The impact of MDCT on optimisation and quality assurance of CT scanners

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Imaging Performance Assessment of CT Scanners

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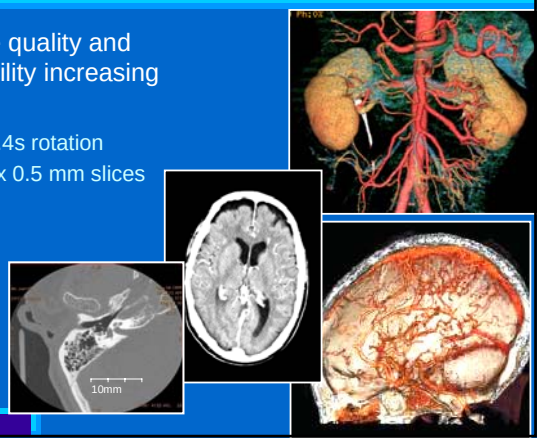
www.impactscan.org

ImPACT

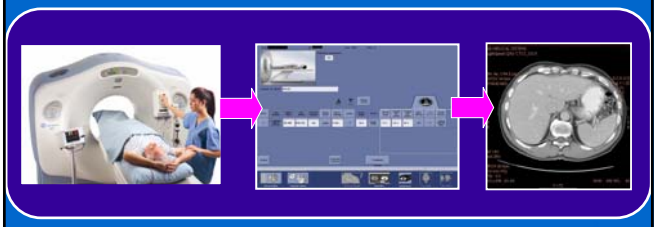
Multi-Slice CT

- Image quality and capability increasing
- 2006
  - < 0.4s rotation
  - 64 x 0.5 mm slices
- Dose



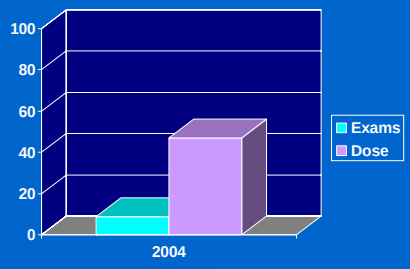
MDCT optimisation and quality assurance

- Multi-slice CT
- Implications for testing
- Optimisation of protocols



CT Radiation Dose

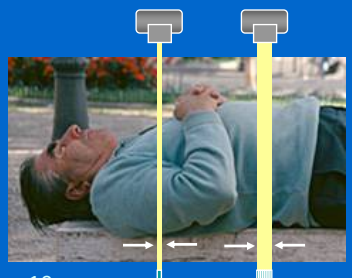
- CT is inherently a high dose examination, and increasing
- ~50% of total contribution to doses from diagnostic x-ray
- ~10% of number of x-ray exams [1]



[1]HPA & DH estimates

Multi-Slice CT

- Wider beam widths



10 mm

single slice

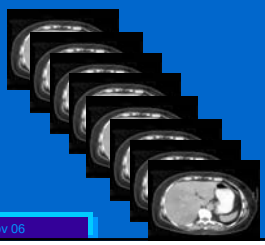
multi slice

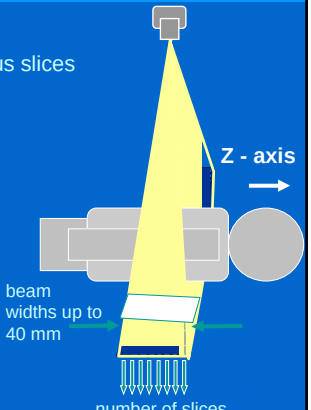
Beam widths up to 40 mm

Z-axis

Issues in Multi-Slice CT

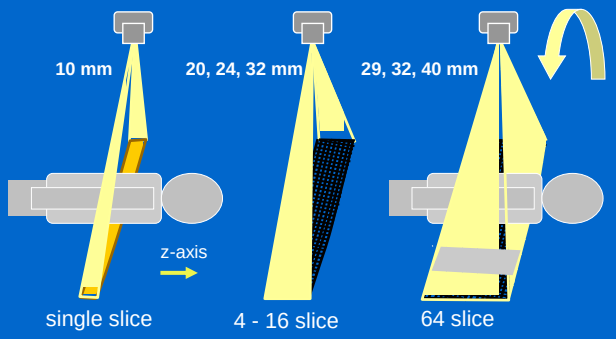
- Thin slice data acquisition
  - 4,16, 32, 40, 64 simultaneous slices
    - Eg
      4 x 0.5 or 5 mm
      16 x 0.625 or 1.25 mm,
      64 x 0.5 or 0.625 mm





