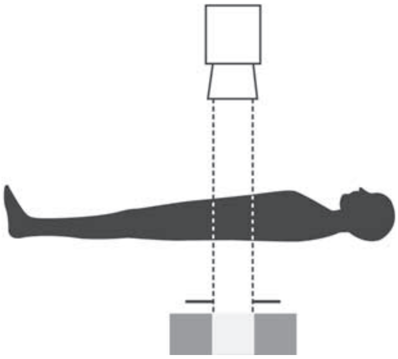
SECTION I

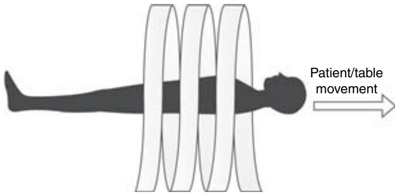
Fundamentals of CT imaging

History

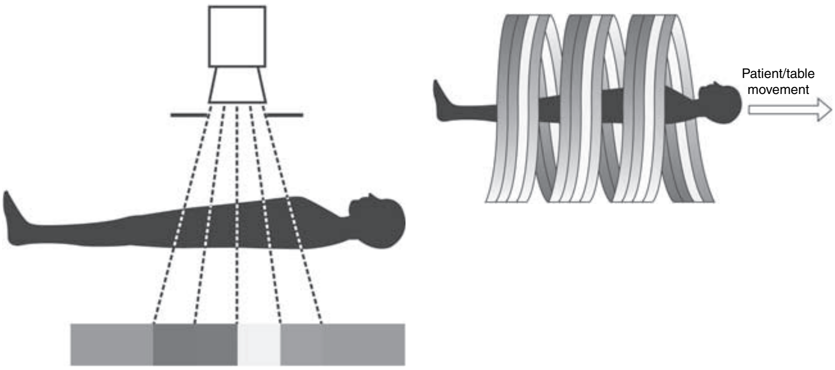
- In the early 1970s Sir Godfrey Hounsfield's research produced the first clinically useful CT scans.
- Original scanners took approximately 6 minutes to perform a rotation (one slice) and 20 minutes to reconstruct. Despite many technological advances since then, the principles remain the same.
- On early scanners the tube rotated around a stationary patient with the table then moved to enable a further acquisition. The machine rotated clockwise and counter-clockwise as power was supplied via a cable.
- Modern-day helical or spiral scanners obtain power via slip ring technology, thus allowing continuous tube rotation as the patient moves through the scanner automatically. This allows a volume of data to be acquired in a single rotation, with the benefits of faster scanning, faster patient throughput and less re-imaging as patient movement artefact is reduced.
- New multi-slice scanners use existing helical scanning technology but have multiple rows of detectors to acquire multiple slices per tube rotation. In turn, advanced computer processing power allows reconstructive techniques, such as three-dimensional and multiplanar reformats, to be more easily accessible. Consequently, scans are now performed routinely at a reporting workstation where the image can be viewed dynamically.



Single slice system.



Single slice helical CT. The X-ray tube continuously rotates as the patient moves through at a constant rate.

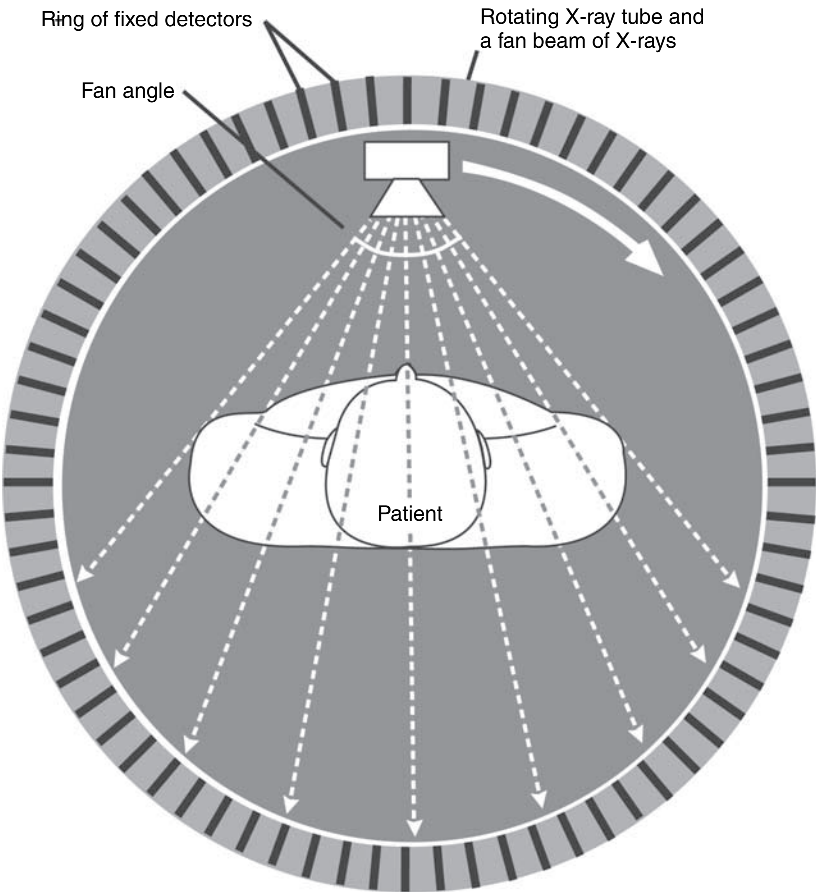


Multidetector helical CT: four detectors shown here.

