Cranial computed tomography 1: technical aspects for clinicians

The importance of cranial computed tomography in the diagnosis and follow up of intracranial pathology cannot be underestimated. Clinicians at every level should have a basic understanding of this technique. This first of two articles looks at the technical strengths and weaknesses of cranial computed tomography, and cranial anatomy.

Cranial computed tomography is widely available and used in cases of suspected brain pathology. It should complement a thorough history and examination and can localize pathology within the brain to guide patient management. Cranial computed tomography is indicated in the assessment of:

- Stroke
- Brain haemorrhage
- Brain tumour
- Cerebral infection
- Cerebral trauma.

This article comprises two parts – the first will cover the technical aspects of cranial computed tomography and the second will look at the place of cranial computed tomography in clinical practice.

Cranial computed tomography

Computed tomography uses a moving X-ray and moving detectors to generate computer images through the brain. A patient moves horizontally through a rotating X-ray and the X-rays are absorbed or attenuated by tissues of differing density. Powerful computers detect the absorption pattern and can generate slice images differentiating between areas in the brain. These images can be optimized by intravenous contrast and 'windowing' to aid diagnosis.

Computed tomography was developed by Sir Godfrey Hounsfield in 1972 (Ambrose and Hounsfield, 1973), and advances in technology allow this basic concept of two-dimensional tomography to generate impressive multiplanar cross-sectional images. First generation computed tomography machines that imaged a single slice in one rotation of the gantry have been superseded by multislice (e.g. 64) machines that can scan faster with greater spatial resolution.

Terminology

Some familiar terminology relating to computed tomography studies (Allisy-Roberts and Williams, 2008) includes:

- Attenuation – the absorption of X-rays by a tissue
- Contrast – the ability to detect differences between tissue types
- Pixel – the basic building block of a computer image
- Voxel – a three-dimensional pixel
- Hounsfield unit – an arbitary number the computer assigns each voxel that corresponds to the attenuation it represents. Centred on zero (water density), and ranging from -3000 to +3000, a Hounsfield number is represented by a shade on a grey scale (*Table 1*)
- Windowing – setting a range of Hounsfield units on the computer screen to emphasize contrast differences. In *Figure 1*, the same image is windowed differently to emphasize either brain tissue (*Figure 1a*) or bone (*Figure 1b*).

Strengths and weaknesses of cranial computed tomography

Magnetic resonance imaging and computed tomography imaging have enormous diagnostic advantages compared to plain film radiology. A standard X-ray is a two-dimensional image of a three-dimensional structure, and with body organs projected on top of each other it is often difficult to delineate true pathology from composite shadowing. Computed tomography and magnetic resonance imaging scans do not have this limitation and look at the body in slices. It is a common misconception that magnetic resonance imaging is always the preferred imaging modality, but that a computed tomography scan is more readily performed because of its ease of accessibility. Both imaging modal-

Table 1. The range of Hounsfield units that correspond to tissue type and grey scale

Tissue type	Hounsfield unit	Colour
Fluid	0–10 HU	Light grey
Air	–1500 HU	Black
Acute blood	60–70 HU	White
Chronic blood	30–40 HU	Dark grey
Bone	>350 HU	Bright white

Dr Robert H Thomas *is Specialist Registrar in Radiology,* **Dr Christopher J Burke** *is Specialist Registrar in Radiology and* **Dr David Howlett** *is Consultant Radiologist, Eastbourne District General Hospital, Eastbourne BN21 2UD*

Correspondence to: Dr RH Thomas

ities have advantages over the other, and a radiologist decides which modality will have the greatest diagnostic yield in a given clinical situation.

