

CT Technology Review

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Adapted from a slide set created by
Dr. J.C.P. Heggie, St Vincent's Hospital
Some graphics taken from
Computed Tomography, Willi A. Kalender, Publicis, 2005
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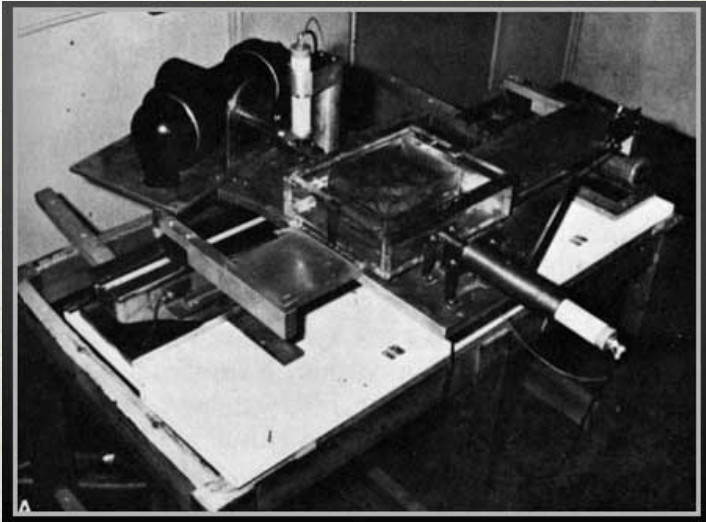
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Principle of CT Scanning

- The basic principle of CT scanning is that the internal structure of an object can be reconstructed from multiple projections of that object
 - Radon (1917) developed mathematical foundation of reconstructing cross sectional images from transmission measurements
 - Cormack (1963) describes a technique for calculating the absorption distribution in the human body
 - Hounsfield (1972) & Ambrose conduct 1st clinical CT examination – head scan
 - Cormack & Hounsfield awarded Nobel Prize

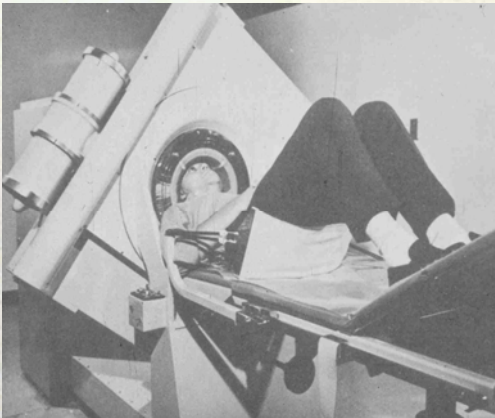
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EMI Prototype



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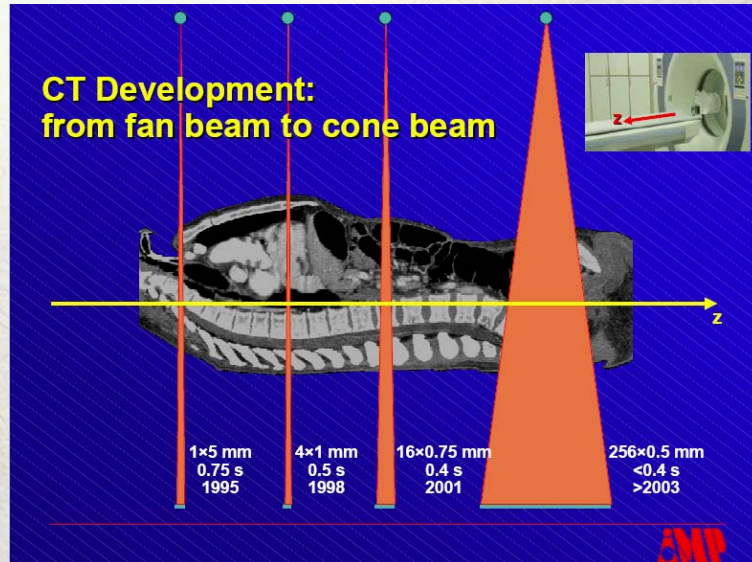
The EMI Mark I



**Head scan circa 1974
Matrix 80 x 80**

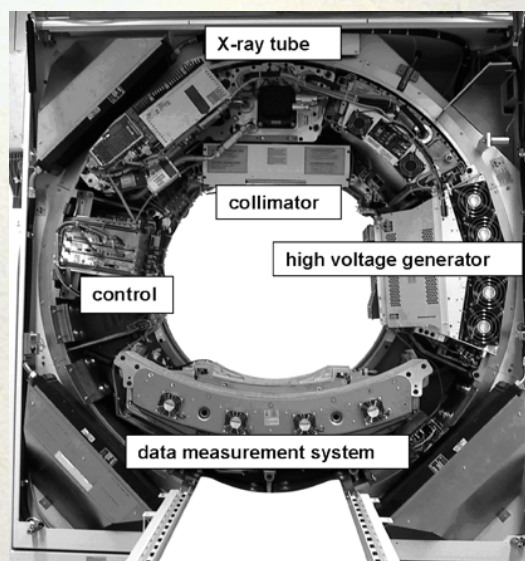
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CT Generations



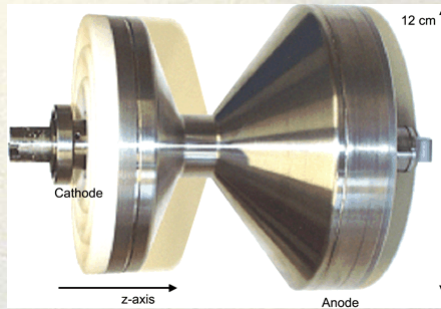
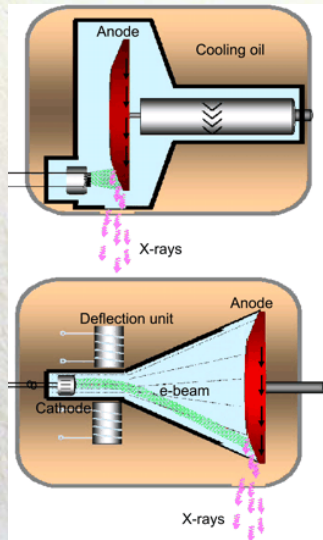
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CT Generations



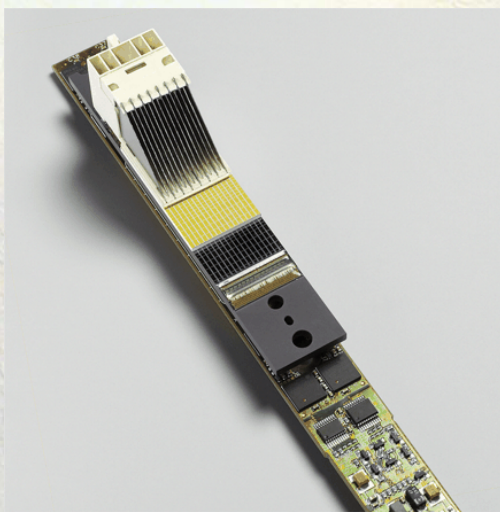
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Siemens Straton Tube



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Siemens 64-slice Array

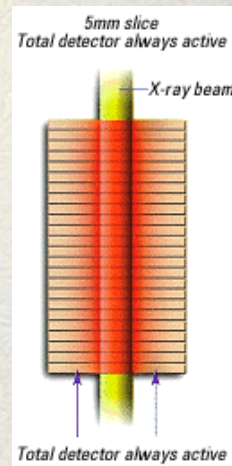


Detector module of the SOMATOM Sensation 64.
Each module consists of 40 x 16 detector pixels with the corresponding electronics.