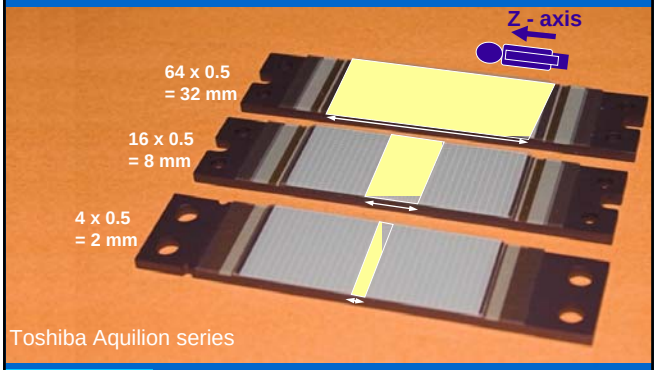
Multi-Slice CT

- Wider beam widths



Multi-Slice CT

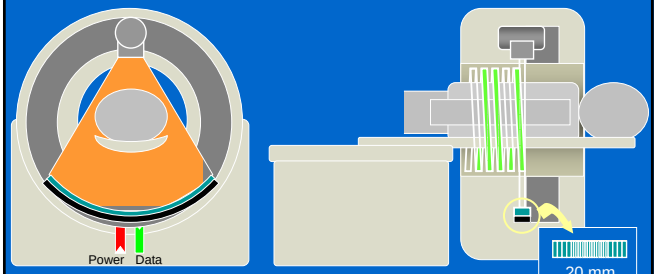
- Thinner slices and more of them



Detector mock-ups courtesy of Toshiba

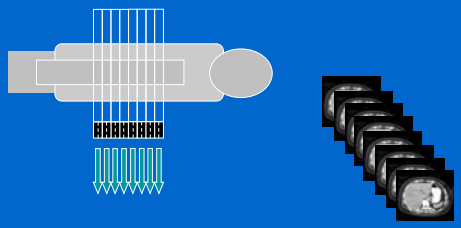
Multi-Slice CT

- Rotating tube and detectors – same as single slice
- Many axial images
- Helical scanning – many data sets



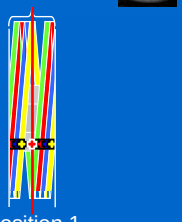
Multi-Slice CT

- Axial scans
  - Limited to ~ 16 slices, even on a 64 slice scanner
  - Cone beam effect



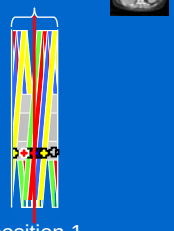
Multi-Slice CT

- Helical scanning – one acquisition
  - All channels acquire data (4,16, 64 slice scanner)
  - Each image uses data from many detectors



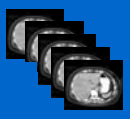
Multi-Slice CT

- Helical scanning – one acquisition
  - All channels acquire data (4,16, 64 slice scanner)
  - Each image uses data from many detectors
  - Reconstruct many images from one scan



Multi-Slice CT

- Helical scanning – one acquisition
  - All channels acquire data (4,16, 64 slice scanner)
  - Each image uses data from many detectors
  - Reconstruct many images from one scan
  - Reconstruct other thicknesses
  - Most scanning done helically



Recon position 2

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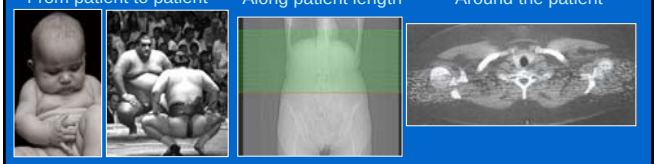
Multi-Slice CT

- Automatic exposure control
  - Varying attenuation of, along, and around patients
  - Tube current automatically adjusted to achieve a standard noise level

From patient to patient | Along patient length | Around the patient



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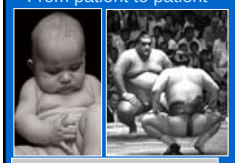
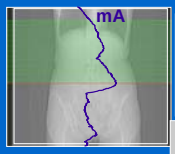
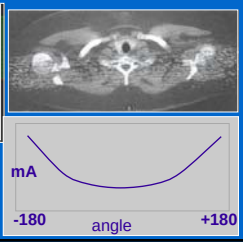
Multi-Slice CT

- Automatic exposure control
  - Varying attenuation of, along, and around patients
  - Tube current automatically adjusted to achieve a standard noise level
  - Scanners do all or some

From patient to patient | Along patient length | Around the patient







Low mA High mA

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CT scanner technical quality

- Quality control part of overall testing process
- Many of the tests are the same

Purchase → Acceptance → Quality control

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References and resources

IPEM Report 91 (2005)

Chapter 12 CT

What to do and when

IPEM Report 32 (2003)

How and why

www.ipem.org.uk

www.impactscan.org

(IPEM) Institute of Physics and Engineering in Medicine

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References and resources

- American College of Radiology www.acr.org
  - CT Accreditation program (Med. Phys, 31 (9) September 2004)
  - Practical tips, artefact examples, pitfalls to avoid
- AAPM, RSNA
  - www.aapm.org
  - www.rsna.org

Issues in multi-slice CT testing

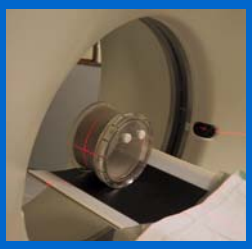
- Wider irradiated beam
  - Is the test object long enough ?
- Many slices acquired simultaneously
  - Should I measure all the axial slices ?
  - Can I deal with all the images ?
- Thinner slices
  - Is the test object good enough ?
- Automatic exposure control
  - What should I do ?
- Mainly helical protocols

CT scanner tests

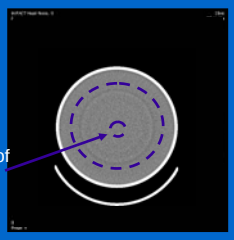
- Image quality
  - image noise
  - imaged slice thickness
  - spatial resolution
- Dose
  - CTDI (in air, in phantom)
- AEC

Image noise

water filled phantom



noise image

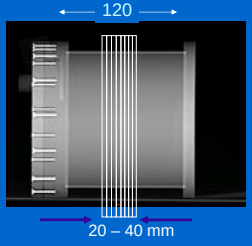


region of interest (roi)

- Axial or helical scan
- Noise = standard deviation (σ) of CT number in roi
- roi ~ 40% of phantom diameter for repeatable results

Is the test object long enough ?

