

COMPUTERISED TOMOGRAPHY & ITS CLINICAL APPLICATIONS

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Definition / facts about CT

- **Computer tomography (CT)**, originally known as **computed axial tomography (CAT or CT scan)** and **body section rentenography**.
- it is a medical imaging method employing tomography where digital geometry processing is used to generate a three-dimensional image of the internals of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation.
- The word "*tomography*" is derived from the Greek *tomos* (slice) and *graphein* (to write). CT produces a volume of data which can be manipulated, through a process known as *windowing*, in order to demonstrate various structures based on their ability to block the X-ray beam.

CT (CAT) scanning

- is a noninvasive medical test that helps physicians diagnose and treat medical conditions.
- combines special x-ray equipment with sophisticated computers to produce multiple images or pictures of the inside of the body.
- These cross-sectional images of the area being studied can then be examined on a computer monitor, printed or transferred to a CD.

- Computed tomography is a cross-sectional imaging technique using x-rays and computers
- CT scans involve the use IV injected radiocontrast to improve the visibility soft tissue on X-ray
- CT is an imaging tool with many applications in various clinical disciplines
- particularly valuable when evaluating areas of complex bony anatomy (e.g. skull) or containing large areas of overlapping soft tissue anatomy (e.g. abdomen).
- CT can differentiate between tissues of similar density because of the narrow x-ray beam and the use of "windowing"

- In conventional radiograph overlying tissues are superimposed on the image.
- CT overcomes this problem by scanning thin slices of the body with a narrow x-ray beam which rotates around the body.

General Principles of CT Scan


- **CT image** composed of a matrix of small tiny squares, called **pixels**.
- Each pixel is a two-dimensional representation of a 3D volume of tissue, the **voxel**
 - more pixels in a matrix the less the transition between the different pixels is visible and the better the spatial resolution
- The colours that are used are black, white and shades of grey.
- ❖ **CT process**
 - ❖ process of CT determines the linear attenuation coefficient to make a useful image
 - ❖ A longer scan time  improved image detail since the number of projections can be higher, but may cause motion artefacts and x-ray tube heating

Image Interpretation

- ❑ Interpretation is simplified in some areas of the body by comparing to the opposite side.
- ❑ Appropriate WL and WW are crucial for the proper interpretation of CT images
- ❑ The identification of structures on one transverse image can usually be accomplished simply by examining multiple adjacent transverse images.
- ❑ The scanned structure can be followed in relation to recognisable surrounding organs as it appears and disappears.
- ❑ Lesions are detected
 - by virtue of displacement or deformity of normal landmarks
 - by changes in tissue density due to pathological processes such as **oedema, haemorrhage, necrosis, calcification and osteolysis.**

History

- The first commercially viable CT scanner was invented by Godfrey Newbold Hounsfield in Hayes, England at Thorn EMI Central Research Laboratories using X-rays.
- Hounsfield conceived his idea in 1967, and it was publicly announced in 1972.
- It is claimed that the CT scanner was "the greatest legacy" of the Beatles; the massive profits from their record sales enabled EMI to fund scientific research.
- Allan McLeod Cormack of Tufts University, Massachusetts, USA independently invented a similar process and they shared a Nobel Prize in medicine in 1979.

Prototype of CT scanner



- The original 1971 prototype took 160 parallel readings through 180 angles, each 1° apart, with each scan taking a little over five minutes. The images from these scans took 2.5 hours to be processed by algebraic reconstruction techniques on a large computer.
- The first production X-ray CT machine (called the EMI-Scanner) was limited to making tomographic sections of the brain, but acquired the image data in about 4 minutes (scanning two adjacent slices) and the computation time (using a Data General Nova minicomputer) was about 7 minutes per picture.
- This scanner required the use of a water-filled Perspex tank with a pre-shaped rubber "head-cap" at the front, which enclosed the patient's head. The water-tank was used to reduce the dynamic range of the radiation reaching the detectors (between scanning outside the head compared with scanning through the bone of the skull).

