

Computed Tomography in Neurology

Computed tomography (CT) of the head was first used in clinical practice at the Atkinson Morley's Hospital, London in 1972. On the earliest equipment, images were low resolution and tediously slow to acquire involving several hours of acquisition and processing time. Now, high resolution images of the brain can be obtained in a few seconds. Speed is a great strength of modern CT making it ideal for ill and poorly co-operative patients. Rapid data acquisition is exploited in contrast enhanced angiography and perfusion techniques, although these will not be discussed in detail in this article. CT is still the best method available to detect bony abnormalities and acute blood products. For these reasons, CT remains at the forefront of neuroradiology despite the remarkable advances in other imaging technologies.

Basic physics

X-ray images are formed by interactions of X-ray photons with matter. As photons pass through objects, they interact primarily with electrons. The photon may be completely absorbed releasing an electron from an atom (photoelectric effect). More usually, the photon is not fully absorbed but part of its energy is used to move an electron into a higher energy orbital (Compton effect). The photon emerges from this interaction with reduced energy and is slightly deflected from its original course. These effects on photons generate image contrast because tissues attenuate photons to differing extents depending on their electron density. The electron density of tissue components is quantified using CT and thus reliably differentiated.

CT uses data from a bank of detectors which are irradiated by a tube rotated around the patient. In the first generations of CT equipment, data was acquired slice by slice. A significant advance came with the development of slip ring technology which allows continuous gantry rotation around the patient and thus data acquisition from a volume of tissue (so called helical or spiral CT). This increases the speed of imaging and provides the information required for 3D reconstructions with no gaps between slices. The latest technology has taken this idea a step further, using a large bank of detectors capable of acquiring up to 320 slices in a single gantry rotation lasting less than a second (so called multislice, mul-

tidetector or volume CT).

Processing the data from detectors is a complicated process requiring powerful computers. Images are constructed using algorithms which not only localise anatomical structures but minimise artefacts. There are different algorithms available which demonstrate bone, brain and soft tissues optimally.

Approach to neurological CT

1. Anatomical localisation of lesions

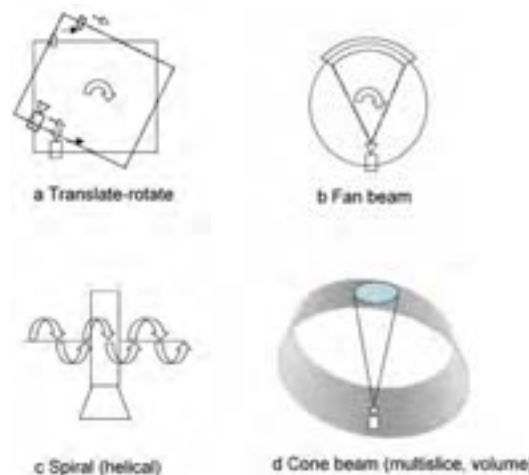
One of the most difficult and important steps in trying to work out the nature of a lesion is to decide whether a mass arises inside the brain parenchyma or outside, usually from the meningeal coverings. A lesion within the brain parenchyma is termed intra-axial and one outside is extra-axial. The shape of a mass and its effect on neighbouring structures (such as displacement of brain and bone remodelling) are helpful in making this distinction. Parenchymal lesions can be usefully divided into those involving grey or white matter. For example, many tumours arise in white matter, whereas ischaemia typically affects grey matter, causing loss of grey-white differentiation.



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◀ Figure 1: Generations of CT scanners.

A. Initial CT equipment used linear motion of tube and detector followed by rotation of the gantry by a few degrees. This process had to be repeated up to 30 times, resulting in acquisition times of 30-60 mins per slice.

B. Later generations of CT scanners avoided the need for linear motion by using a fan beam. This reduced acquisition times to less than 1 minute per slice.

C. Spiral or helical CT allows continuous gantry rotation while the patient is moved through the scanner. This further increased acquisition speed.

D. Multislice equipment uses banks of detectors to acquire multiple slices (typically 64) per rotation so that the whole brain can be imaged in a few seconds.