- Phantom long enough to accommodate all slices
- Don't forget scatter



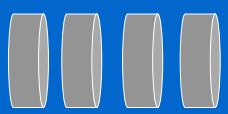
ImPACT (30 → 120 mm)

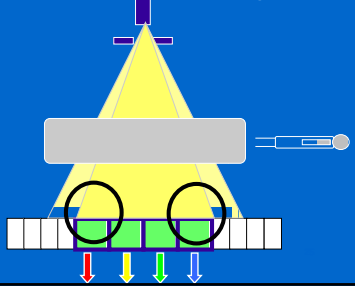
Catphan (20 → 40 mm)

Manufacturer's phantom

Should I measure all the axial slices ?

- For equal noise in each slice need
  - Equal sensitivity of detectors
  - Equal dose to detectors
- On four slice scanners, outer slices ~ 5% higher





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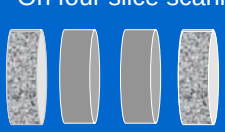

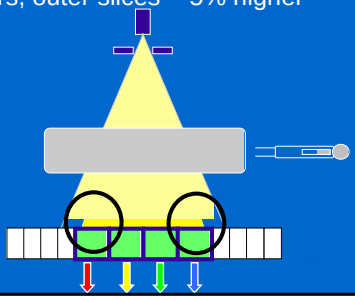

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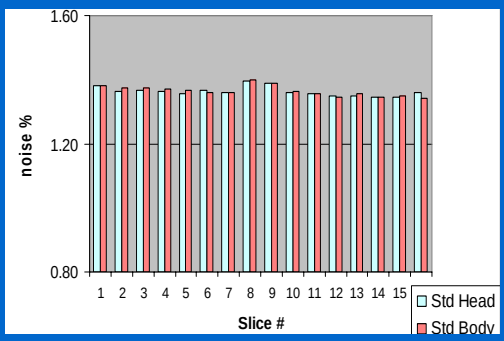
Noise measurements in multi-slice

- Measure all or some of the slices



16 x 0.63 mm slices

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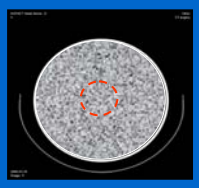
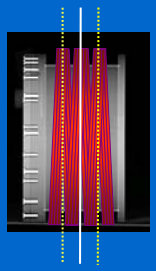
Noise measurements in multi-slice - helical





- All detectors contribute to image
  - no need for four, eight or sixteen sets of images
- Phantom length
  - Need to account for extra rotations at either end
  - Don't forget scatter

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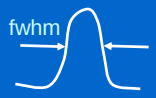
Image slice thickness

- In axial scan - determined by detector group



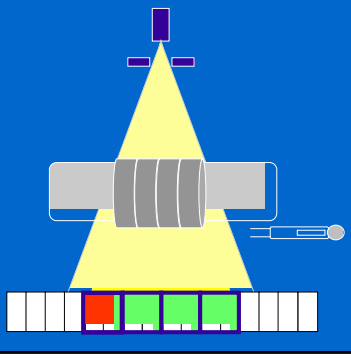


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Image slice thickness

- In helical scanning - interpolated from helical data

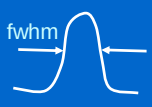

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Image slice thickness - axial

- 0.6 mm Al plate,
- 30 degrees to scan plane

- A typical test object – aluminium inclined plate
- Some use wire, at 25, 30, or 45 º

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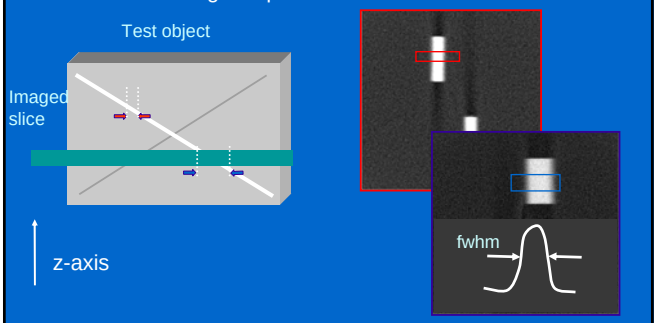
Image slice thickness - axial

- Shown by width of plate projected into image
- Corrected for angle of plate



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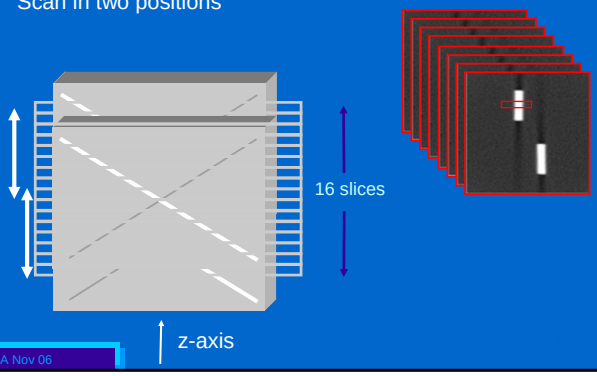
Multi-slice imaged slice width - axial