EMI scanner



Generations

generation	configuration	detector	beam	Min scan time
first	Translate -rotate	1-2	Pencil thin	2.5min
second	Translate -rotate	3-52	Narrow fan	10sec
Third	Rotate- rotate	256-1000	Wide fan	0.5sec
fourth	Rotate- fixed	600-4800	Wide fan	1sec
fifth	Electron beam	1284	Wide fan electron beam	33ns

1st & 2nd generation

- In the first and second generation designs, the X-ray beam was not wide enough to cover the entire width of the 'slice' of interest.
- A mechanical arrangement was required to move the X-ray source and detector horizontally across the field of view.
- After a sweep, the source/detector assembly would be rotated a few degrees, and another sweep performed.
- This process would be repeated until 360 degrees (or 180 degrees) had been covered. The complex motion placed a limit on the minimum scan time at approximately 20 seconds per image.

3rd & 4th generation

- In the 3rd and 4th generation designs, the X-ray beam is able to cover the entire field of view of the scanner.
- This avoids the need for any horizontal motion; an entire 'line' can be captured in an instant.
- This allowed simplification of the motion to rotation of the X-ray source.

- Third and fourth generation designs differ in the arrangement of the detectors.
- In 3rd generation, the detector array is as wide as the beam, and must therefore rotate as the source rotates.
- In 4th generation, an entire ring of stationary detectors are used.

Electron Beam CT

- Electron beam tomography (EBCT) was introduced in the early 1980s, by medical physicist Andrew Castagnini.
- It is a method of improving the temporal resolution of CT scanners.
- Because the X-ray source has to rotate by over 180 degrees in order to capture an image the technique is inherently unable to capture dynamic events or movements that are quicker than the rotation time.

- Instead of rotating a conventional X-ray tube around the patient, the EBCT machine houses a huge vacuum tube in which an electron beam is electro-magnetically steered towards an array of tungsten X-ray anodes arranged circularly around the patient.
- Each anode is hit in turn by the electron beam and emits X-rays that are collimated and detected as in conventional CT.
- The lack of moving parts allows very quick scanning, with single slice making the technique ideal for capturing images of the heart.
- EBCT has found particular use for assessment of coronary artery calcium, a means of predicting risk of coronary artery disease.

Helical or Spiral CT

- Helical, also called spiral, CT was introduced in the early 1990s, with much of the development led by Willi Kalender and Kazuhiro Katada.
- In older CT scanners, the X-ray source would move in a circular fashion to acquire a single 'slice', once the slice had been completed, the scanner table would move to position the patient for the next slice; meanwhile the X-ray source/detectors would reverse direction to avoid tangling their cables.

- In helical CT the X-ray source are attached to a freely rotating gantry.
- During a scan, the table moves the patient smoothly through the scanner; the name derives from the helical path traced out by the X-ray beam.
- It was the development of two technologies that made helical CT practical: slip rings to transfer power and data on and off the rotating gantry, and the switched mode power supply powerful enough to supply the X-ray tube, but small enough to be installed on the gantry.

Multislice CT

- Multislice CT scanners are similar in concept to the helical or spiral CT but there are more than one detector ring.
- It began with two rings in mid nineties, with a 2 solid state ring model designed and built by Elscint (Haifa) called CT TWIN, with one second rotation.
- Later, it was presented 4, 8, 16, 32, 40 and 64 detector rings, with increasing rotation speeds. Current models (2007) have up to 3 rotations per second, and isotropic resolution of 0.35mm voxels with z-axis scan speed of up to 18 cm/s.
- This resolution exceeds that of High Resolution CT techniques with single-slice scanners, yet it is practical to scan adjacent, or overlapping, slices - however, image noise and radiation exposure significantly limit the use of such resolutions.

- The major benefit of multi-slice CT is the increased speed of volume coverage. This allows large volumes to be scanned at the optimal time .
- The ability of multi-slice scanners to achieve isotropic resolution even on routine studies means that maximum image quality is not restricted to images in the axial plane - and studies can be freely viewed in any desired plane.