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Single Slice CT

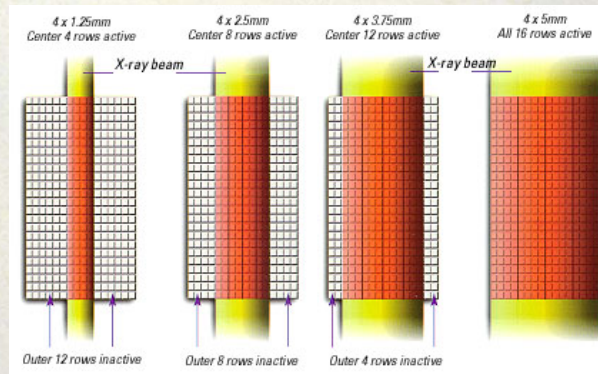
- Beam Collimated to Desired Slice Thickness & Focused on Centre of Detector Arc
- Changing Slice Thickness Is Easy
 - Open the Collimator to Increase the Width of the X-ray Beam
- A Single Data Set Is Acquired for Each 360 Degree Rotation of the X-ray Tube



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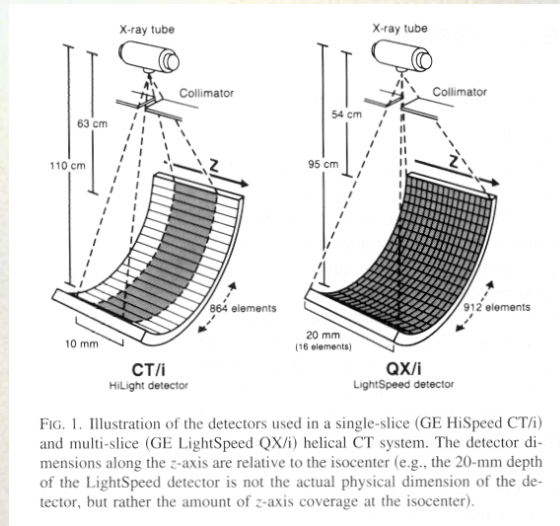
Multi-Slice CT

- With the Multi-slice CT Detector, the Technology Is Much More Complex. The X-Ray Beam Is Collimated to a Wider Thickness & Focused on the Central 4, Central 8, Central 12, or All Rows of Detectors
- For Each Rotation, Four Separate Data Sets Are Acquired



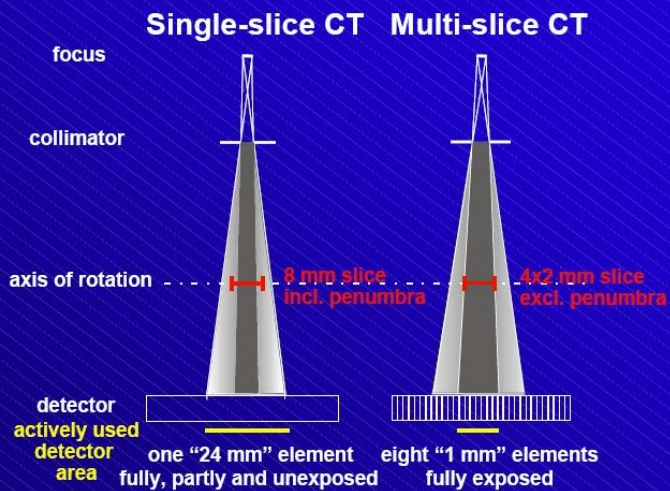
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Multislice Geometry



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Dose Efficiency in Multi-Slice Acquisition

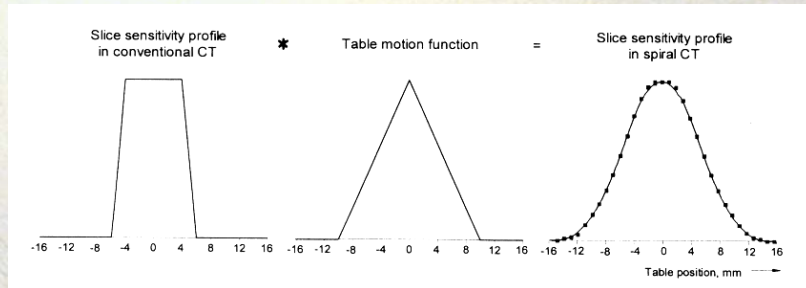


Kalender WA. Computed Tomography. Wiley, New York 2001



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Slice Sensitivity Profiles (Dose)

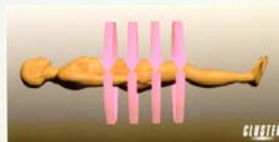


Thinner slices (larger penumbra) and slower table speed (smaller pitch) = larger dose profile and deposition

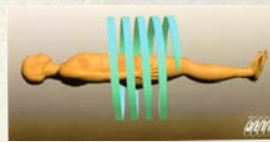
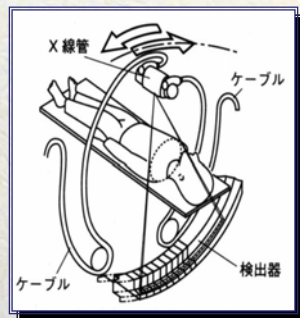
With a pitch ≤ 1 means penumbral overlap and increased organ dose

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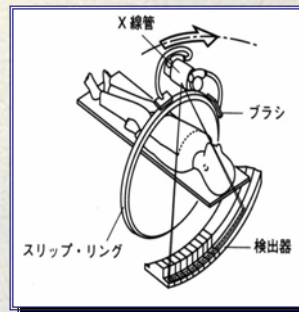
Conventional CT vs Slip Ring CT