Table 1: CT terminology (see Figure 1)

Helical/spiral/volumetric CT	Data acquisition occurs as the patient moves through the gantry generating a volume dataset. This can be post-processed into images of different slice thickness in any plane.
Multislice/multidetector/multirow CT	Multiple rows of detectors (typically 16, 64 or 128 rows of 0.5mm thickness) are installed in the gantry so that many imaging slices can be obtained with one rotation.
Post-processing	Image manipulation performed after data has been acquired.
High resolution CT	Thin section images viewed after processing with an edge-enhancing algorithm. This allows detection of very small structures (eg bone in the middle ear down to 0.5 mm or less in thickness). This technique only works in tissues where there is high intrinsic contrast (eg bone or lung). When applied to soft tissues the algorithm provides a very grainy appearance.
Image contrast/Contrast resolution	The difference in density between tissues determines how easily they can be distinguished using imaging. The areas of the body where there is greatest contrast between pathology and normal tissue on CT are the lungs and bones. In brain, white matter and grey matter can be differentiated with Hounsfield Unit (HU) of 20 and 30 respectively (see Figure 10).
Algorithm/Kernel	Computerised reconstruction of data which optimises images. This ranges from image smoothing (for soft tissue) to edge enhancement (for bone and lung). Algorithms are used to suppress artefacts caused for example by beam hardening.



Figure 2: X-ray photons of suitable energy interact with electrons, either releasing them from the atom (ionisation) or pushing them into a higher energy orbital. In the process, the photon may be completely absorbed, or reduced in energy. The interaction may also cause deflection of the photon (see Table 2).

Table 2: Physics/techniques (see Figure 2)	
Compton and photoelectric effects	These describe the interaction of X-ray photons with physical matter. In the photoelectric effect, a photon of suitable energy is completely absorbed, releasing an electron from its orbit around the nucleus. In this process, positively charged ions are produced. In Compton interactions, the X-ray photon is not completely absorbed, but deposits some of its energy, displacing but not removing an electron from an atom. The X-ray photon's course is deflected and its energy is reduced. The deflection of the photon is a source for the loss of sharpness in the CT image.

a. Skull/scalp (Figure 3)

Lytic or sclerotic metastatic bone lesions may be seen on CT. Fractures are often better seen on plain films than CT.

b. Dura mater (Figure 4)

Most normal dura mater (apart from the falx and tentorium) is not seen on CT as it is applied to the skull.

c. Arachnoid mater/subarachnoid space (Figure 5)

CSF spaces are easily compressed by space occupying lesions or by brain swelling. In hydrocephalus, the ventricles are typically large with effacement of cerebral sulci. In young people the sulci are normally small and this can be misinterpreted as brain swelling. Enlargement of the sulci usually indicates volume loss, either focal (eg related to an infarct) or diffuse (usually related to atrophy/neurodegeneration). Increased density in the sulci typically indicates subarachnoid haemorrhage.

d. Grey matter (Figure 6)

Infarcts typically involve grey matter but contusions and low grade tumours may be seen here.

e. White matter (Figure 7)

This is a typical site for high grade gliomas. Metastases and abscesses are often seen near the grey-white junction because of the high blood flow here, and the size of the vessels in which tumour cells and bacteria can lodge. Oedema also involves white matter (Figure 11).

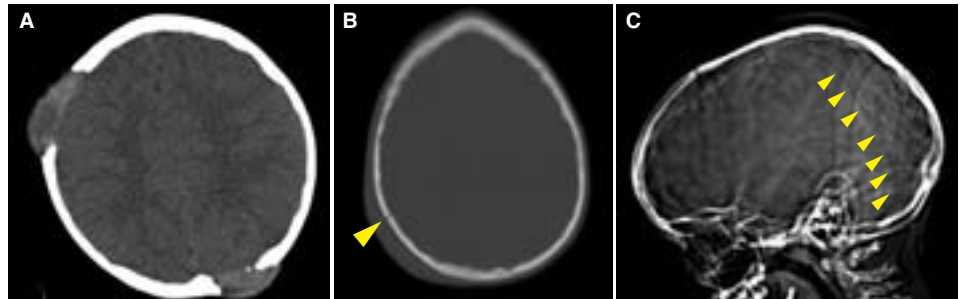


Figure 3: Scalp/skull lesions. A. Skull lesions from Langerhan's cell histiocytosis. B and C. Skull fracture. Note the full extent of the fracture is often better appreciated on plain film (arrowheads indicate fracture).

