Technical Aspects of Cardiac CT

Including image quality and dose

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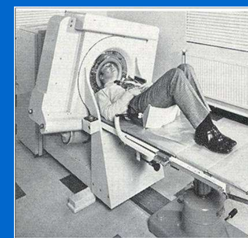
Imaging Performance Assessment
of CT Scanners
St. Georges Hospital
www.impactscan.org

ImPACT

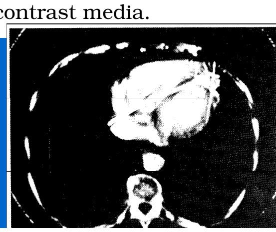
Cardiac CT

- Godfrey Hounsfield, inventor of clinical CT, 1972
  - 1979 Nobel prize
  - died Aug 12th 2004



Godfrey Hounsfield – Nobel Speech 1979

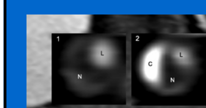
Fig. 14 shows a picture from the experiment. The heart chambers can be discerned by a little intravenous injected contrast media.

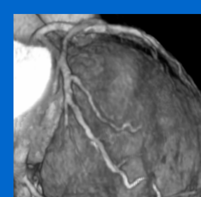


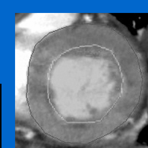
A further promising field may be the detection of the coronary arteries. It may be possible to detect these under special conditions of scanning.

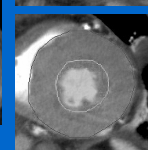
Applications of cardiac CT

- Calcium scoring
- Coronary CT angiography (CTA)
- Functional imaging







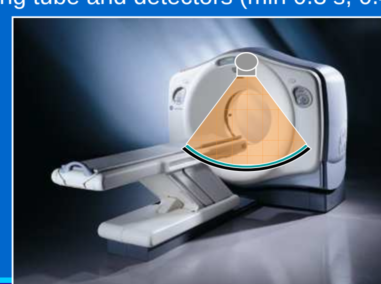


Learning Objectives

- Principles of MSCT scanning
- Particular challenges of imaging the heart and how MSCT overcomes them
- Radiation dose
- Scanner technology
  - Existing 64 slice scanners
  - New technologies: dual source and wider arrays

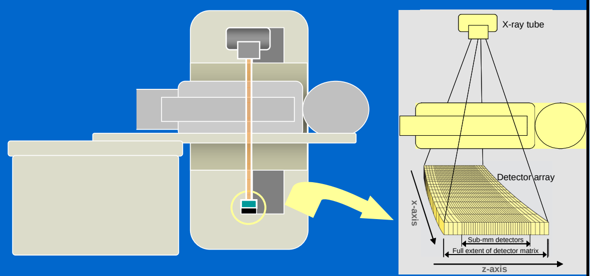
What is a CT scanner ?

- 'Doughnut' shaped gantry, moving patient table
- X-fay fan beam in scan plane, arc ~1000 detectors
- Rotating tube and detectors (min 0.3 s, 0.4 s)



Side View of CT Scanner

- Narrow → wider in z-direction



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Side View of CT Scanner

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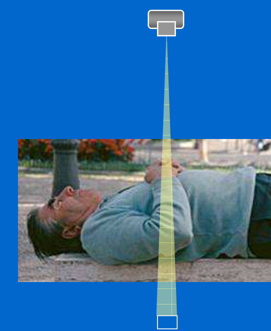

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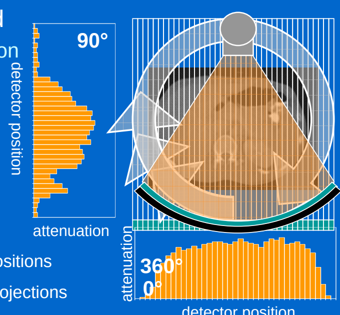
Projections

- measure attenuation
  - Each detector, each rotation angle
- Image reconstructed
  - Filtered backprojection
  - More complex
    - 16, 64 slice



~1000 positions

~1000 projections

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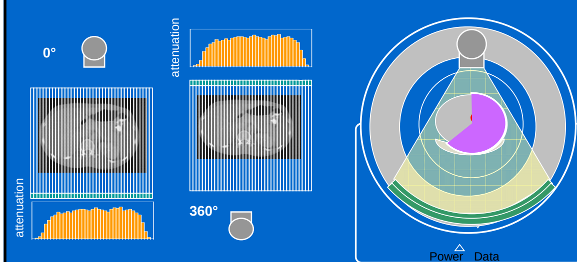
CT imaging requirements