Step & Shoot Axial



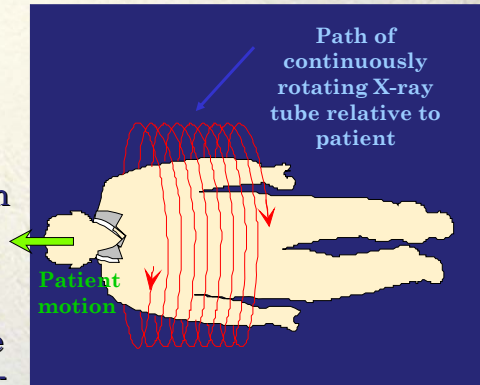
Axial & Helical/Spiral



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Helical Scanning

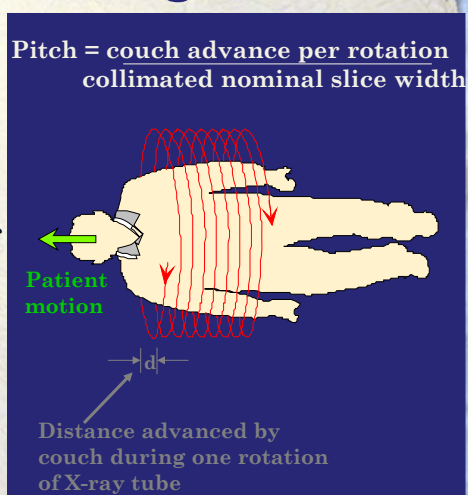
- 3rd generation plus:
 - Slip ring technology allows for continuously rotating X-ray tube with transfer of high voltage and data from/to outside world
 - Continuous advance of patient couch @ 1-10 mm/s
 - Single breath hold imaging (~60 s)



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Helical Scanning (2)

- Unique features:
 - Pitch values typically 1 to 2 – high pitch means reduced dose
 - Note: even for pitch > 1 the technique is one of volume imaging (contrast step & shoot axial scanning)
 - Down side of pitch > 1 is an increase in the effective slice width & potential for poorer resolution



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Pitch Definition

$$p = \frac{D}{M.S}$$

p = pitch

D = table feed per rotation (mm/360°)

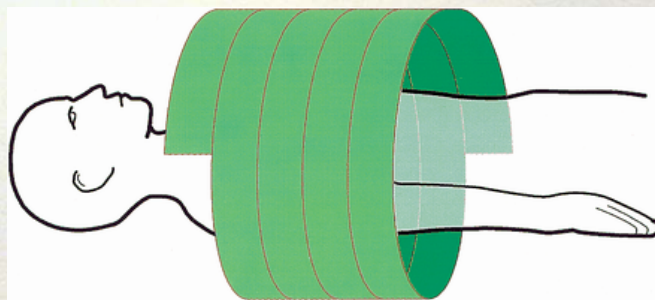
M = number of simultaneously scanned slices

S = nominal acquired slice width (mm)

M.S = isocentric beam width (mm)

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Anatomical Coverage

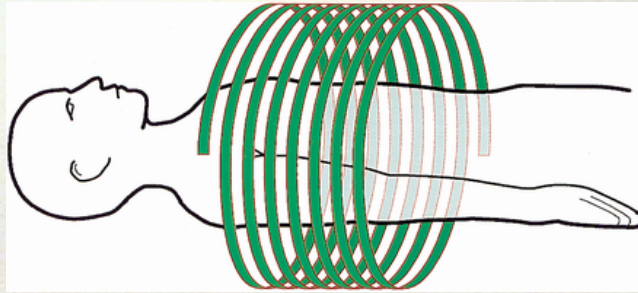


Pitch = 1 Contiguous slices

Patient Dose = relatively equal to gapless axial scanning
Image Quality = relatively equal to gapless axial scanning

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Anatomical Coverage

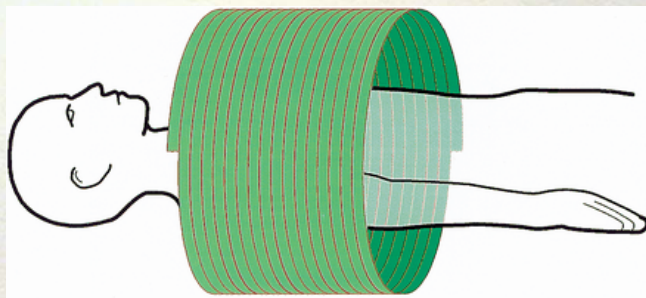


Pitch > 1 Slices with gaps

Patient Dose is less as same photons spread over larger volume
Image Quality is compromised due to data interpolation

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Anatomical Coverage

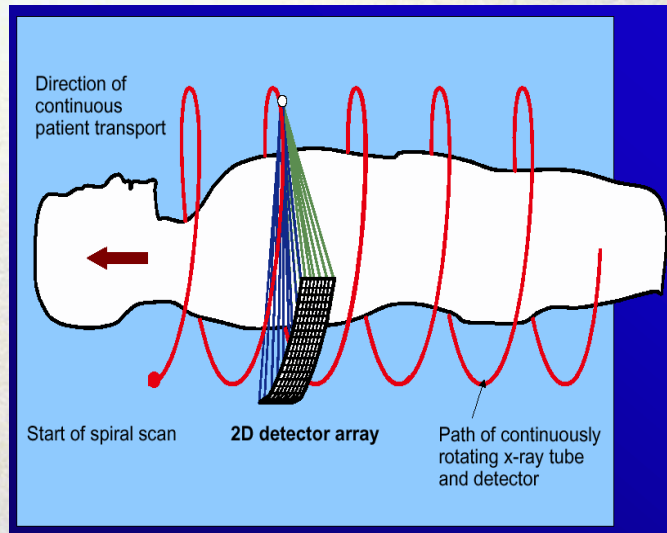


Pitch < 1 Overlapping slices

Patient Dose is greater as same photons spread over smaller volume
Image Quality is better due to more photon data per unit volume

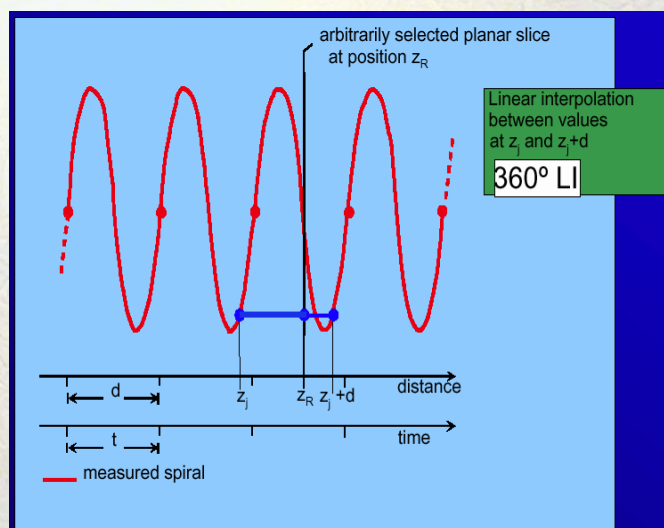
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Multislice Spiral Acquisitions