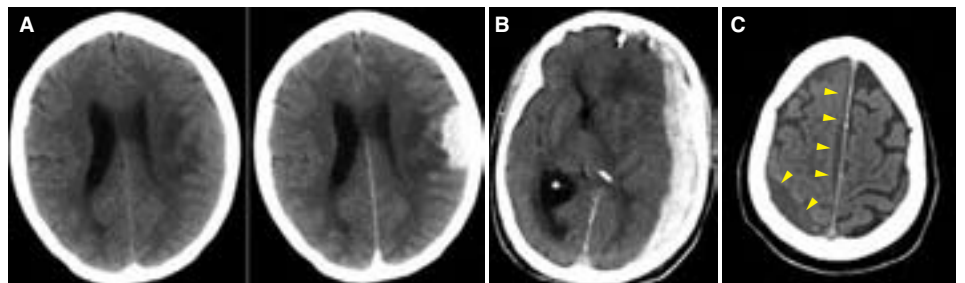


Figure 4: Dura mater. A. Images with and without contrast medium. Meningioma with a wide base on the convexity dura. B. Subdural haematoma extending along the dural surface of the hemisphere. C. Post contrast CT image with a subdural empyema indicated by arrowheads. Note compression of the subarachnoid spaces.

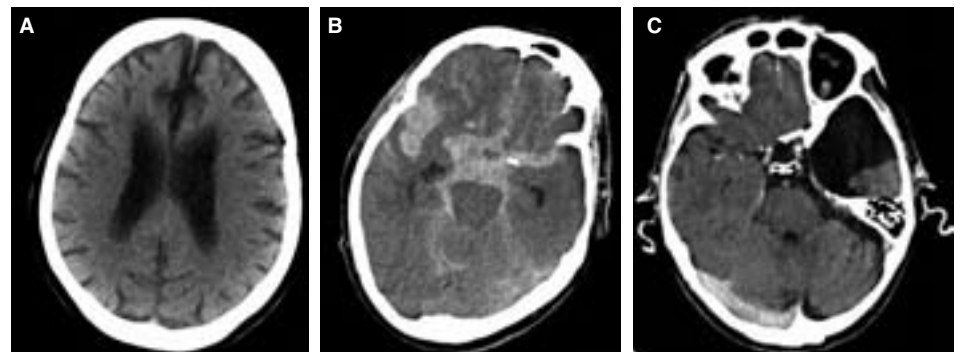


Figure 5: Arachnoid mater/ subarachnoid space. A. Prominent subarachnoid spaces due to atrophy. B. Subarachnoid haemorrhage. C. Arachnoid cyst.

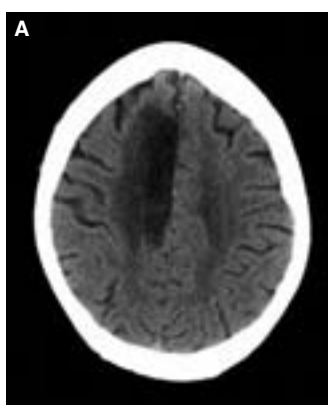


Figure 6: Grey matter. A. Established cortical infarct in the anterior cerebral artery territory. B. Calcified low grade oligodendroglioma.