- Opposing projections provide the same information
- To reconstruct images
  - Only 180° (+ fan angle) of scan data is required



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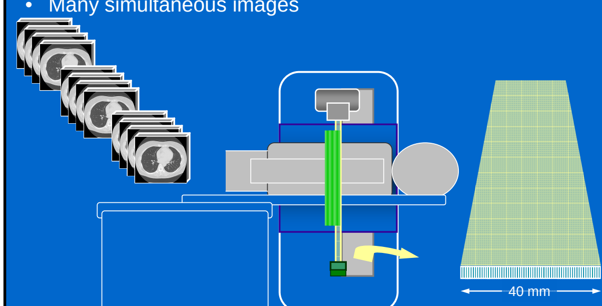
Multi-slice CT Scanners

- Axial acquisition ('step and shoot')
- Many simultaneous images



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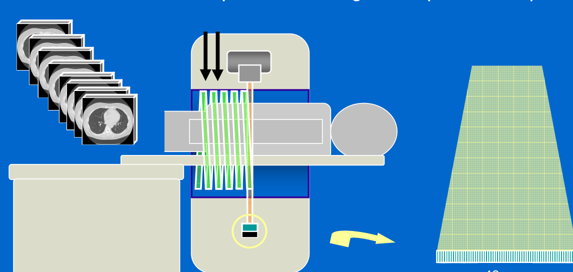
Multi-Slice CT

- Helical scanning – volume set of data
- Attenuation data interpolated to image slice position required



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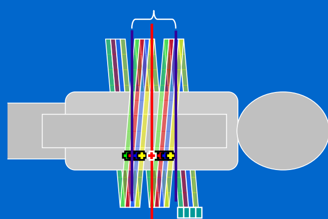
Helical MSCT Scanning

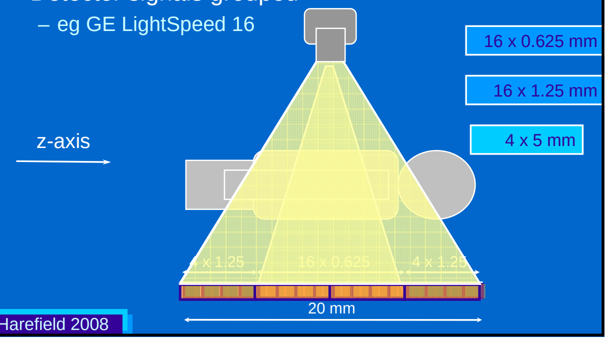
- Projection data interpolated to required image position
- A number of detectors contribute to an image
- Complex 3-D reconstruction for MSCT



Recon position

Multi-Slice CT scanners

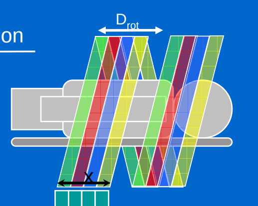
- Beam width switched
- Detector signals grouped
  - eg GE LightSpeed 16



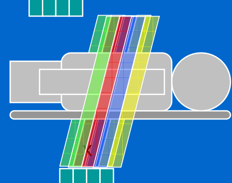
Definition of Pitch

$$Pitch_x = \frac{\text{table travel in one rotation}}{\text{total acquisition width}}$$

$$Pitch_x = \frac{D_{rot}}{X} = 1.25$$



In cardiac CT use a pitch ~0.2



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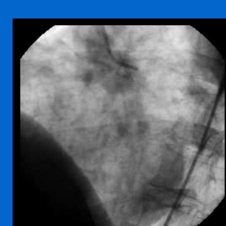
- Radiation dose
- Scanner technology
  - Existing 64 slice scanners
  - New technologies: dual source and wider arrays

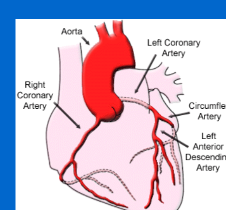
Challenges of the heart

- Spatial resolution
- Low contrast resolution
- Coverage
  - In one breath hold
- Temporal resolution
  - Freezing the motion of the heart
  - Gating techniques for registration
  - Sector reconstruction

The Heart – Spatial Resolution

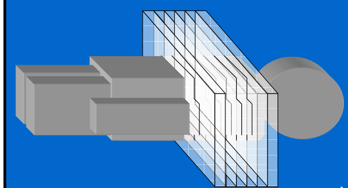
- Tortuous vessels narrowing to < 1 mm
- Require good 3-D spatial resolution << 1 mm