- Most inserts are not long enough to measure all slices
- Scan in two positions



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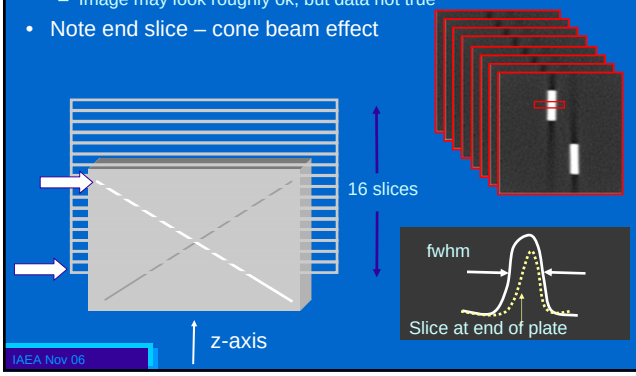
Multi-slice imaged slice width - axial

- Beware slice at end of inclined plate
  - Image may look roughly ok, but data not true
- Note end slice – cone beam effect



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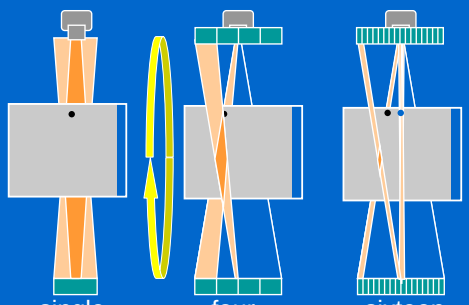
Multi-Slice CT

- As number of slices increases, beam is more diverging, outer slices are distorted



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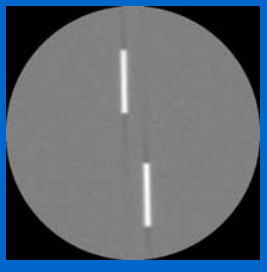
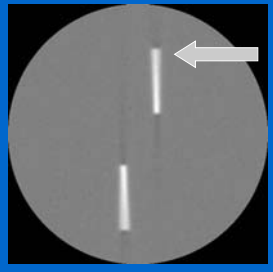
Multi-slice imaged slice width - axial

central slice



outer slice (16 slice)



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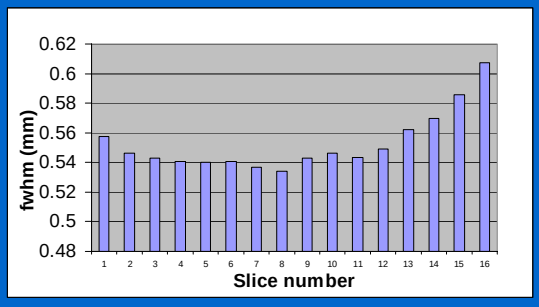
Multi-slice imaged slice width - axial

- Measure all or some of the slices



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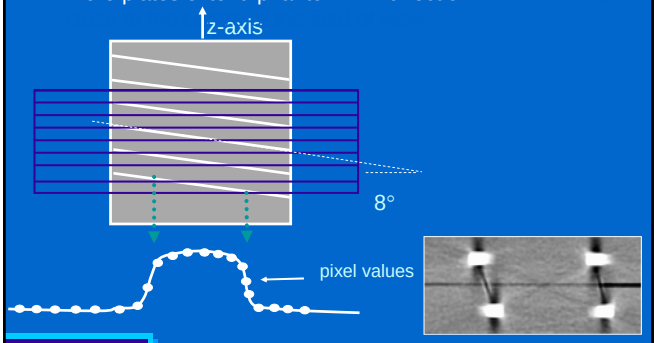
Is my test object good enough ?

- Measurement of slice widths of < 1mm
  - not possible where thickness of plate is < or = image width
- ImPACT use two phantoms
  - 0.5 mm aluminium, 30° (slices 2 - 20 mm)
  - 0.05 mm titanium, 8° (slices 0.5 - 4 mm)

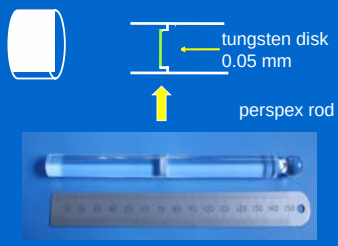
Multi-slice imaged slice width - axial

- Shallow angle gives more pixels in projection in image
- More plates extend phantom in z-direction



Imaged slice width – helical

- High contrast bead or disc
- Same test for single and multi-slice

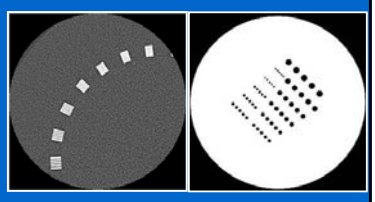


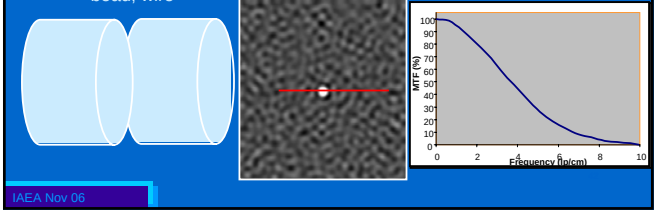
Imaged slice width – helical

- Scan test object
  - Images reconstructed at sub-slice intervals
  - CT number in each image used to create the profile

Scan plane spatial resolution

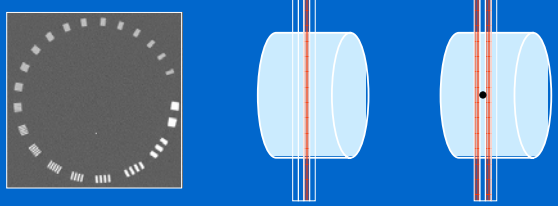
- Subjective
  - visual assessment of repeating pattern
- Objective
  - calculation of MTF
    - edge
    - bead, wire