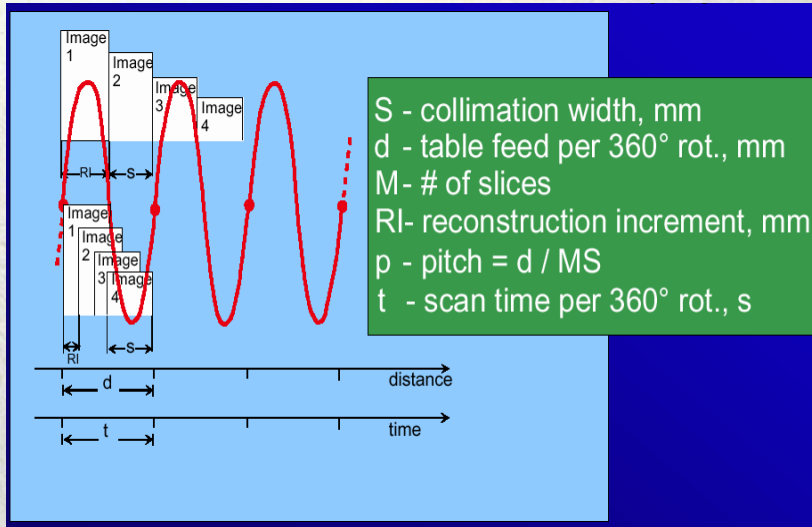
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360° Interpolation



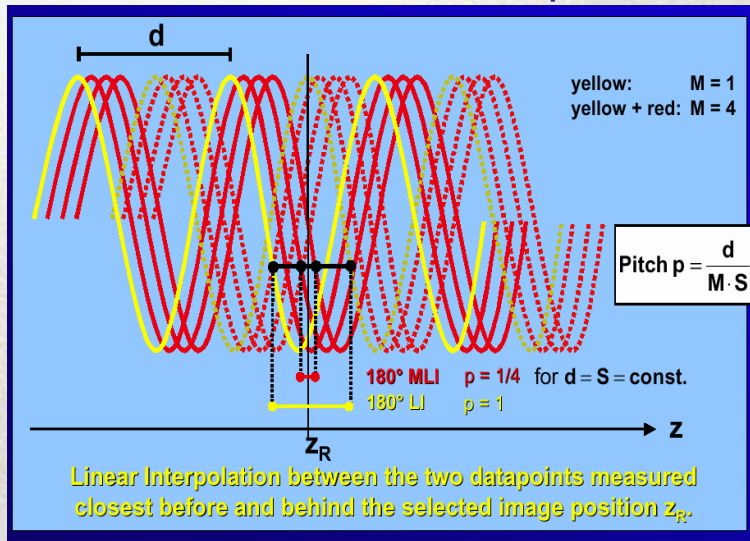
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Retrospective Interpolation



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Multislice z-axis Interpolation



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Cone Beam Correction

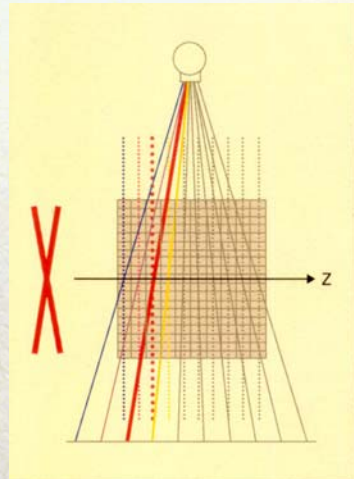


Figure 8. Reconstruction from cone-beam (conventional scan) by fan-beam back-projection, showing widening of the SSP.

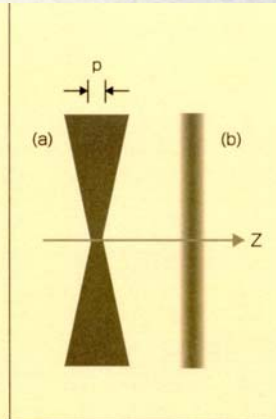


Figure 12. Conceptual images of SSP, showing the range of the data contributing to the reconstruction plane when HFI (a) and TCOT (b) are employed for cone-beam helical data.

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Cone Beam Correction

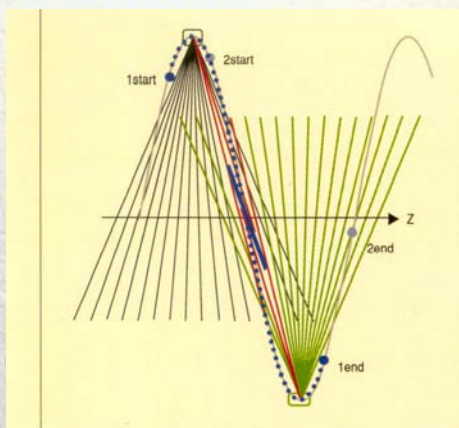


Figure 9. Simple cone angle countermeasures, ASSR method.

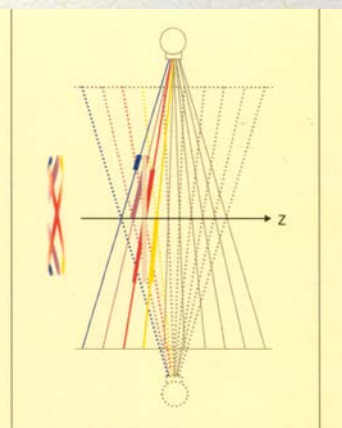


Figure 10. Image reconstruction from cone-beam (conventional scan) by the Feldkamp method, showing the SSP.

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Cone Beam Correction

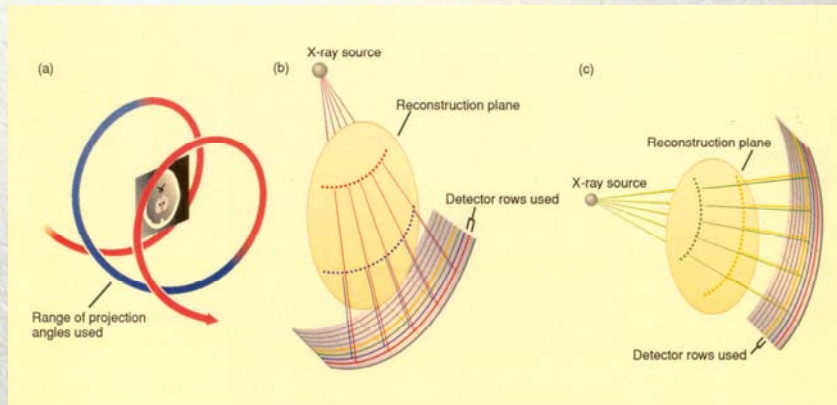


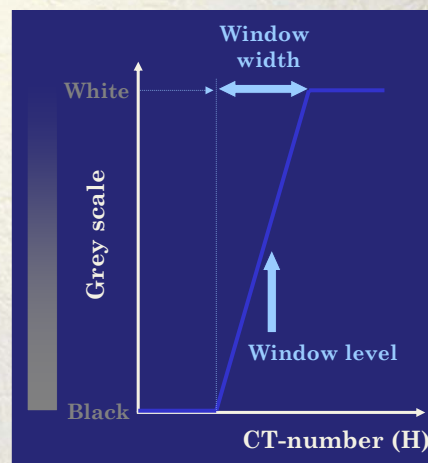
Figure 11. Back-projection approach employed in the TCOT method.
 a. Blue indicates the range of projection angles used.
 b. The source is at the z position, at a distance from the reconstruction plane, and the rows at the end are used.
 c. The source is near the z position, and the inner rows are used.
 In both "b" and "c" the data used are dependent on the pixel position. The nearest data are used for all pixels.

