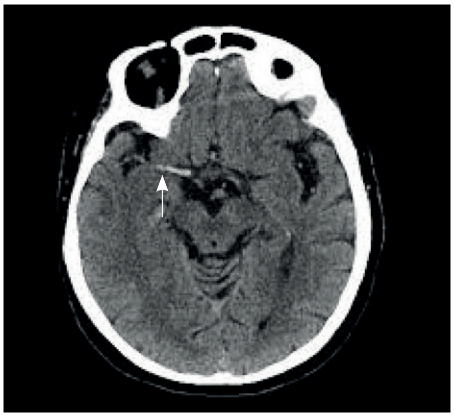

Figure 14. A hyperdense right middle cerebral artery is seen (arrow), highly suggestive of a right acute middle cerebral artery infarct. It is important to compare paired arteries to one another, as in cases of atherosclerotic disease, both arteries may appear dense, although no acute thrombus is present.

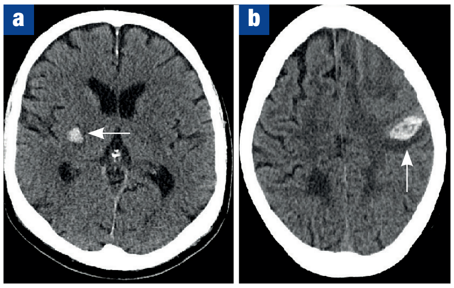

Figure 15. Haemorrhagic stroke. **a.** A focus of high attenuation (arrow) within the right internal capsule and posterior aspect of the putamen consistent with a hypertensive stroke. **b.** An example of amyloid angiopathy (arrow) – in contrast to hypertensive haemorrhage, this is characteristically based in a lobar cortico-subcortical location.

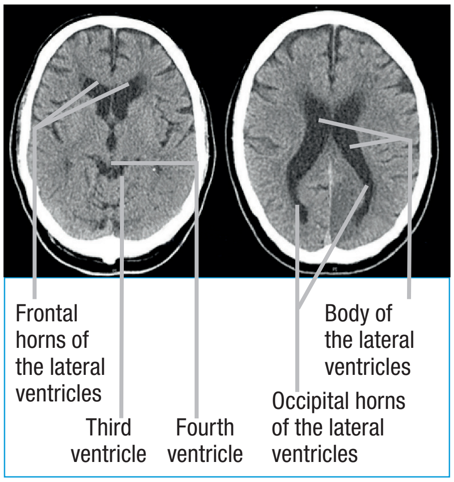

Figure 16. Normal appearances of the third, fourth and lateral ventricles. Note that the lateral ventricles extend posteriorly to the occipital lobes and inferiorly to the temporal lobes, forming the occipital and temporal horns respectively.

Ventricles

The ventricular system includes the left and right lateral ventricles, which communicate with the third ventricle via the foramen of Munro. The third ventricle communicates with the fourth ventricle via the cerebral aqueduct of Sylvius and then the fourth ventricle communicates with the cisterna magnum and the rest of the subarachnoid space via the foramens of Magendie (medially) and Luschka (laterally) (*Figure 16*).

Interrogation of the occipital horns of the lateral ventricles is important in evaluating for intraventricular haemorrhage, which can often be seen as hyperdensity layering within the occipital horns. Intraventricular haemorrhage can be associated with concurrent subarachnoid haemorrhage so it is important to look for both of these pathologies once one is found (*Figure 17*).

Hydrocephalus may also develop secondary to acute haemorrhage.