MSCT - Scan plane spatial resolution

- Same test for single and multi-slice
- Use for both axial and helical images
- Only need measure for one axial image
  - Factors affecting scan plane spatial resolution are in the scan plane, and do not change from slice to slice



Dose

- Computed tomography dose index (CTDI)
- Measured with 100 mm ion chamber
  - In air for quality control
  - In phantom for acceptance, dose reference levels

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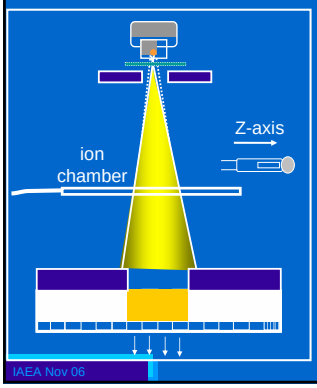
CTDI on multi-slice scanners

- Use total nominal beam width (n.T)



$$CTDI_{100} = \frac{1}{n.T}\int_{-50}^{+50} D(z)dz$$

n = no. slices imaged simultaneously
T = nominal imaged width

n.T = total detection width
= nominal beam width

Eg n.T = 4 x 2.5 mm = 10 mm

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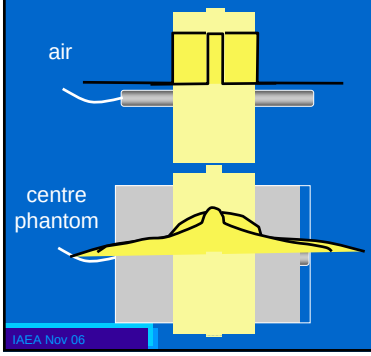
What about wider beam widths ?

- More scatter, but proportionally the same
- As a dose index, CTDI ok for larger beam widths



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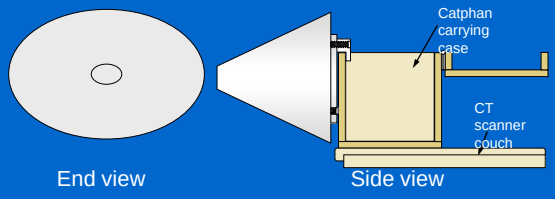
Testing the AEC

- Test object needs to vary in z-direction and rotationally
  - eg Conical Perspex phantom with elliptical cross section



- Based on 'Apollo' phantom developed by Muramatsu, National Cancer Centre, Tokyo

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Testing the AEC

- Images along length of phantom (no AEC)

Constant mA

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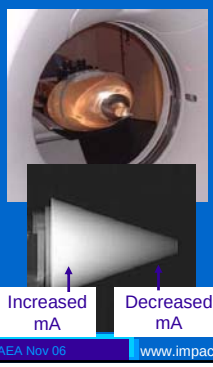
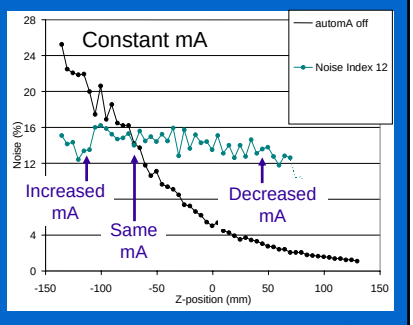
Testing the AEC

- Measure noise with AEC off and on
- Monitor mA, $CTDI_{vol}$





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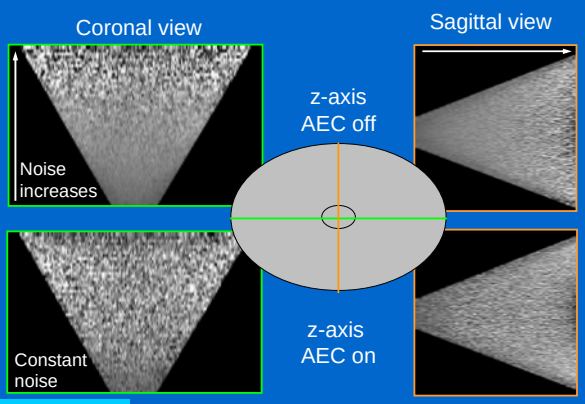
www.impactscan.org/bluecover.htm

GE LightSpeed[16]

Testing the AEC – Viewing with MPR



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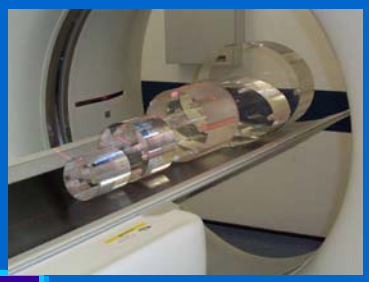
Testing the AEC

- Circular, elliptical phantoms of various sizes
- Scan short lengths over each section
- Monitor mA, $CTDI_{vol}$, image noise



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Which scan protocols ?

	Noise	Image width	Scan plane resolution	Dose
mA				
kV				
Focal spot selection				
Scan time			^	
Nominal image width				
Beam width	*			
Detector group size				
Convolution kernel				
Pitch	^^	^^		^^
Interpolation algorithm				

^ If scan time affects no. samples, ^^ In some circumstances , * In almost all cases

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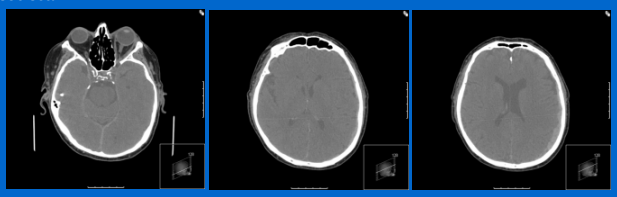
Which scan protocols ?