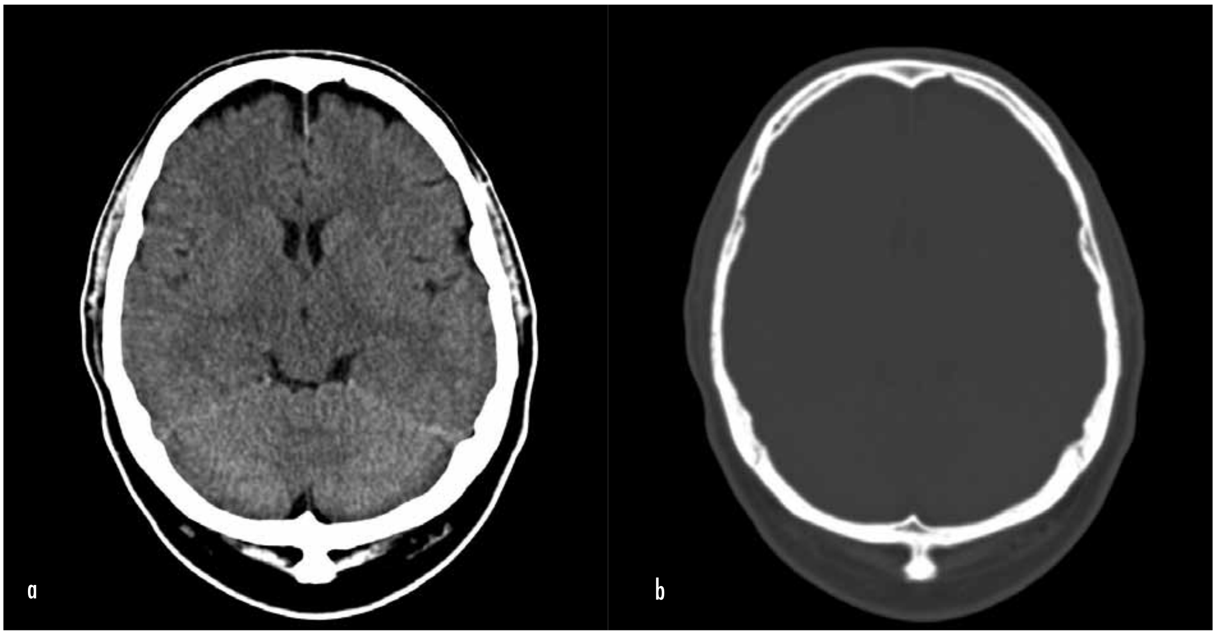
Strengths of cranial computed tomography

- Excellent resolution of bony pathology and is especially useful in trauma where the presence of a skull fracture carries far greater morbidity
- In very unwell patients, a computed tomography scan is usually accessible 24 hours a day and a complete cranial scan, including cervical spine if needed, can be performed within a few seconds with newer scanners
- Computed tomography scans are excellent at resolving acute blood, which is important in differentiating between a haemorrhagic or infarctive stroke (Widjaja et al, 2005)
- Computed tomography scans are painless, quiet and do not incite feelings of claustrophobia in the same way that magnetic resonance imaging scanners do
- There are no limitations on metallic objects (e.g. pacemakers, orthopaedic prostheses, metallic foreign bodies) or with ventilator usage in intensive care unit patients
- Real-time computed tomography allows biopsies to be taken under computed tomography guidance
- Powerful computers allow multiplanar reformatting with enormous diagnostic potential
- Computed tomography scans are cheap compared to magnetic resonance imaging and are cost effective in the diagnosis and follow up of disease
- The images from both computed tomography and magnetic resonance imaging scans can be electronically sent to different hospitals for advice, comparison and continued patient care.

Weaknesses of cranial computed tomography

- Computed tomography scanning will expose a patient to X-rays, and this radiation dose can have long-term biological effects. To put this in perspective, an unenhanced cranial computed tomography has the same radiation dose as 100 chest X-rays
- Pathology has to be of a particular size to be demonstrated on a computed tomography scan. Small changes, for example in very early stroke, may not be demonstrated on a computed tomography scan. A magnetic resonance imaging scan may be more effective in this situation (Chaldla et al, 2007)
- Enhancement agents are often needed to improve tissue contrast, but computed tomography contrast agents (e.g. Omipaque) are nephrotoxic and patients require a level of endogenous renal function (creatinine <150 mmol/litre) to clear the contrast load. Renal failure is a realistic post-scan complication in brittle or impaired kidneys (e.g. in diabetics) (Schrader, 2005)
- Allergy to computed tomography contrast agents is well documented, and this can range from simple skin rashes to life-threatening anaphylaxis. Administering contrast requires trained staff who are able to recognize and treat complications. This can limit computed tomography scan availability out of hours
- Computed tomography tables and magnetic resonance imaging scanners have weight limits set by the manufacturers, limiting the diagnostic options in obese patients (usually <150 kg)
- Magnetic resonance imaging is better than computed tomography at looking at soft tissue.

Figure 1. a. An unenhanced cranial computed tomography scan with soft tissue windowing – W80 L40. b. An unenhanced cranial computed tomography scan with bone windowing – W3500 L500.