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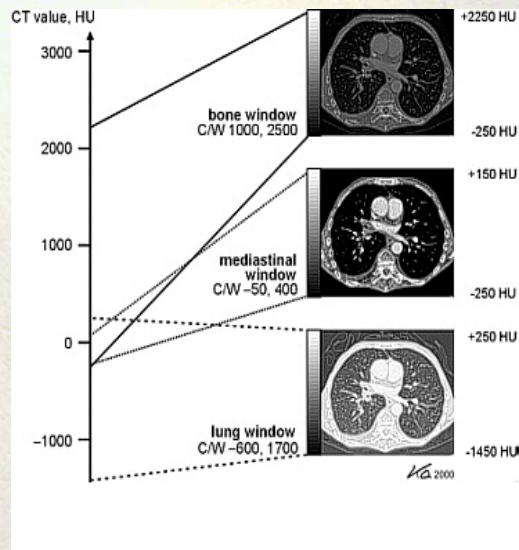
Image Display

- Outcome of reconstruction process is a map of linear attenuation coefficients.
 - Calculate pixel value in Hounsfield Units
- $$HU = \frac{\mu_{material} - \mu_{water}}{\mu_{water}} \times 1000$$
- The image is then displayed using a map which converts CT-number (H) to shades of grey



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Display Windows



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Image Display

Impact of grey scale display parameters on image appearance



L=50, W=200



L=50, W=400

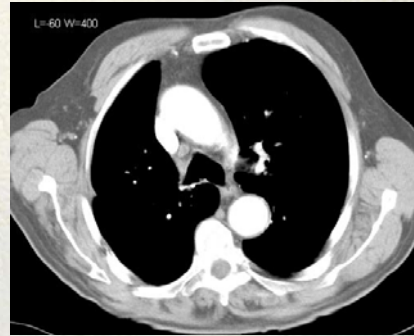
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Image Display

Impact of grey scale display parameters on image appearance



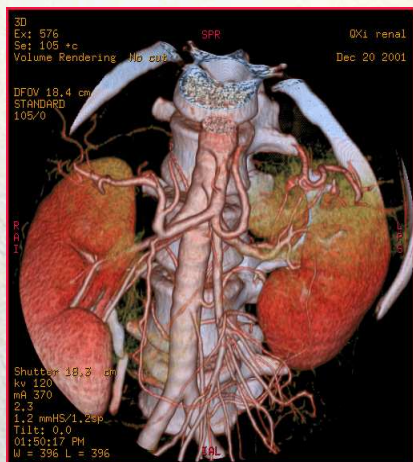
L=600, W=1700



L=60, W=400

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Image Display



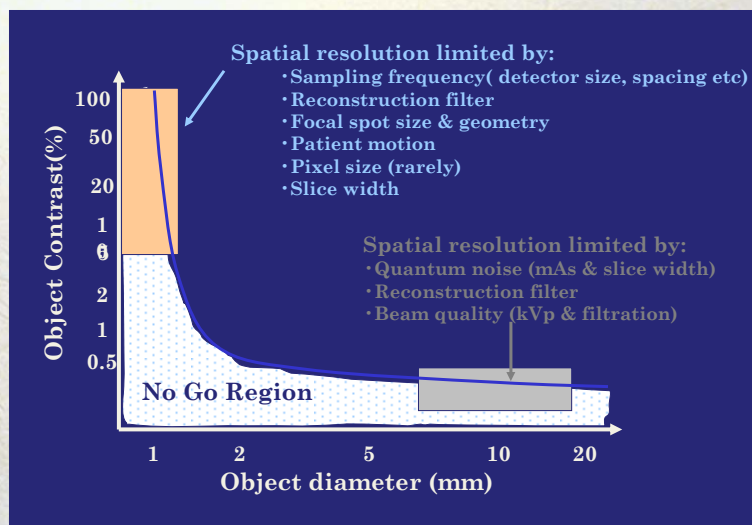
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Image Quality

- Spatial resolution
- Low contrast resolution which is dictated by image noise
- Artifacts

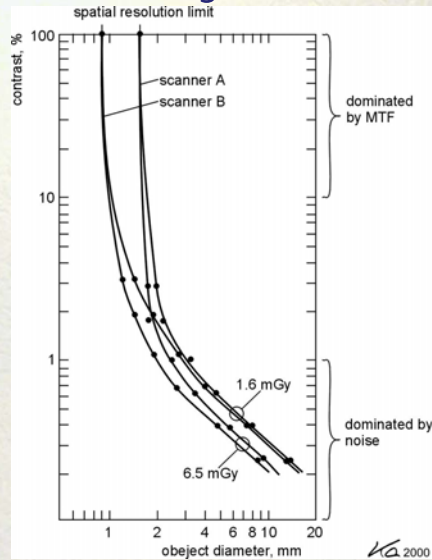
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Contrast Detail Curve



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Image Quality – Size & Noise



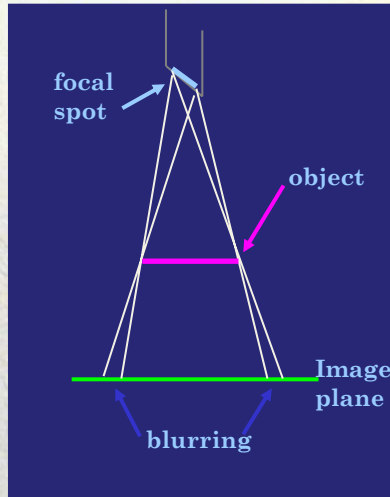
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Spatial Resolution

- Primarily dictated by geometrical factors
 - Geometric unsharpness (magnification & focal spot size)
 - Sampling frequency (Detector element size, spacing & number of profiles)
 - Voxel size (pixel size & slice thickness)
- Object contrast
- Reconstruction filter (kernel)
- Patient motion