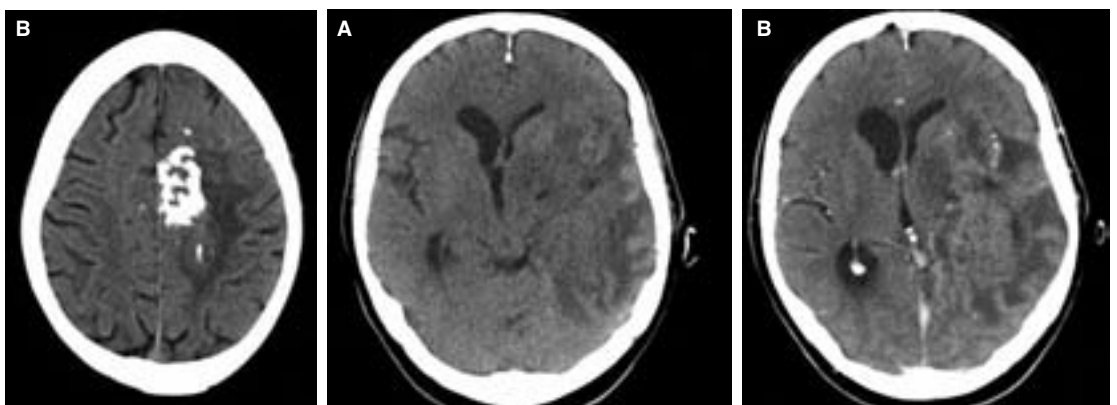


Figure 7: White matter. A and B. High grade glioma with vasogenic oedema (A before and B after contrast medium). See Figure 11 for description of patterns of oedema.



Figure 8: Vessels. Dense middle cerebral artery following recent occlusion (arrowhead).

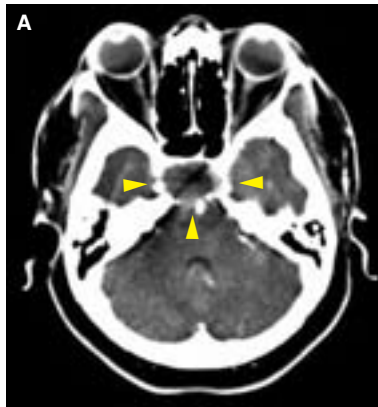


Figure 9: Blindspots.

A. The sella is enlarged by a pituitary adenoma (arrowheads). B. Orbital mass (arrowheads). C. Lymphoma involving nasopharynx and infratemporal fossa (arrowheads).

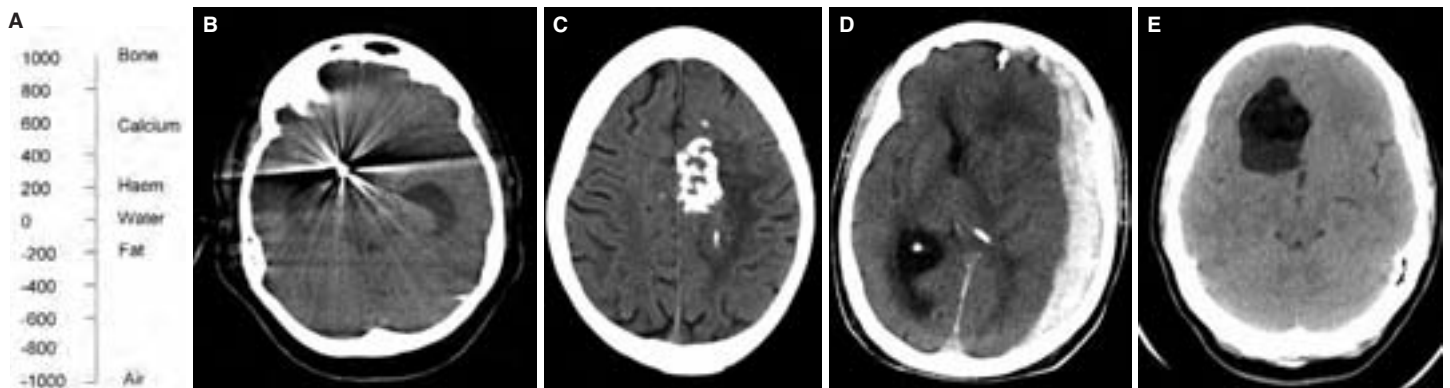
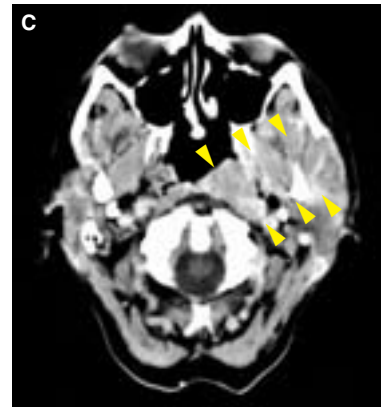
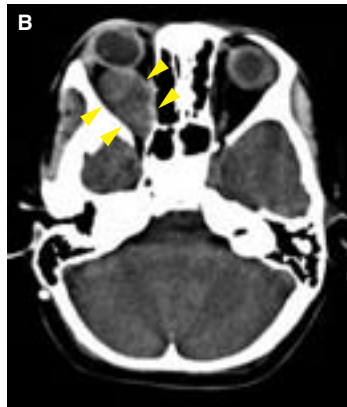