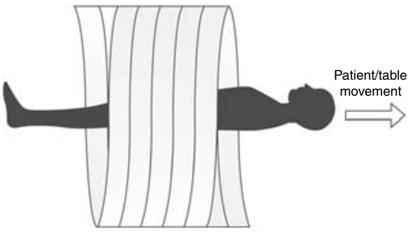
Technical details

- The X-ray tube produces a narrow fan-shaped beam of collimated X-rays, which pass through the patient to reach a bank of detectors opposite the source.
- X-rays are attenuated differentially by the patient, depending on the tissues through which they pass. Low density tissues such as fat/aerated lung absorb fewer X-rays, allowing more to reach the detector. The opposite is true of dense tissues such as bone.
- The amount of transmitted radiation received provides information on the density of the tissue.
- A CT slice is divided up into a matrix of squares, e.g. 256×256, 512×512 and 1024×1024. The slice thickness determines the volume of these squares; these are called voxels. Using mathematical calculations, the degree to which a tissue absorbs radiation within each voxel, *the linear attenuation coefficient*, μ, is calculated and assigned a value related to the average attenuation of the tissues within it $\equiv$ *the CT number* or *Hounsfield Unit*.
- Each value of μ is assigned a grey scale value on the display monitor and is presented as a square picture element (pixel) on the image.
- Spiral scanners acquire a volume of information from which an axial slice is reconstructed, as above, using computer technology. Slices are created from data during the reconstruction phase.
- *Pitch* is defined as the distance moved by the table in millimetres, during one complete rotation of the X-ray tube, divided by the slice thickness in millimetres. In general, increasing pitch (increase table speed with a fixed slice thickness) reduces radiation dose; as a result image resolution can be affected and thus a compromise usually exists.

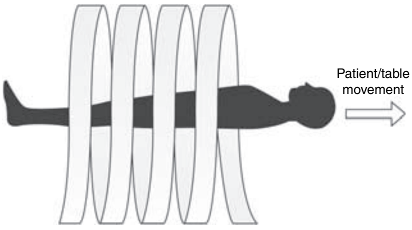
$$\text{Pitch} = \frac{\text{Distance moved by the table during one complete rotation}}{\text{Slice thickness}}$$



Helical system. Ring of detectors surrounding a patient.



The pitch is low with the table moving less for each tube revolution, resulting in a sharper image.



The pitch is high, effectively stretching out the helix. The table moves more for each revolution, resulting in some loss of image quality.

Cambridge University Press
978-0-521-68242-8 - Interpretation of Emergency Head CT: A Practical Handbook
Erskine J. Holmes, Anna C. Forest-Hay and Rakesh R. Misra
Excerpt
More information

Windowing and grey scale

- Modern CT scanners are able to differentiate in excess of 2000 CT numbers; however, the human eye can differentiate only around 30 shades of grey.
- To maximise the perception of medically important features, images can be digitally processed to meet a variety of clinical requirements.
- The grey scale values assigned to processed CT numbers on a display monitor, can be adjusted to suit special application requirements.
- Contrast can be enhanced by assigning just a narrow interval of CT numbers to the entire grey scale on the display monitor. This is called *window technique*; the range of CT numbers displayed on the whole grey scale being called the *window width* and the average value the *window level*.
- Changes in window width alter contrast, and changes in window level select the structures in the image to be displayed on the grey scale, i.e. from black to white.
- Narrowing the window compresses the grey scale to enable better differentiation of tissues within the chosen window. For example, in assessment of CT of the head, a narrow window of approximately 80 HU is used, thus allowing the eye to discriminate tissues only 2–3 HU apart. In practical terms, if we centre the window at 30 HU, then CT numbers above 70 will appear white and those below −10 will appear black. This allows subtle differences in tissue densities to be identified.
- Conversely, if the window is widened to 1500 HU, then each detectable shade of grey would cover 50 HU and soft tissue differentiation would be lost; however bone/soft tissue interfaces would be apparent.
- In practical terms the window width and level are preset on the workstation and can be adjusted by choosing the appropriate setting, i.e. a window setting for brain, posterior fossa, bone, etc.