- Time constraints of quality control
  - Use typically used protocols
  - Many are helical, axial gives good basic data
- Rotate through to ensure all modes are looked at

2 sec scan



Courtesy Elly Castallano, Royal Marsden Hospital, London

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Which scan protocols ?

2 sec scan

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Courtesy Elly Castallano, Royal Marsden Hospital, London

Testing of multi-slice scanners

- Large amount of data
  - Think through the testing carefully
  - Can you handle the data you are generating ?
  - Do you need to consider an automated process ?

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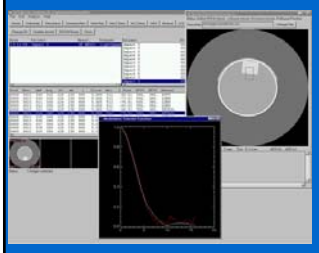
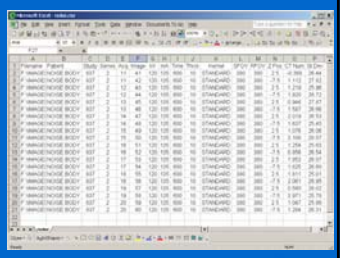
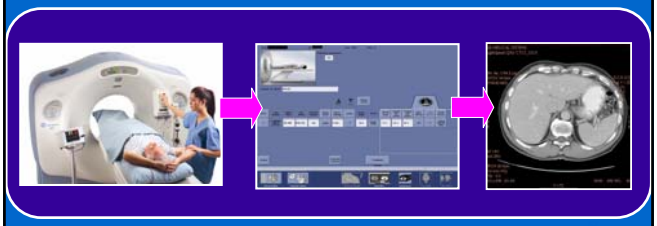
Data analysis

- Analysis tools, need programming
  - IDL, MatLab, C#
  - UK CT Users Group,16 Nov 2006 (ctug.org.uk) looking at this issue

MDCT optimisation and quality assurance

- Multi-slice CT
- Implications for testing
- Optimisation of protocols



CT Scanner – operational quality

Optimisation – required image quality, without unnecessary dose

Optimisation of scan protocols

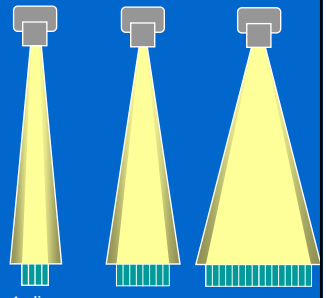
- Beam width
- Image slice width
- Automatic exposure control (AEC)
- Required image noise?

Beam width

- Penumbra typically 3 mm for all beam widths
  - lower proportion of total dose with larger beam widths
- Wider is generally better

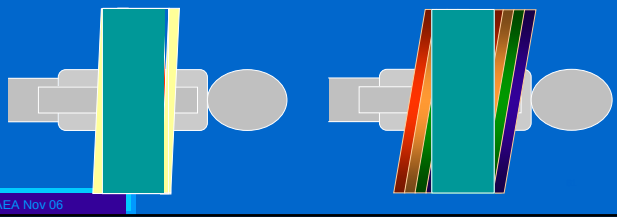
GE LightSpeed: 4, 8, 16 - slice

Collimation	Penumbra dose (%)
5 mm (4 x 1.25)	33
10 mm (8 x 1.25)	17
20 mm (16 x 1.25)	3



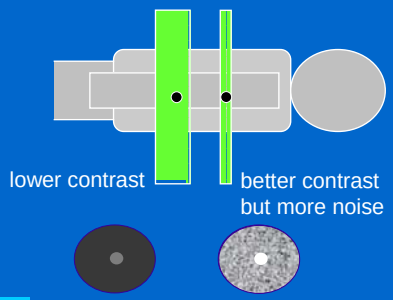
Beam width

- To image entire volume, extra rotations are needed at both ends of scan
  - This is larger for wide beam widths
- Significant when using short scan lengths, or higher pitches
  - Use narrower beam widths, or axial scans



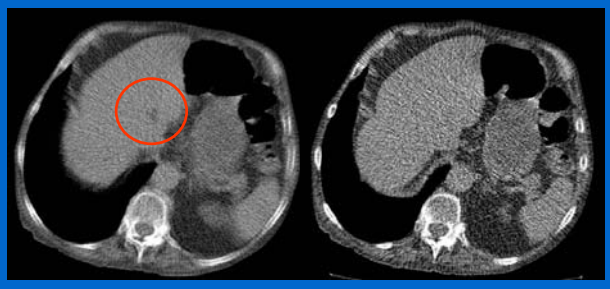
Imaged slice width

- Slice width affects contrast and noise of object
- Optimised slice width: imaged slice ≈ object size