Figure 10: Density of lesions.

A. Hounsfield Units (HU). Each tissue type has a specific electron density which can be quantified into attenuation coefficients or Hounsfield Units. B. Coil inserted in an intracranial aneurysm is of very high density and causes artefact (HU>1000) because of the attenuation of the x-ray beam. C. Calcification in a low grade glioma (HU=500). D. Recent haemorrhage in a subdural collection (HU=200). E. Dermoid containing fat (HU=-200).

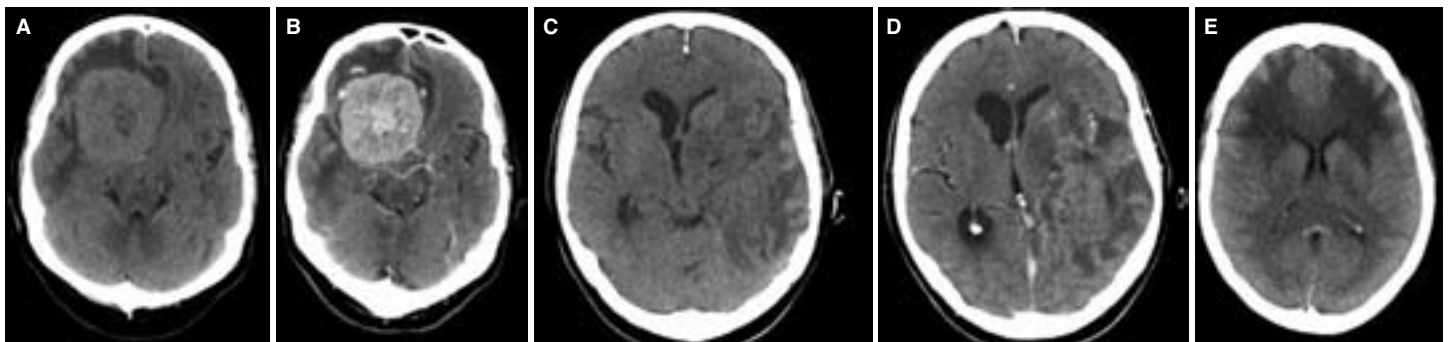


Figure 11: Outline/ patterns of oedema.

A and B. Pre- and post-contrast imaging. Meningioma showing a well defined margin. C and D. Pre- and post-contrast imaging. Glioma showing ill defined margins. E. Vasogenic oedema involving white matter only, in a case of olfactory groove meningioma (tumour not shown).