Dual Source CT

- Siemens introduced a CT model with dual X-ray tube and dual array of 64 slice detectors, at the 2005 Radiological Society of North America (RSNA) medical meeting.
- Dual sources increase the temporal resolution by reducing the rotation angle required to acquire a complete image, thus permitting cardiac studies without the use of heart rate lowering medication, as well as permitting imaging of the heart in systole.
- The use of two x-ray units makes possible the use of dual energy imaging.

Diagnostic use

- Since its introduction in the 1970s, CT has become an important tool in medical imaging to supplement X-rays and medical ultrasonography. Although it is still quite expensive, it is the gold standard in the diagnosis of a large number of different disease entities.
- It has more recently used for preventive medicine or screening for disease, for example CT colonography for patients with a high risk of colon cancer.
- Although a number of institutions offer full-body scans for the general population, this practice remains controversial due to its lack of proven benefit, cost, radiation exposure.

Advantages

- First ,CT completely eliminates the superimposition of images of structures outside the area of interest.
- Second, because of the inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished.
- Third, data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task. This is referred to as multiplanar reformatted imaging.

Contrast studies

- ▣ To increase the amount of soft tissue information, -Ve (air) and +Ve contrast agents, such as radiopaque iodine can be used
- ▣ IV contrast is used to differentiate between normal and abnormal tissue

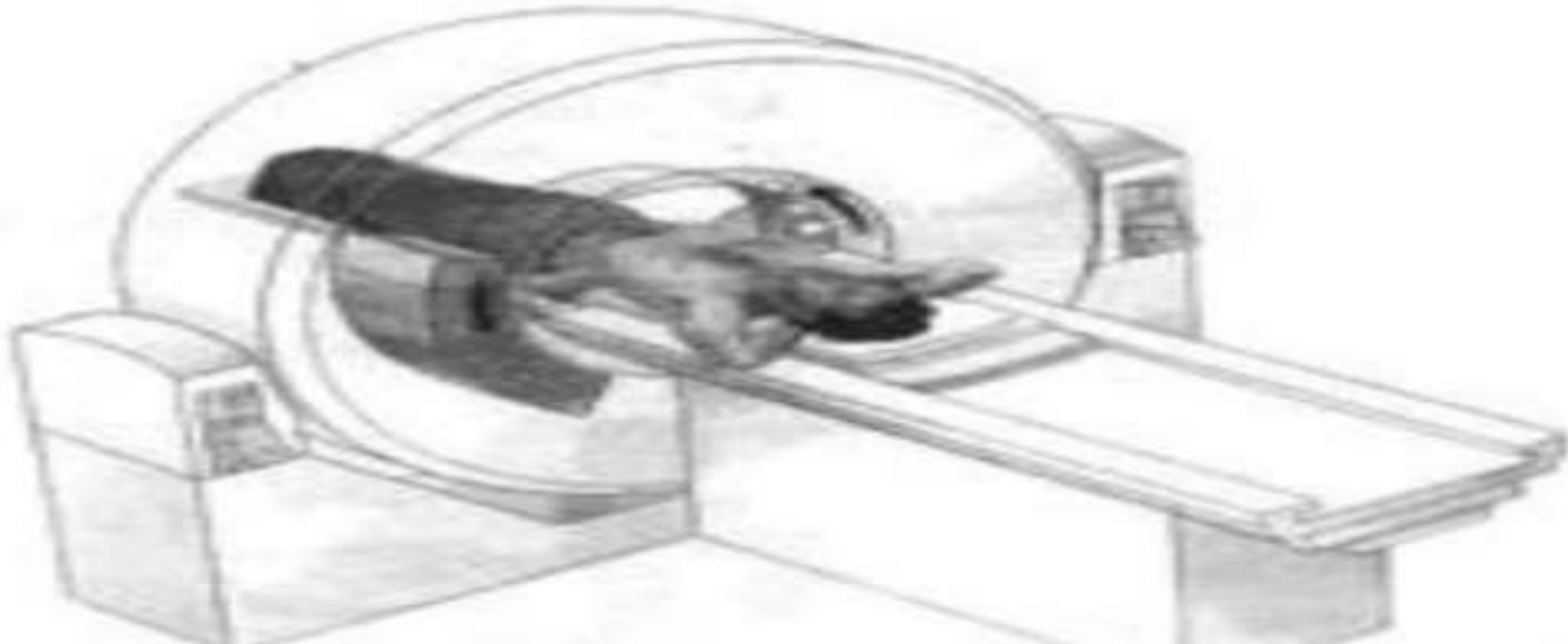
Hazards : Adverse reactions to contrast agents