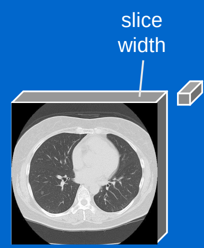




CT Image

- Grey level represents the average attenuation of the 3-D volume element
- 3-D resolution of image
  - in-plane
  - slice thickness





In plane resolution = ~0.3 mm

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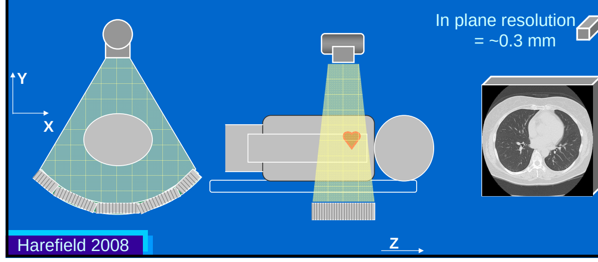
MSCTScanners - Spatial Resolution

- 3-D resolution (scan plane, z) determined by
  - Detector size
  - Sampling
  - Reconstruction parameters
- For isotropic resolution - limit is in the z-axis



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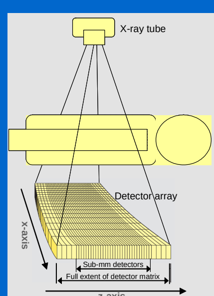
MSCTScanners - Spatial Resolution

- Many thin slices of data
  - eg 4, 16, 32, 64 slices x 0.5, 0.625 mm



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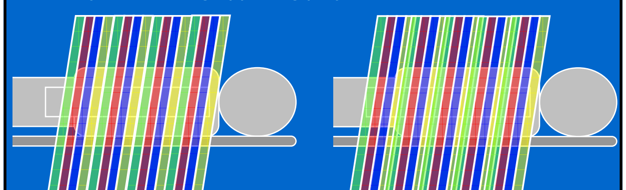
Z-axis Spatial Resolution – Sampling

- Improved z-sampling with optimised pitches
  - By interleaving opposing projections



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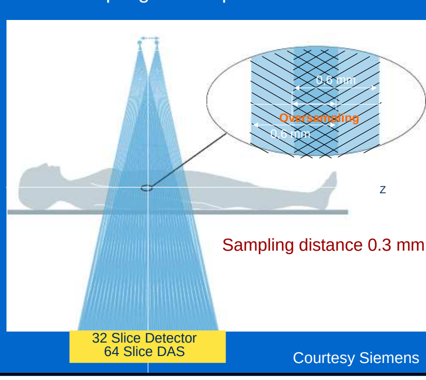
Z-axis Spatial Resolution – Sampling

- 64-Slice CT: double z-Sampling: Overlap doubles information



Courtesy Siemens

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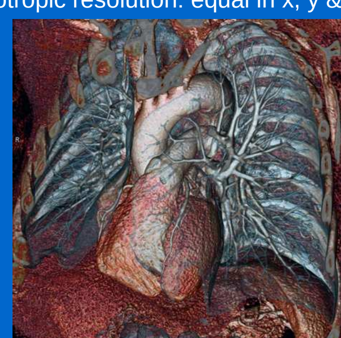
3D Spatial Resolution

- Isotropic resolution: equal in x, y & z



0.3 x 0.3 x 0.3 mm

Courtesy Siemens Medical Solutions

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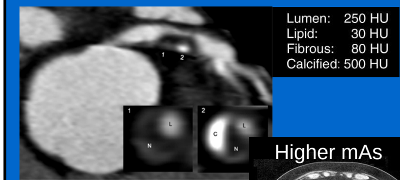
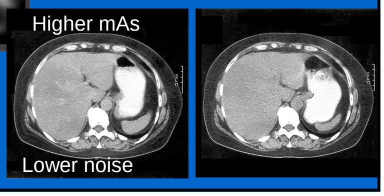
The Heart – Low Contrast Resolution

- Low contrast resolution (non-calcified plaque)
  - require noise levels equivalent to current CT imaging





L – Vessel Lumen
N – Non-calcified plaque
C – Calcified plaque

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Challenges of the heart

- Spatial resolution
- Low contrast resolution
- Coverage
  - In one breath hold
- Temporal resolution
  - Freezing the motion of the heart
  - Gating techniques for registration
  - Sector reconstruction

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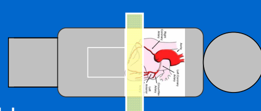
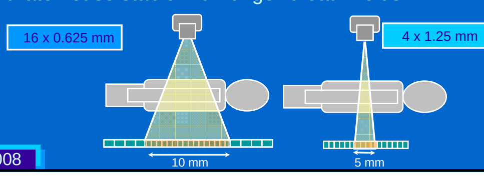
The Heart