Bone

Best visualized on bone windows, a common difficulty many have in interpreting skull fractures is differentiating them from normal cranial sutures. One should compare both sides – linear low-density regions presenting bilaterally at approximately the same location and in the normal locations for the major sutures are highly likely to represent suture,

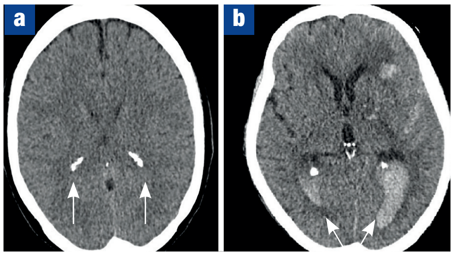

Figure 17. A common pitfall for the unfamiliar eye. **a.** Normal appearances of calcified choroid plexus. Calcification is hyperdense on computed tomography and can be seen in commonly calcified intracranial structures such as the choroid plexus and pineal gland (arrows). This is a normal physiological finding and should not be mistaken for acute haemorrhage. **b.** Appearances of an intraventricular haemorrhage, alongside subarachnoid haemorrhage and intracerebral haemorrhage (arrows). Note that the density of calcification from the choroid plexus is much greater than that of acute blood when seen on the same image.

while unilateral skull defects are more likely to represent fractures (*Figure 18*).

Conclusions

The CT head scan is an investigation that can give a great deal of information in a relatively short space of time. An increasing role of the CT head scan is in providing a pertinent negative result, allowing swift discharge from the emergency department.

Providing more radiological education to clinicians allows them to undertake a structured preliminary approach to looking at scan images. While no degree of expertise is expected, a simple call to the duty radiologist flagging up potential adverse findings may aid prioritisation of studies in order of clinical need, and enable most efficient management of those with pathology. **BJHM**

TOP TIPS

- Always try to elicit the cause of the presentation. This may give further information as to what findings to expect through both a traumatic or insidious nature.
- A well-structured, systematic approach is always best. Do not rush looking through a different part of a scan without finishing the preceding area first.
- Be wary of blood mimics on CT including the choroid plexi and pineal gland. If unsure a discussion with the radiologist is always advised.

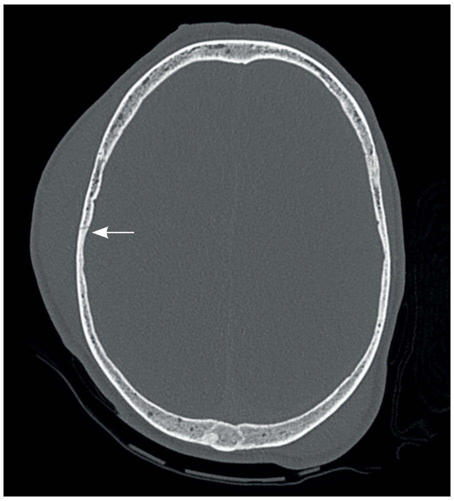

Figure 18. A 44-year-old man presented with an acute skull fracture (arrow) following a road traffic accident. Overlying scalp haematomas, as in this case, may help localize potential fracture sites in the majority of cases. However, there are always exceptions to this and all areas of the calvarium must be thoroughly assessed when reviewing computed tomography. The presence of overlying soft tissue swelling, depression or displacement of the fracture, the presence of intracranial gas and underlying parenchymal or extra-axial haemorrhage raises the probability of fracture.

Figure 12 *is reproduced from Radiopaedia.org Case courtesy of Dr Matt Skalski, rID: 45683.*
Conflict of interest: none.

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KEY POINTS

- The mnemonic ‘blood can be very bad’ (blood, cisterns, brain, ventricles, bone) provides a structured approach to interpreting a CT head scan.
- CT windowing, often a preset on many picture archiving and communication systems, provides optimal visualization of the brain, bone and associated intracranial haemorrhage.
- Where available, use previous CT studies to provide a comparison for the most recent scan, particularly in cases of chronic disease.
- Be aware of differing ages of blood and their respective appearances on CT, particularly when a mixed picture may be seen in an acute on chronic event.
- Compare both sides of the brain to assess for mass effect and midline shift, which may often be subtle.
- Loss of the insular ribbon sign may be an early indicator of acute stroke.

CURRICULUM CHECKLIST

This article addresses the following requirements from the general internal medicine training curriculum

- Managing an acute specialty-related take
- Providing continuity of care to medical inpatients, including management of comorbidities and cognitive impairment