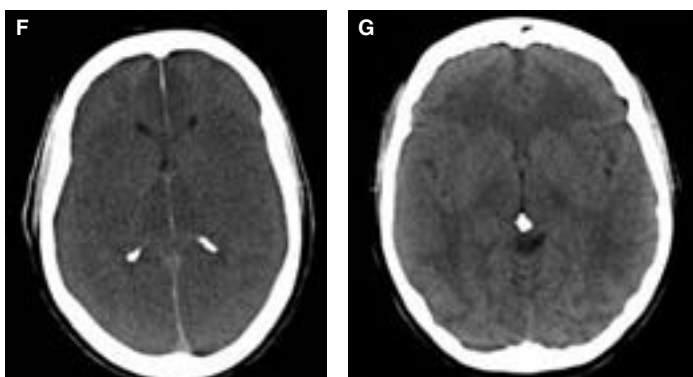


Figure 11
F. Cytotoxic oedema involving grey and white matter in diffuse cortical necrosis following cardiac arrest. G. Normal brain for comparison

f. Vessels (Figure 8)

Focal increased density in a vessel may indicate recent thrombosis. Aneurysms are rarely identified on unenhanced CT but may be seen following contrast enhancement.

g. Blindspots (Figure 9)

Extracranial soft tissues may show pathology which is incidental to the symptoms for which imaging was performed. The sella, skull base and orbits are frequent blind spots.

2. Characterising lesions

a. Density (Figure 10)

The CT density of different tissue types can be predicted (Fig 10a-e). In practice, tumour types cannot be precisely differentiated from density alone, but certain tumours (meningioma, lymphoma, medulloblastoma) tend to be higher density than others (glioma). Detection of calcium and blood is often easier on CT than MRI.

Table 3: Artefacts (see Figure 14)

Beam hardening	As the beam of X-ray photons pass through dense bone, lower energy photons are absorbed resulting in a beam with higher average energy. These photons traverse soft tissue adjacent to the bone with less attenuation than on other slices and the soft tissue appears spuriously low in density.
Partial volume	Partial volume effects occur when the slice of data acquisition includes tissues of different density. For example a slice containing half ventricle and half brain will be displayed as having a density intermediate between the two.
Motion	Artefact from movement is usually easily recognised, although with more complex methods of CT data acquisition, motion has less predictable effects on the image.
Back projection	The CT image is constructed by computerised back projection of data. This would produce a perfect image if an infinite number of back projections were used. Star like radial lines may be seen around dense structures because of imperfect back projection.
Faulty detectors	If one or more detectors are not functioning, a variety of artefacts may be produced, the most common of which is a ring near the centre of the image.

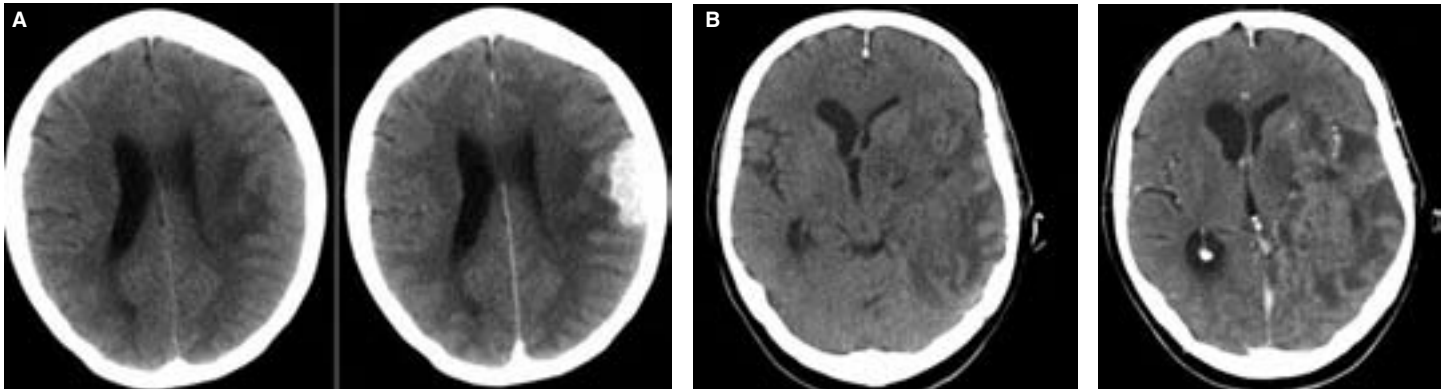


Figure 12: Patterns of contrast enhancement.