- Approximately 12 cm in length
  - Existing technology
    - 4 slice < 20 mm
    - 16 slice 20 – 32 mm
    - 64 slice ~30 – 40 mm



- Coverage single breath hold
  - Limited in four slice scanners
  - Heart rate not so stable with longer breath holds



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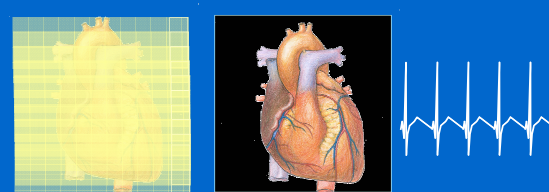
Volume coverage

- For cardiac CTA need overlapping pitch (0.2 - 0.3)

64 slice



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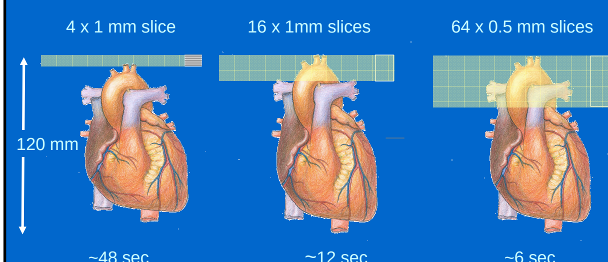
Volume coverage – in one breath hold

- Time to cover heart



0.5 s, 0.33 pitch

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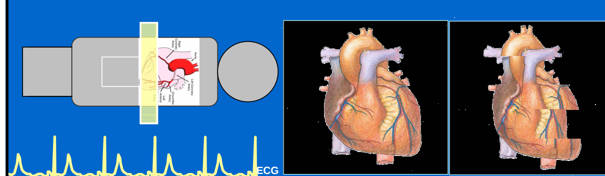
The Heart

- Beating at 60 – 120 bpm (1 – 2 bps)
  - Freeze motion
  - Registration of sections
  - Not necessarily repeatable – irregular heart rate
  - Image in as few beats as possible



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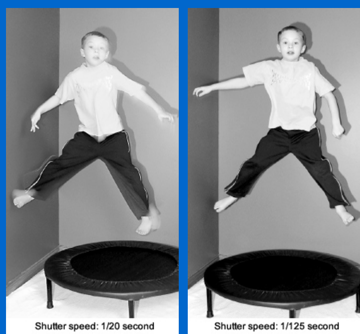
Cardiac Motion



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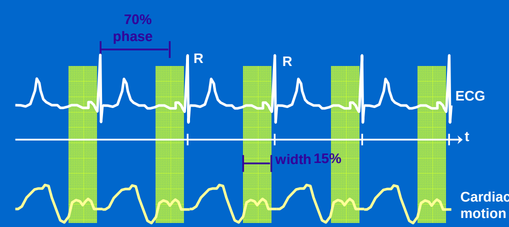
Cardiac Motion and the ECG

- Imaging 'window' during period of least cardiac motion
  - Eg ~ 70% of R-R
  - Width between 10-20% of R-R



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Cardiac Motion - Temporal resolution

- Heart rate 60 -120 bpm ie 1 -2 bps
- Temporal resolution required ~10 % of R-R interval
  - eg 60 bpm = 100 ms, 120 bpm = 60 ms
- Half rotation of data needed for image reconstruction
  - Temporal resolution = ½ rotation time

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ECG Gating Techniques

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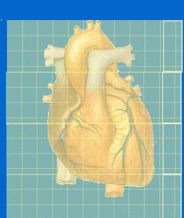
Cardiac Motion - Registration

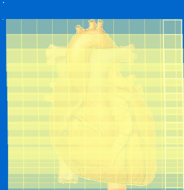
- Need gating techniques to avoid misregistration

64 slice

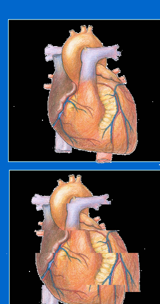


axial scans, prospective gating of irradiation

64 slice



helical scan retrospective gating of data



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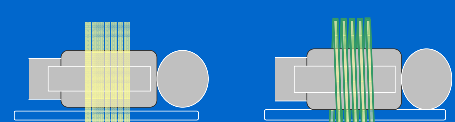
ECG Gating Techniques