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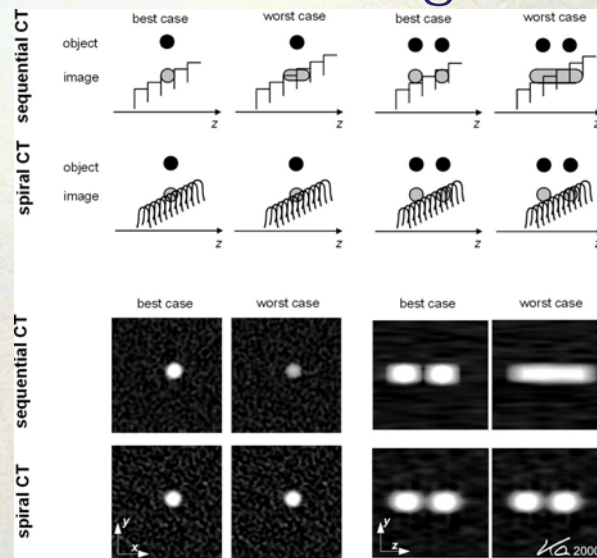
Geometric Unsharpness



- Cause is finite size of focal spot
- Extent is influenced by
 - size of focal spot (f)
 - focus to image distance
 - magnification (m)
- Resolution limit is:
 - $R_c = m / (m-1) \times 1 / f$

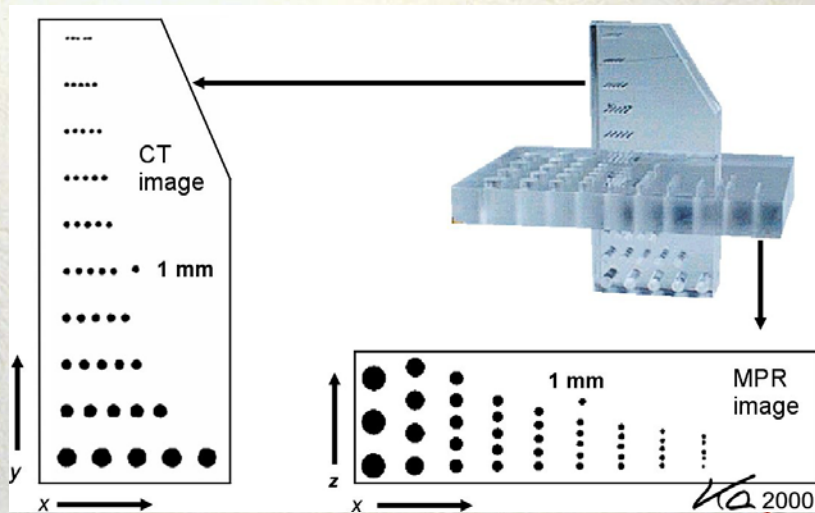
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Spiral vs Axial Image Quality



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Isotropic Spatial Resolution



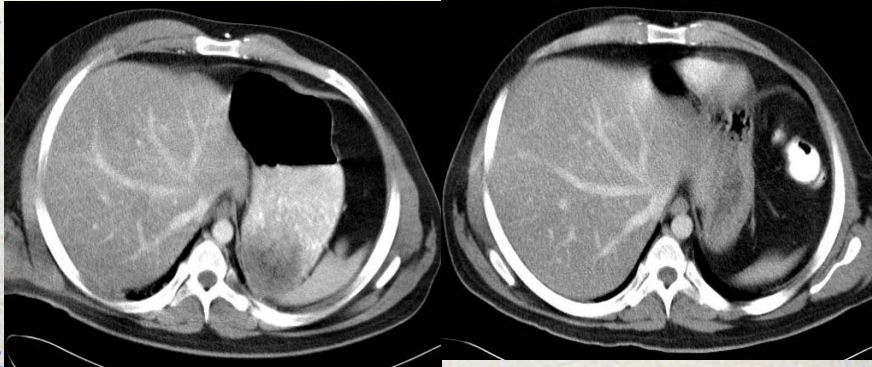
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Noise

- Limits ability to observe low contrast
- Primarily dictated by # of detected X-rays
 - Detector efficiency
 - mAs
 - Number of profiles (sampling frequency)
 - kVp & filtration
 - Slice width
- Reconstruction filter (kernel)

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Noise & Dose

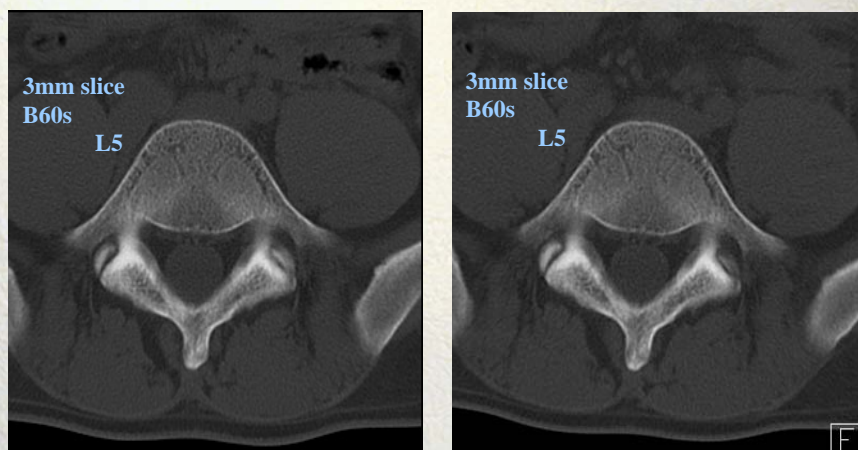


Effective mAs = 149

Effective mAs = 105

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Noise & Dose



3mm slice
B60s
L5

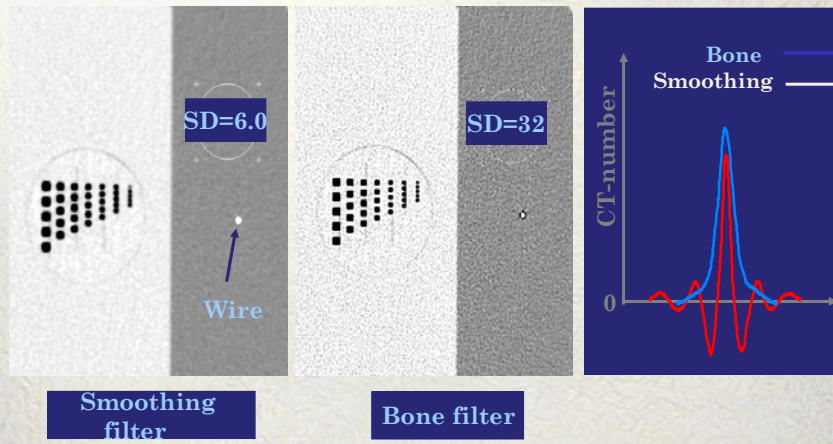
3mm slice
B60s
L5

Fixed effective mAs = 360

Effective mAs = 232

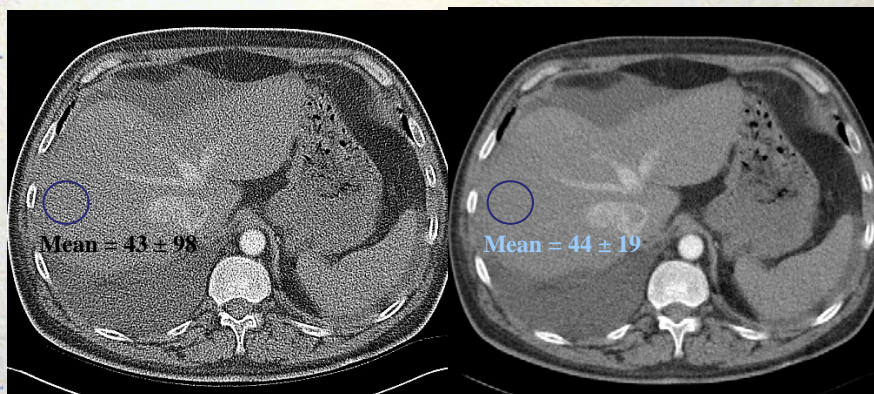
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Reconstruction Algorithm