A. Image before and after IV contrast medium. Homogeneous enhancement in a meningioma. B. Image before and after iv contrast medium. Heterogeneous enhancement in a glioma.

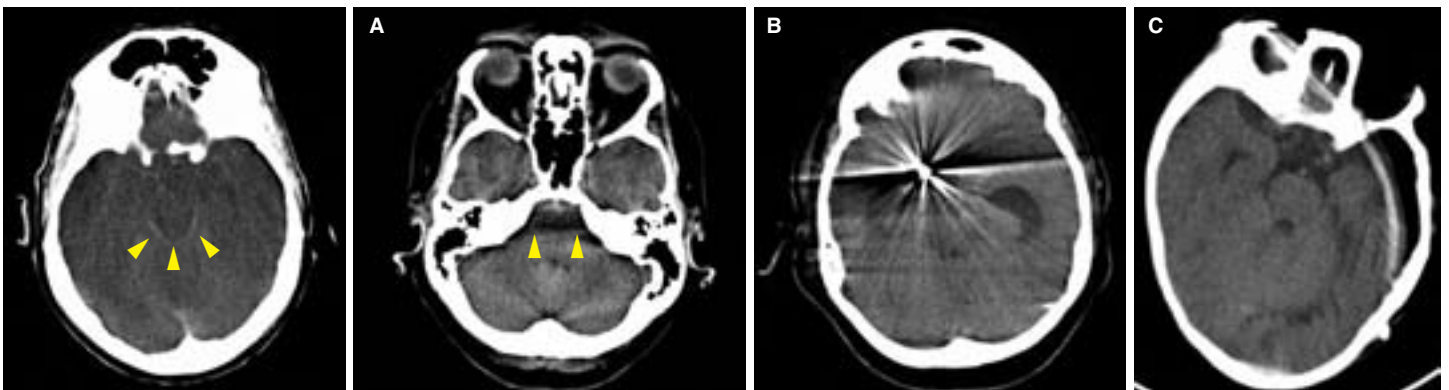


Figure 13: Mass effect. Diffusely swollen brain with effacement of perimesencephalic cisterns indicating trans-tentorial herniation (arrowheads).

Figure 14: Artefacts (see Table 3).

A. Beam hardening causing apparent low density in the brainstem (arrowheads).

B. Back projection or star artefact around a dense metal coil.

C. Motion artefact on multislice CT can result in an unusual appearance with distortion of only part of the image.

b. Outline/ patterns of oedema (Figure 11)

Many benign tumours have well defined margins whereas aggressive tumours and inflammatory processes tend to be ill-defined. This does not apply universally and some rapidly growing tumours may appear well-defined.

Vasogenic oedema is caused by disruption of the blood brain barrier around inflammatory, neoplastic or ischaemic lesions. This is usually confined to white matter. Cytotoxic oedema is caused by ischaemia and involves grey and white matter.

c. Contrast enhancement (Figure 12)

Contrast enhancement is caused by a combination of increased vascularity and disruption of the blood brain barrier. Patterns of enhancement clarifies the extent of abnormality and can help differentiate disease processes.

d. Mass effect (Figure 13)

Recognising the consequences of mass effect is important as shift between intracranial compartments can result in rapid clinical deterioration because of pressure on vital structures.

3. Recognising artefacts (Figure 14)

The appearance of artefacts is learned through experience but a few examples are provided in Figure 14.

Conclusion

Neurological CT continues to develop rapidly with new technology becoming available almost every year. CT is not only the first line neurological imaging investigation, but also provides excellent diagnostic information which is complementary to other techniques such as MRI. More advanced applications of

CT such as angiographic imaging and quantification of perfusion have not been covered in this article, but are becoming more widely used in clinical practice.

References

- Smirniotopoulos JG, Murphy FM, Rushing EJ et al. *Patterns of contrast enhancement in the brain and meninges*. Radiographics 2007;27: 525-51.
- Osborn AG, Blaser S, Salzman K et al. *Diagnostic Imaging: Brain*. Amirsys 2004.