- Prospective ECG gating (of irradiation)
  - Sequential ('step and shoot') scanning
  - Calcium scoring, CTA (newer scanners)
- Retrospective ECG gating (of acquired data)
  - Helical scanning
  - CTA, Functional imaging



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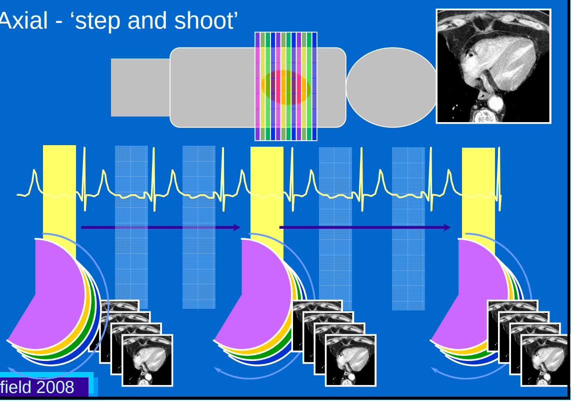
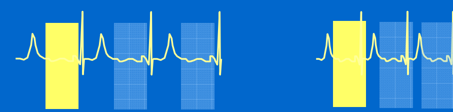
Prospectively gated cardiac CT

- Axial - ‘step and shoot’



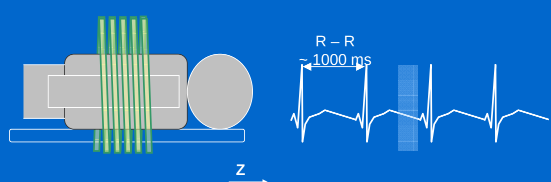
Prospective Gating

- Unsuitable for high heart rates
  - Limited to ½ rotation time
- Niche for calcium scoring – Agatston, mass
- Beginning to be used for CTA
  - Better coverage with 64 narrow slice scanners



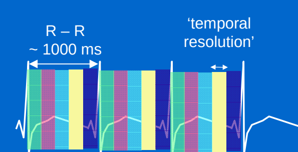
Retrospective gating

- Helical scan
  - Volume set of data acquired
  - Reconstructions can be made at any phase



Retrospective Gating

- ECG-gated images reconstructed
  - choose optimal cardiac phase for coronary angiography
    - Diastole, systole
  - multiple phases for functional studies
- Temporal resolution limited by rotation time
  - Multi-sector reconstruction improves this

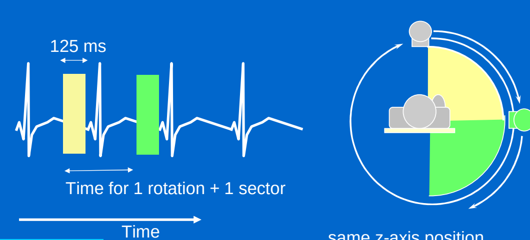


Single-sector reconstruction

- Single sector
  - Data used from 180°
  - Sector time window = ½ rotation time
    - eg 0.5 sec rotation (500 ms), sector = 0.25 s (250 ms)

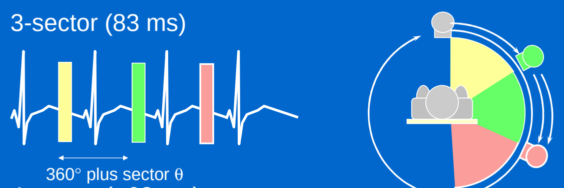
Multi-sector reconstruction

- Two sector
  - Two sectors each of 90 °
    - Sector time = ¼ rotation, eg = 125 ms
  - data from 1 ½ rotations, in two heart beats

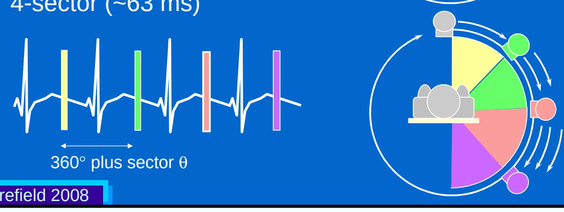


Multi-sector reconstruction

- 3-sector (83 ms)

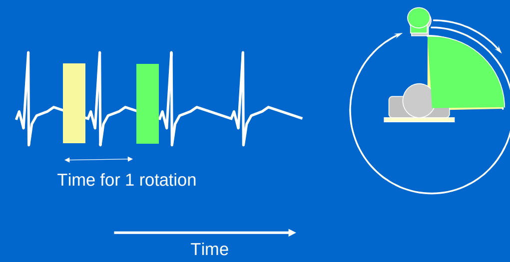


- 4-sector (~63 ms)