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Reconstruction Algorithm



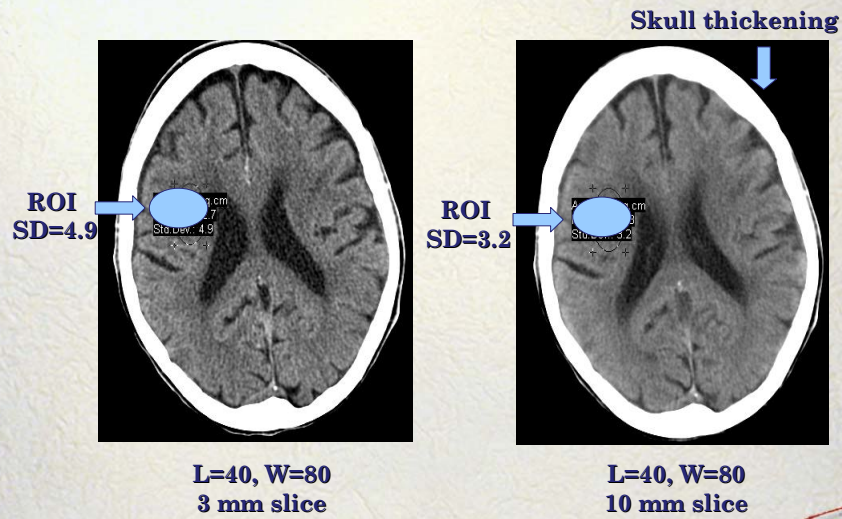
90 mAs Kernel = B80

90 mAs Kernel = B41

To achieve the same level of noise reduction would require an INCREASE in mAs (dose) by a factor of 25!

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Slice Width



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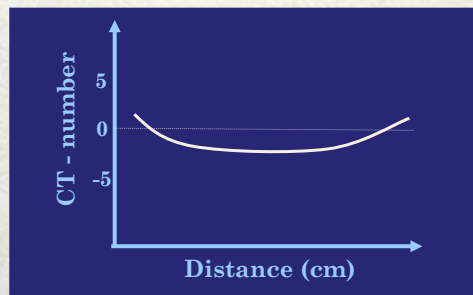
Artifacts

- Beam hardening (cupping)
- Partial volume
- Ring
- Algorithm limitation (see earlier)
- Streak
- Motion
- Detector over ranging

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Cupping Artifact

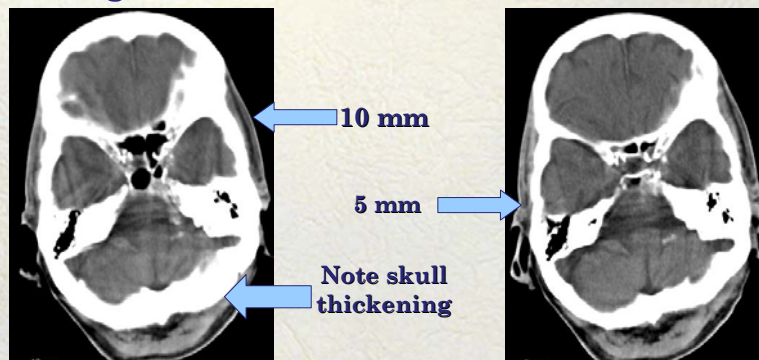
- CT number decreases in centre of image
 - cause is preferential attenuation of low energy X-rays
 - leads to lower value of μ & hence of H



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Partial Volume Effect

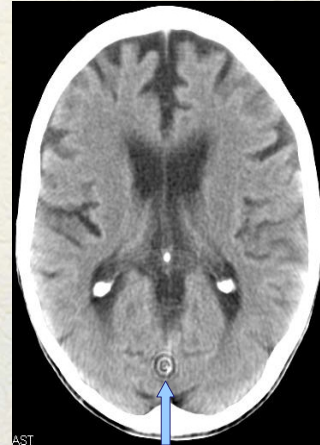
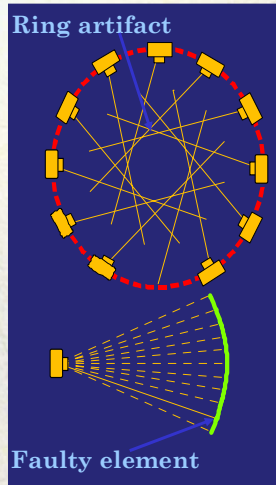
- Attributable to finite size of voxel. The calculated value of μ (or H) is a weighted average of the tissue contributions



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Ring Artifact

- Caused by faulty detector element in 3rd generation scanner

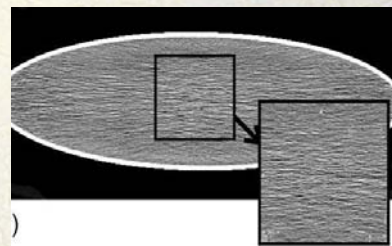


Ring artifact

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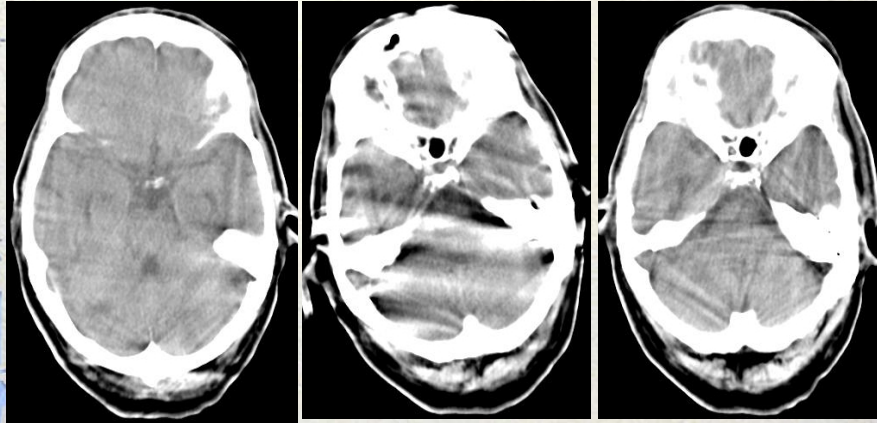
Streak Artifact