Thinner slice: higher noise

- Object ~ 5 mm

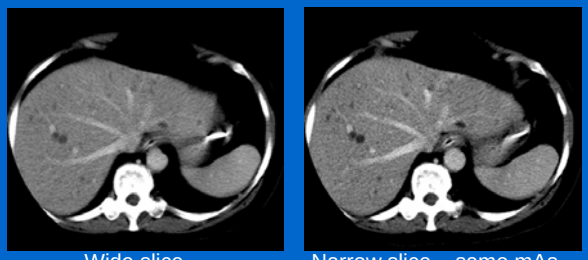


5mm 1mm

Courtesy: Matthew Benbow, RBH

Thinner slice: improved contrast

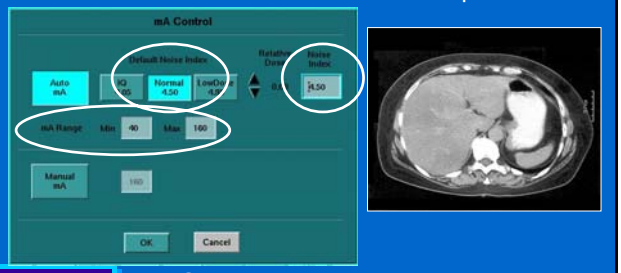
- Better contrast for small structures



Wide slice Narrow slice – same mAs

Automatic exposure control

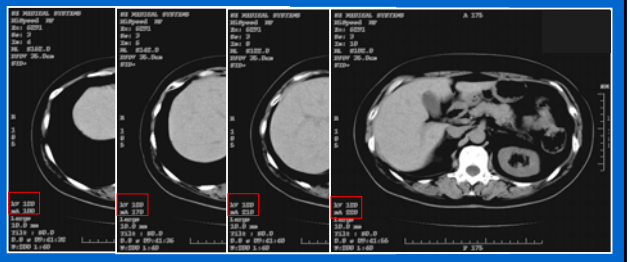
- Most systems allow users to set a required noise level
  - An image noise index
  - Specifying a reference image with acceptable image quality
- Maximum and minimum mA sometimes specified



Eg GE Auto mA

Automatic exposure control

- GE Auto mA
  - Varies mA along patient



100 mA 170 mA 210 mA 220 mA

Courtesy: GE Medical / Eugenia Kulama Royal Marsden Hospital London

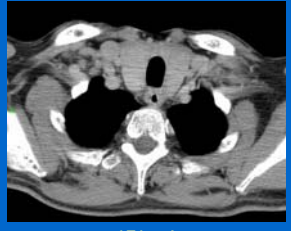
Automatic exposure control

- Additional benefit
  - Reduction of artefacts with rotational AEC
  - Low photon count in lateral projections gives streak artefacts

Scan with constant mA

327 mAs

Scan with real-time dose modulation



171 mAs

Siemens CAREDOSE (4D)
Courtesy: Siemens / Eugenia Kulama Royal Marsden Hospital London

What do AECs give us?

- Lower patient doses than before?
  - Possibly, but not necessarily
  - It is possible to use AEC and give higher dose
    - 'dose can go up as well as down'
- More consistent image quality?
  - Yes
- The optimum image quality?
  - If they are used well
- What is the required image noise?

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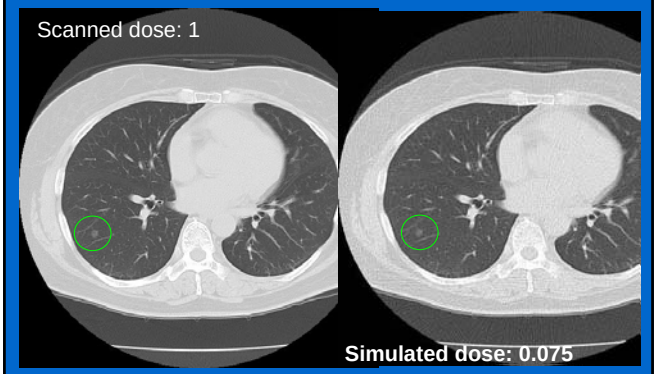
What noise level is needed?



Images courtesy Y. Muramatsu, NCC Tokyo

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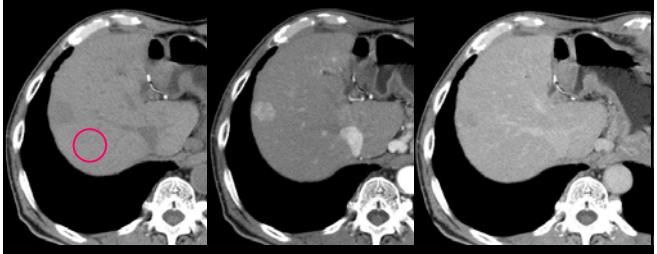
What noise level is needed?

Original (16 x 1 mm, 200 mAs, pitch 0.9375)

Plain (no contrast) Early Late



Scanned dose : 1.0

Noise SD: 8.0

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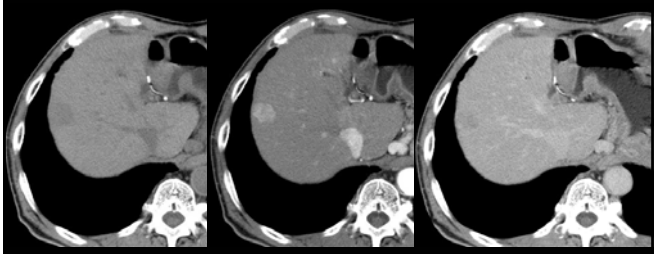
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.83

SD: 8.5

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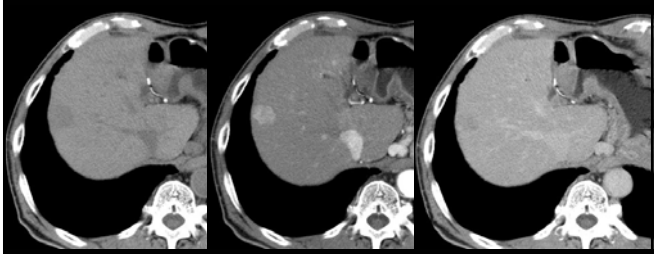
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.67