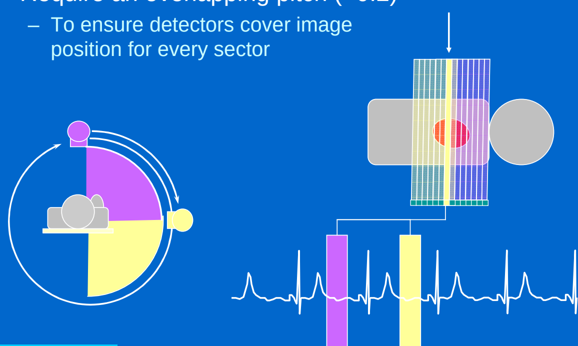
Multi-sector reconstruction

- If heart R-R matches scan time
- Synchronisation
  - Two sector



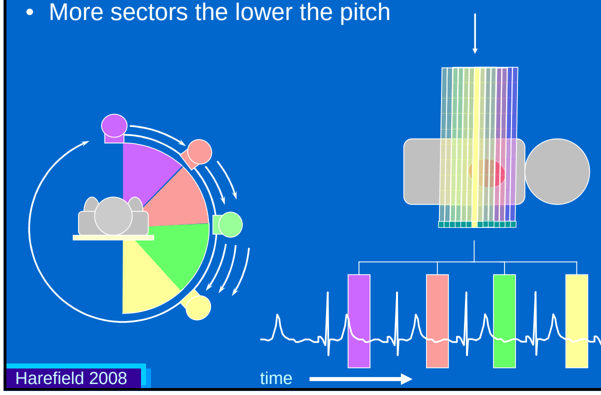
Pitch

- Require an overlapping pitch (~0.2)
  - To ensure detectors cover image position for every sector

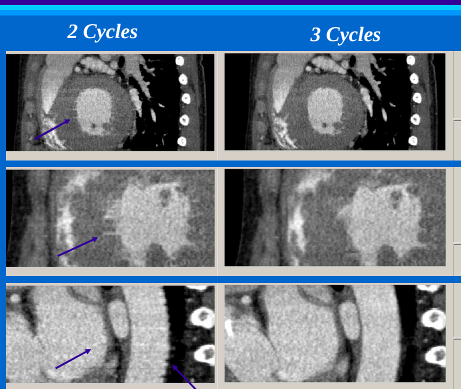


Pitch

- More sectors the lower the pitch



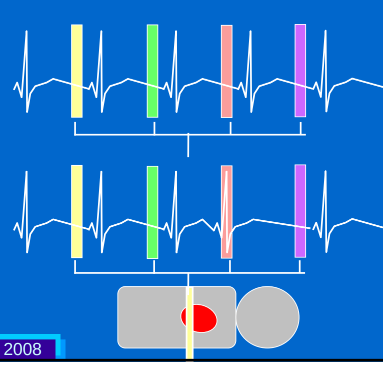
Multi-sector reconstruction



Courtesy Philips

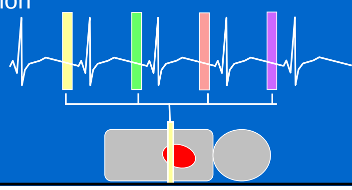
Multi-sector reconstruction

- Require steady heart beat for good registration



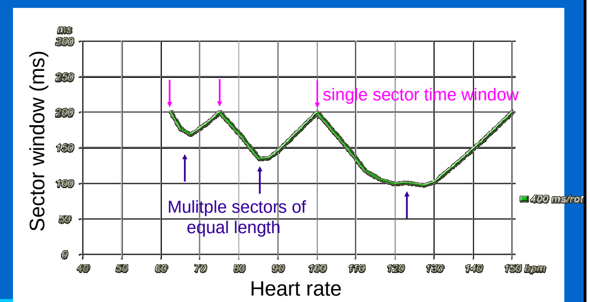
Multi-sector reconstruction

- Minimum rotation time important
- Sector time = 'temporal resolution'
  - eg Two sectors halve the time window
- More sectors require more beats
  - lower pitch
  - Require steady heart beat for good registration
- Avoid synchronisation



Temporal resolution graph – multi-sector

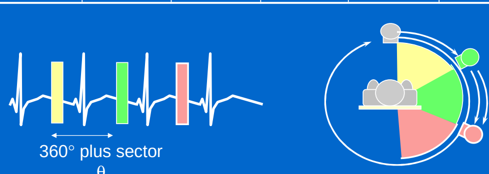
- Complex relationship of heart rate, temporal resolution, and scan time