- Could arise from:
 - partial volume effects
 - Motion (see later)
 - inadequate sampling & frequently
 - Photon starvation



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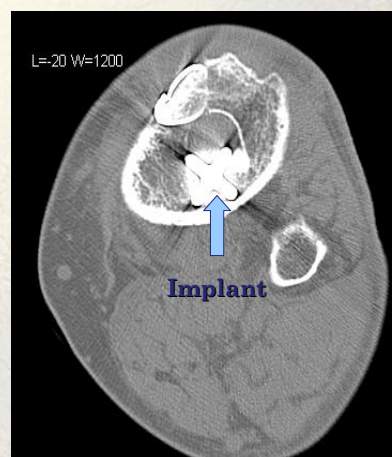
Motion Artifact



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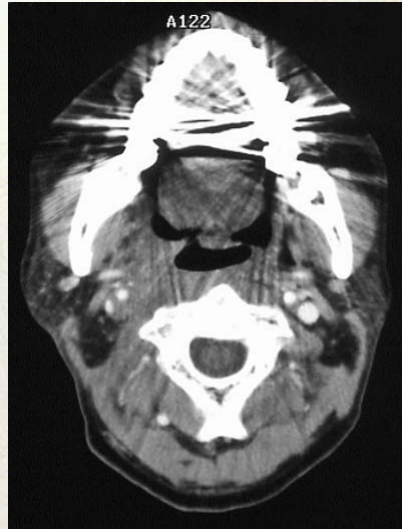
Detector Over Ranging

- Caused by metal implants (usually) with high attenuation resulting in pixel value outside normal range
- Can be black or white in image depending on scanner software



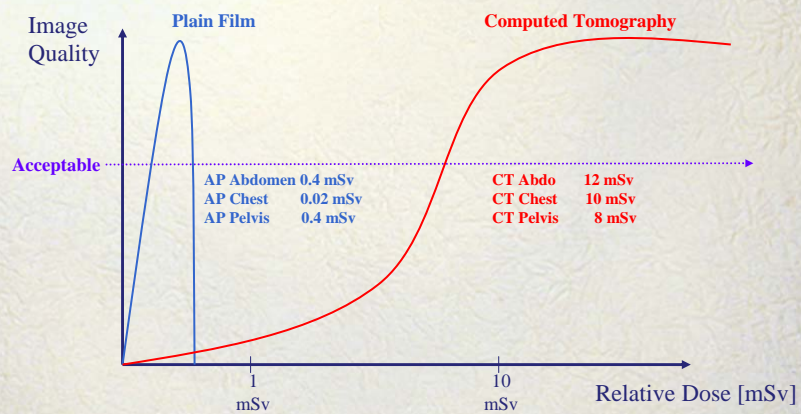
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Surgical Clips



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Plain Film & CT Dosimetry



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Image Quality

- multislice spiral CT
 - can provide isotropic 3D sub-millimetre resolution,
 - high z resolution requires, thin slices, reconstruction of several slices per slice thickness and the use of 180° acquisition,
 - by combining slices, low noise images can be acquired which are almost free of partial volume artifacts and exhibit high contrast resolution,
 - it is better to use a higher zoom factor rather than a higher magnification factor as low zoom factors may limit spatial resolution by matrix size or pixel size limitations

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Image Quality

- reconstruction algorithms
 - high resolution kernels,
 - use for high contrast objects,
 - view with a wide viewing window display to reduce noise visualisation,
 - standard & smooth resolution kernels,
 - reduces maximum resolution along with noise and artifacts,
 - increases low contrast detectability,
 - view with narrow window appropriately levelled.

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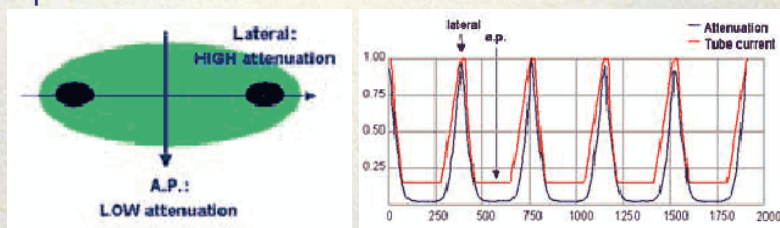
Image Quality

- for high resolution CT
 - use thin slices,
 - reconstruct at small reconstruction increments with high resolution convolution kernels with a high zoom factor,
 - view with a wide window display

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Dose Modulation

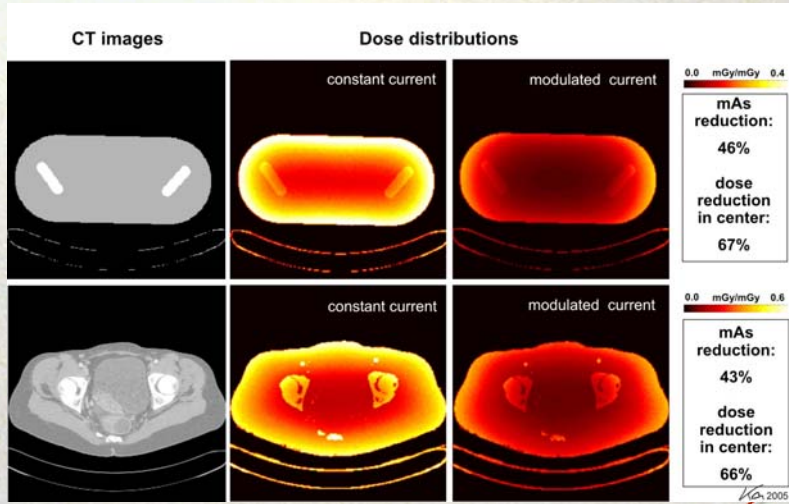
- fixed mA vs variable mA systems
- longitudinal and z-axis dose modulation of ap vs lateral diameters/attenuation values,



- 3D data interpolation algorithms being developed

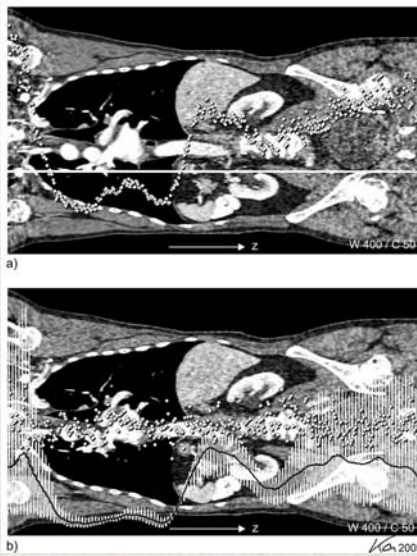
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Dose Modulation



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Dose Modulation



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That's All Folks



*If you use too
much radiation*

...

*you will get your
ass in trouble*

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