Tissue characteristics

- Unlike conventional radiography, CT has relatively good contrast resolution and can therefore differentiate between tissues which vary only slightly in density. This is extremely valuable when assessing the brain, as grey and white matter vary only slightly in density.
- Artefacts aside, the densest structure in the head is bone, appearing white on CT. This is followed by acute haematoma, which is denser than flowing blood, due to clot retraction and loss of water. Blood is thought to be hyperdense due to the relative density of the haemoglobin molecule. With time, blood appears isodense and then hypodense, compared to brain parenchyma, due to clot resorption. Rebleeding and layering of blood (haematocrit effect due to gravity) can often cause confusion.

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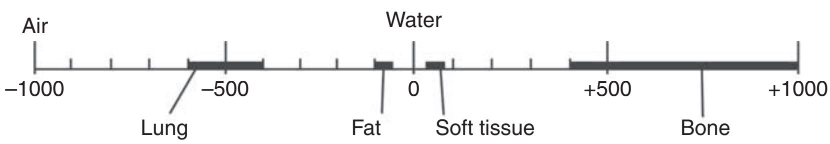
- Brain can be differentiated into grey and white matter due to the difference in fatty myelin content between the two. Typically white matter (higher fatty myelin content – HU ≈ 30) is darker than the adjacent grey matter (HU ≈ 40).
- Fat and air have low attenuation values and can be readily identified.
- CSF has a similar attenuation value to water, appearing black.
- Pathological processes may become apparent due to oedema within, or adjacent to, an abnormality. Oedema is less dense than normal brain.
- Occasionally the use of a contrast medium will reveal an abnormality either due to the inherent vascular nature of a lesion or due to alteration in the normal blood brain barrier.
- Tumours may be very variable in their appearance, but may be hyper-dense due to a high nuclear/cytoplasmic ratio or tumour calcification.



Bone	+400 → +1000
Soft tissue	+40 → +80
Water	0
Fat	–60 → –100
Lung	–400 → –600
Air	–1000

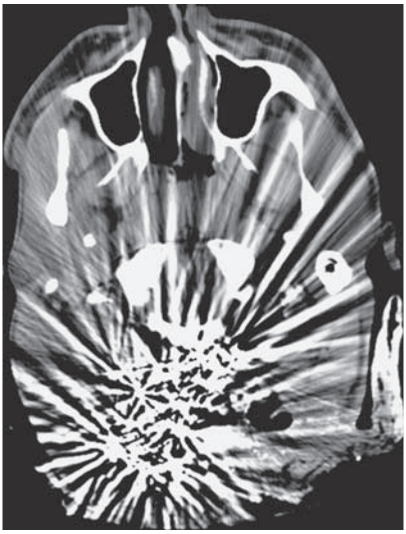
Hounsfield Scale of CT numbers.

Image artefacts

- An artefact is a visual impression in the image of a feature that does not actually exist in the tissue being imaged. They are important to recognise so as not to be confused with pathology. Artefacts may occur due to scanner malfunction, patient movement and the presence of extrinsic objects within the slice being scanned, e.g. a metal foreign body.
- Fortunately, many artefacts have now been reduced or eliminated by advances in CT speed and technology.
- *Motion artefacts* – Occur with voluntary and involuntary patient motion.
  - Tend to result in streak patterns.
  - Can be reduced by patient co-operation, quicker scan times and software compensation.
- *Partial volume artefacts* – The CT number reflects the average attenuation within the voxel and thus, if a highly attenuating structure is present within the voxel, it will raise the average attenuation value ≡ *partial volume artefact*.
  - Contamination can occur especially with thicker slices and near bony prominences.
  - Always review the slices above and below to assess for structures likely to cause partial volume artefacts.
  - Reduced by using thinner slices (e.g. posterior fossa) and software compensation.
- *Metallic artefacts* – The attenuation coefficient of metal is much greater than any structure within the body. As a result, radiation is completely attenuated by the object and information about adjacent structures is lost.
  - Produces characteristic star-shaped streak artefacts
  - Can be reduced by widening the window; at a cost to intracranial detail.
  - Again, software manipulation may help.
- *Beam hardening artefacts* – Results from an increase in the average energy of the x-ray beam as it passes through a tissue. Think of CT as using a spectrum of radiation energy; low energy radiation is filtered out by high density structures such as bone, leaving higher energy radiation which is less absorbed by soft tissues, thus reducing tissue differentiation.
  - Characterised by linear bands of low attenuation connecting two areas of high density, such as bone, e.g. the posterior fossa.
  - Can be reduced by using a filter to adjust the spectrum of radiation and by post-processing software.

Beam hardening artefact: band of low attenuation across the pons (arrowheads). This reduces tissue differentiation and is characteristic of beam-hardening artefact.

Motion artefact: characteristic movement blurring.



Metallic artefact. Gross star-shaped metallic streaks due to gunshot pellets.

Important anatomical considerations

Review of normal anatomy

Key for cerebral anatomy

1 = Sphenoid sinus
2 = Medulla oblongata
3 = cerebellum

4 = Fourth ventricle
5 = Middle cerebellar peduncle
6 = Sigmoid sinus
7 = Petrous temporal bone and mastoid air cells
8 = Cerebellopontine angle
9 = Pons
10 = Pituitary fossa