Number of segments used

- Number of sectors available
- Automatic selection to varying degrees

	IGE	Philips	Siemens(1 tube)	Siemens (2 tube)	Toshiba
No of sectors	1, 2, 4	Up to 5	1 or 2	1 or 2	Up to 5



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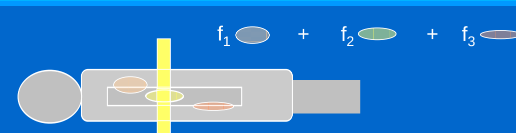
Dosimetry

- Dose parameters used in CT
  - Effective dose
  - CTDI and DLP
- Typical dose values
  - Comparison with other examinations and modalities
- Dose Saving techniques
  - Increased pitch
  - ECG dose modulation
  - Special beam shaping filters

Dosimetry



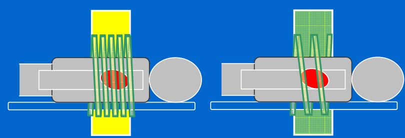
absorbed dose: - localised dose (mGy)

organ dose : - localised dose averaged over the organ (mGy)

effective dose: - sum of all the average organ doses
- modified by tissue radio-sensitivity factors
- describes risk (mSieverts)
- Measure of total amount of radiation given

Dose

- Pitch doubled
  - Organ dose halved
  - Effective dose halved



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Cardiac Scanning

- High dose
  - overlapping pitch
  - lot of wasted information if only reconstructing one phase

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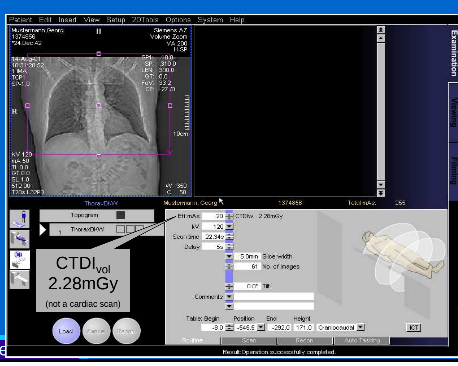
Dose parameters used in CT

- $CTDI_{vol}$ and DLP are indicated on scanner



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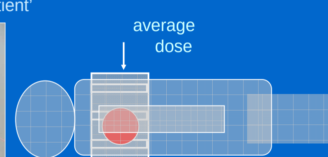
Dose parameters used in CT

- CTDIvol
  - Average dose to perspex phantom of standard size
    - 32 cm (body), 16 cm (head)
  - Indication of effect of exposure settings (kV, mAs, pitch)
  - Rough indication of average organ dose
    - 'Standard size patient'



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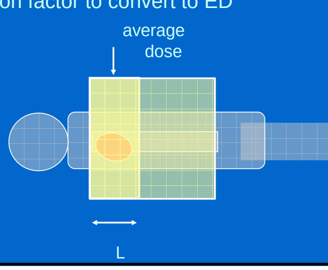
Dose parameters used in CT

- DLP = CTDI x L
  - Average dose x scan length
  - Includes the effect of the length irradiated (total irradiation)
  - Rough indication of effective dose
  - Can use a conversion factor to convert to ED



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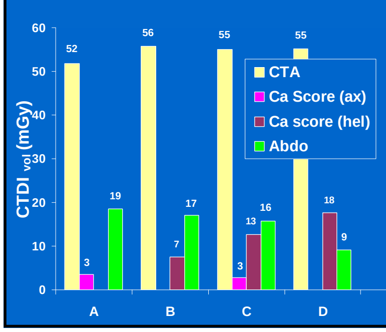
Dose parameters used in CT

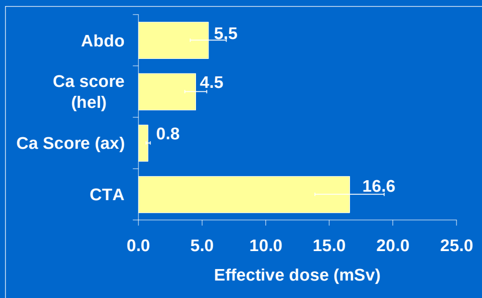
- Typical CTDI
  - From manufacturers suggested protocols



Mean Values	
Exam	CTDI (mGy)
Abdo 54	15
Ca (axial)	3
Ca (helical)	13
CTA	54

Effective Doses

- From manufacturers suggested protocols



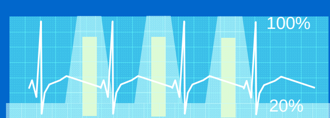
Effective Doses

- Cardiac CT radiation doses are relatively high.
- Ball park figures (dependent on technique etc)
- In practice cardiac CTA figures often higher