SD: 9.0

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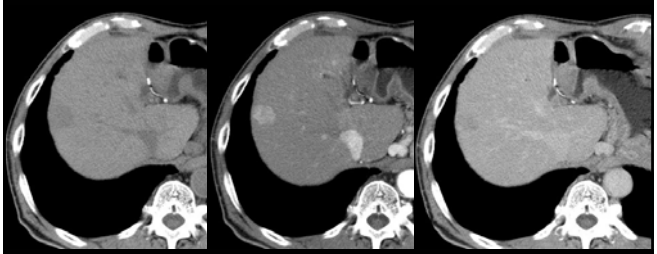
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.50

SD: 10.0

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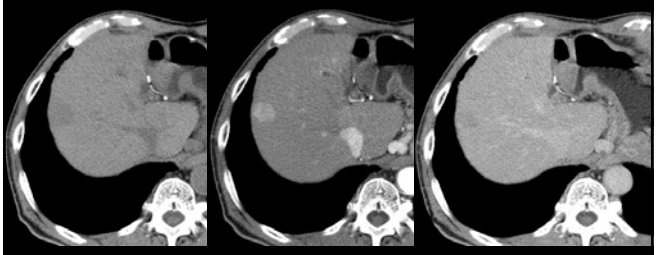
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.33

SD: 11.5

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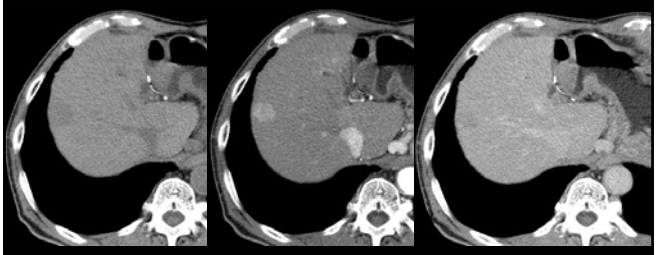
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.25

SD: 13.5

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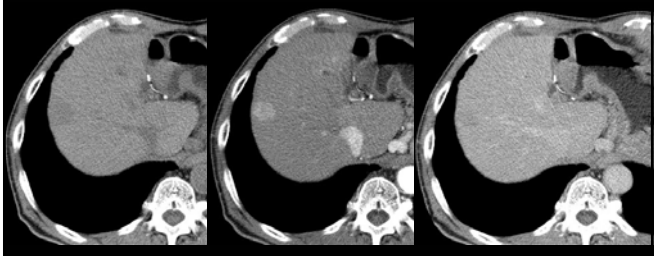
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.17

SD: 16.5

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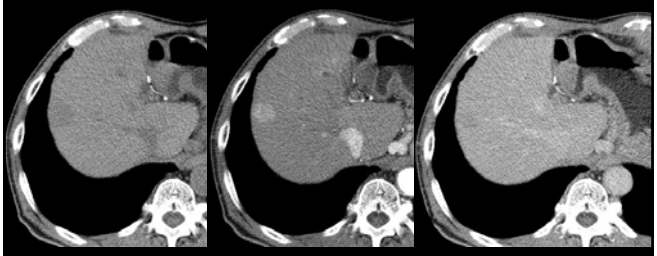
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.13

SD: 19.5

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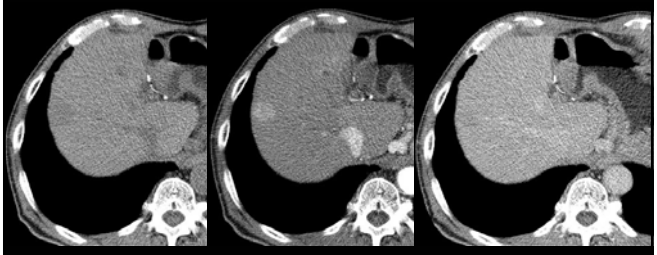
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.08

SD: 25.0

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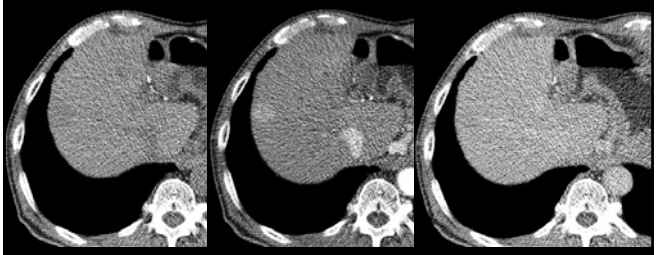
Images courtesy Y. Muramatsu, NCC Tokyo

What noise level is needed?

Simulation

Plain Early Late



Dose Ratio: 0.04

SD: 42.0

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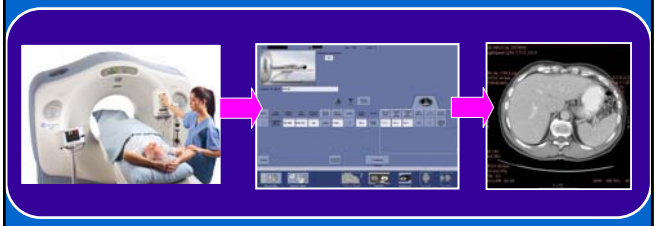
Images courtesy Y. Muramatsu, NCC Tokyo

MDCT optimisation and quality assurance

- Multi-slice CT
- Implications for testing
- Optimisation of protocols



The ImPACT of MDCT on optimisation and quality assurance of CT scanners

S. Edyvean

Imaging Performance Assessment of CT Scanners

St. Georges Hospital

www.impactscan.org

ImPACT