Patient preparation for cranial computed tomography

Computed tomography departments perform numerous head computed tomography scans every day, and strict protocols are enforced to avoid complications. Protocols change between departments and it is important to familiarize yourself with local policy when you move to a new hospital. The following are important to keep in mind:

1. Establish the suitability of the patient before requesting a computed tomography scan, as the patient has to be able to lie flat on his/her back and remain still for the scan duration
2. As acute head injury can reduce a patient's level of consciousness, ensure that the patient has a stable airway and will remain haemodynamically compliant during the computed tomography scan
3. Communication with the radiology department is essential, and a clear concise history should be given with a list of differential diagnoses to be excluded
4. Every computed tomography scan must have a formal request form with a current bleep number legibly written should a radiologist need to contact the team
5. Document whether the patient can travel by bed or chair to the computed tomography scanner to improve portering efficiency
6. If the patient requires oxygen or other intravenous infusions while in the department a trained nurse may have to accompany the patient
7. Every patient requires a venflon to be inserted before the computed tomography scan, should there be a need for contrast enhancement or other intravenous therapy. It is recommended that the patient's recent renal function be documented clearly in the notes
8. The patient's infectious status (e.g. meticillin-resistant *Staphylococcus aureus*) should be confirmed. This helps to reduce cross infection and prioritize work lists to minimize disruption with deep cleaning
9. Any patient concerns about the procedure should be addressed.

Basic anatomy

Having a good understanding of anatomy is essential when interpreting cranial computed tomography. The skull comprises four bones on either side separated by fibrous sutures. These fuse with age and transform the skull into a tight skeletal box.

The brain parenchyma is a complex mass of interdigitating neurones. The peripheral neurones are unmyelinated and are referred to as 'grey matter', with the central myelinated fibres appearing as deep 'white matter'. The brain is anatomically defined in lobes:

Frontal lobe

The frontal lobe is seen most anteriorly and is separated from the temporal lobe inferiorly by the Sylvian fissure and from the parietal lobe by the central sulci. The frontal lobe is associated with personality, behaviour, problem solving and decisions making.

Parietal lobe

The parietal lobe is seen superiorly. It has motor and sensory afferent and efferent pathways for reception and initiation of movement.

Occipital lobe

Most posteriorly, the occipital lobe receives and interprets visual stimulus from the ocular pathway.

Temporal lobe

Sitting under the parietal lobe, the temporal lobe is involved with emotion, hearing and memory.

Cerebellum

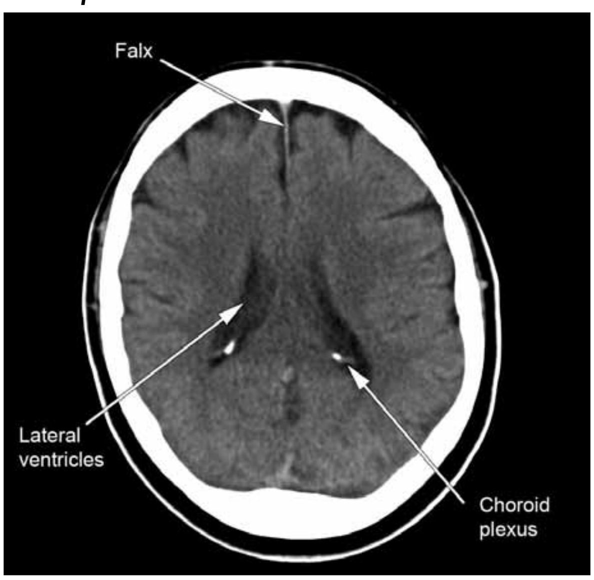
This is a posterior-inferior structure separated from the cerebral cortex which controls balance and coordination.

Specific functions within the body are related to a particular area of the cerebral cortex, and this is clinically relevant when localizing a lesion on cranial computed tomography, e.g. lesions within the cerebellum would result in ataxia and dizziness.

It is confusing to note that on cranial computed tomography there is grey/white matter reversal as a result of the presence of low attenuation fatty myelin, with the grey matter appearing whiter and vice versa (*Figures 2* and *3*).

Blood supply to the cerebral hemispheres is via the cerebral arteries. The circle of Willis allows collateral flow from the basilar and internal carotid arteries to supply the anterior, middle and posterior cerebral arteries. The brain territory supplied is demonstrated in *Figure 4*.

Figure 2. An axial slice from an unenhanced computed tomography scan with arrows pointing to the falx cerebri, lateral ventricles and choroids plexus.