- Because CT scans rely on intravenously administered contrast agents in order to provide superior image quality, there is a low but non-negligible level of risk associated with the contrast agents themselves.
- Certain patients may experience severe and potentially life-threatening allergic reactions to the contrast dye.
- The contrast agent may also induce kidney damage. The risk of this is increased with patients who have preexisting renal insufficiency, preexisting diabetes, or reduced intravascular volume.

- In general, if a patient has normal kidney function, then the risks of contrast nephropathy are negligible.
- Patients with mild kidney impairment are usually advised to ensure full hydration for several hours before and after the injection.
- For moderate kidney failure, the use of iodinated contrast should be avoided; this may mean using an alternative technique instead of CT e.g. MRI.

Process

- CT scan illustration



- X-ray slice data is generated using an X-ray source that rotates around the object; X-ray sensors are positioned on the opposite side of the circle from the X-ray source.
- Many data scans are progressively taken as the object is gradually passed through the gantry.
- They are combined together by the mathematical procedure known as tomographic reconstruction.

- contrast materials such as intravenous iodinated contrast are used.
- This is useful to highlight structures such as blood vessels that otherwise would be difficult to delineate from their surroundings.
- Using contrast material can also help to obtain functional information about tissues.

Windowing

- Windowing is the process of using the calculated Hounsfield units to make an image.
- The various radiodensity amplitudes are mapped to 256 shades of gray. These shades of gray can be distributed over a wide range of HU values to get an overview of structures.
- Alternatively, these shades of gray can be distributed over a narrow range of HU values (called a "*narrow window*") centered over the average HU value of a particular structure to be evaluated. In this way, variations in the internal makeup of the structure can be discerned. This is a commonly used image processing technique known as contrast compression.

- For example, to evaluate the abdomen in order to find Small masses in the liver, one might use liver windows . Choosing 70 HU as an average HU value for liver, the shades of gray can be distributed over a narrow window or range. One could use 170 HU as the narrow window, with 85 HU above and 85 HU below it, with 70 HU average value; Therefore the liver window would extend from -15 HU to +155 HU.

- All the shades of gray for the image would be distributed in this range of Hounsfield values.
- Any HU value below -15 would be pure black, and any HU value above 155 HU would be pure white in this example.
- Using this same logic, bone windows would use a "*wide window*" (to evaluate everything from fat-containing medullary bone that contains the marrow, to the dense cortical bone) .

Artifacts

- Although CT is a relatively accurate test, it is liable to produce artifacts, such as the following:
- ❖ **Aliasing Artifact or Streaks**
- These appear as dark lines which radiate away from sharp corners.
- It occurs because it is impossible for the scanner to 'sample' or take enough projections of the object, which is usually metallic. It can also occur when an insufficient penetration of the x-ray occurs.

❖ **Ring Artifact**

- Probably the most common mechanical artifact, the image of one or many 'rings' appears within an image. This is due to a detector fault.

❖ **Noise Artifact**

- This appears as graininess on the image and is caused by a low signal to noise ratio. This occurs more commonly when a thin slice thickness is used. It can also occur when the kV or mA is too low.

❖ **Motion Artifact**

- This is seen as blurring which is caused by patient movement. This is not so much a problem these days with faster scanning times in the use of MDCT.

❖ **Beam Hardening**

- This can give a 'cupped appearance'. It occurs when there is more attenuation in the center of the object than around the edge. This is easily corrected by filtration .