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, multidetector 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.

Table 1: CT terminology (see Figure 1)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tr>
<td>Helical/spiral/volumetric CT</td>
<td>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.</td>
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<tr>
<td>Multislice/multidetector/multirow CT</td>
<td>Multiple rows of detectors (typically 16, 64 or 128 rows of 0.5mm thickness) are installed into the gantry so that many imaging slices can be obtained with one rotation.</td>
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<td>Post-processing</td>
<td>Image manipulation performed after data has been acquired.</td>
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<td>High resolution CT</td>
<td>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.</td>
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<tr>
<td>Image contrast/Contrast resolution</td>
<td>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).</td>
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<tr>
<td>Algorithm/Kernel</td>
<td>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,</td>
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</table>
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).

### 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. |

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.
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.

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.

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).

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