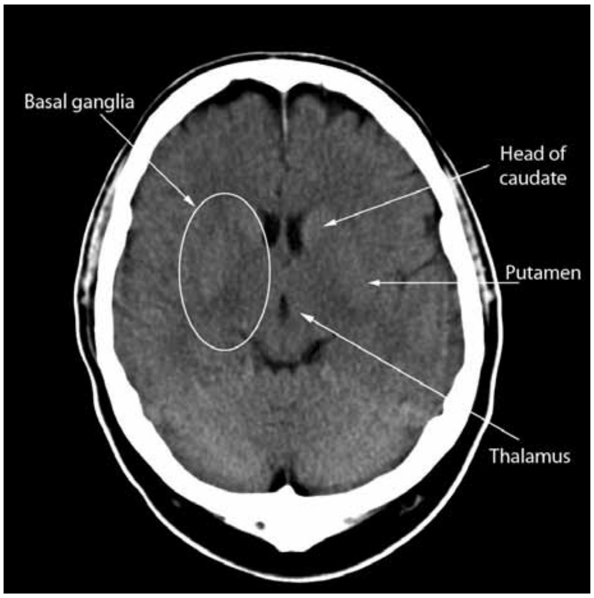


Figure 3. An axial slice from an unenhanced computed tomography scan demonstrating the head of the caudate nucleus, putamen of the lentiform nucleus and the thalamus. Collectively they make up the basal ganglia.

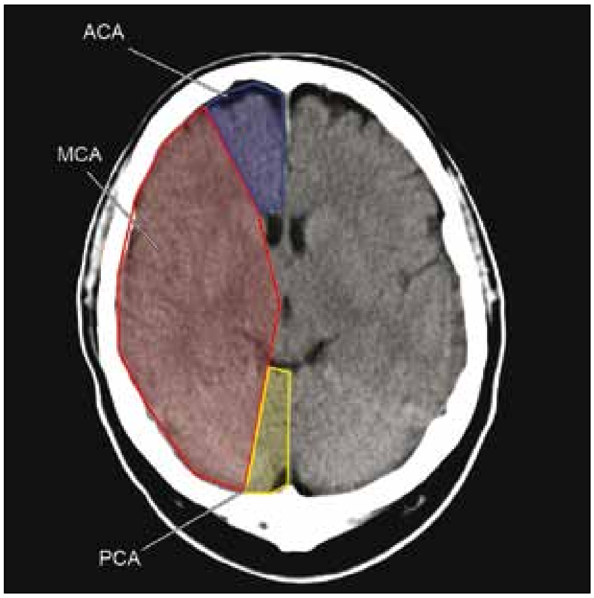


Figure 4. An annotated unenhanced computed tomography scan demonstrating the blood supply to the brain. Colours delineate the territory of the anterior (ACA; blue), middle (MCA; red) and posterior (PCA; yellow) cerebral arteries.

The brain and spinal cord are bathed in CSF that provides mechanical and immunological protection within the skull. Produced in the lateral ventricles, it circulates through the brain to flow around the spinal cord and cerebral hemispheres. Extra-axially, it occupies the space between the arachnoid and pia mater. Sampling the CSF in suspected illness is performed by lumbar puncture at the L3/4 level.

Conclusions

This first of two articles has discussed the technical aspects of cranial computed tomography as an important imaging modality in the diagnosis and follow up of intracranial pathology. Dependant on ionizing radiation, powerful computers reconstruct data to allow clinicians to look at slices through the brain. As an imaging modality, computed tomography is cheap and easily accessible with good resolution of soft tissue and bony pathology. Radiation dose is the major limiting factor. A magnetic resonance imaging scan can be a useful adjunct or alternative to cranial computed tomography, but is not always the preferred imaging modality.

Understanding cranial anatomy is very important, and clinical symptoms can be localized to particular territories on the computed tomography scan. The images generated are reproducible and can be electronically transferred between institutions to optimize referral times and patient care. Well established as an imaging modality in teaching and district general hospitals, it is important that clinicians at every level have a basic understanding of cranial computed tomography. The second article will discuss the practical use of computed tomography in the clinical setting focussing on the common pathologies of haemorrhage, ischaemic stroke, cerebral tumour and trauma. BJHM

KEY POINTS

- Computed tomography uses a moving X-ray source and moving detectors to generate axial computer images through the brain.
- Each voxel is assigned a Hounsfield unit corresponding to the density of the brain tissue it represents.
- Computed tomography is excellent at resolving bony pathology and acute blood, but magnetic resonance imaging has superior soft tissue resolution.
- Appropriate patient preparation is necessary to optimize scan images and avoid complications.
- An understanding of cranial anatomy is essential.

Conflict of interest: none.

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