Technique	Approximate Dose (mSv)
CT angiography	10 – 15 +
planar coronary angiography	5
PET ^{82}Rb	5
PET $^{13}NH_3$	2
SPECT	10

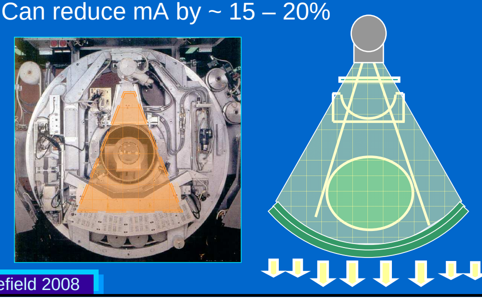
ECG Tube Current Modulation

- mA reduced outside of required recon. phase by ~ 80%
  - Claim net dose savings ~ 50%
- Best for regular heart rates. Better for slow.
- Can be automatically deactivated if ECG changes
- Can only image one phase
- Can't use normal dose modulation systems with ECG mod.



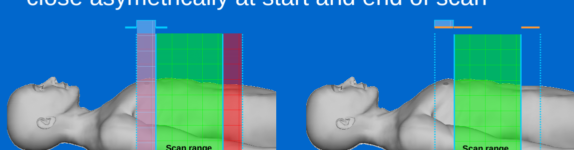
Beam Shaping Filters

- Beam shaping filters more appropriate for small fov reconstruction within a larger fov
  - Eg Toshiba use 'small fov' filter, GE use 'head' filter
- Can reduce mA by ~ 15 – 20%



Dynamic Collimation

- In helical scanning extra rotations are needed at end of imaged volume
  - Significant extra dose: wide beam widths and short scans
- Dynamic collimation - collimator blades open and close asymetrically at start and end of scan



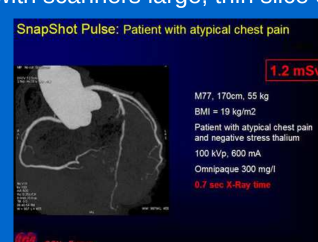
Conventional technology without Dose Shield

SOMATOM Definition AS+ with Adaptive Dose Shield

Courtesy Siemens Medical Systems

Prospective Gating of CTA

- Prospectively gated coronary CT angiography
  - GE: SnapShot Pulse
  - Philips: Step and Shoot
- Possible with scanners large, thin slice coverage

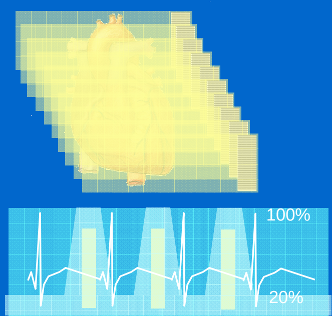


Courtesy GE Healthcare

Retrospective Gating of CTA

- Retrospectively gated CCTA

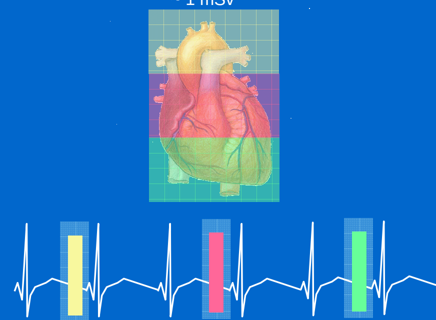
~15 mSv



Prospective Gating of CTA

- Prospectively gated CCTA

~ 1 mSv



Learning Objectives

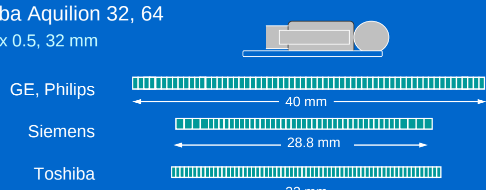
- Principles of MSCT scanning
- Particular challenges of imaging the heart and how MSCT overcomes them
- Radiation dose
- Scanner technology
  - Existing 64 slice scanners
  - New technologies: dual source and wider arrays

Current 64 Slice CT Scanners

- Coverage
  - Beam widths 20 – 40 mm
- Narrow slices
  - 0.5 – 0.625 mm detectors
- Speed of rotation
  - 0.3 – 0.4s
- Ability to do multi-sector reconstruction
  - 2-5 sectors

64 Slice Systems

- GE LightSpeed 32, 64
  - 64 x 0.625 (40 mm total)
- Philips Brilliance 40, 64
  - 64 x 0.625 (40 mm total)
- Siemens Sensation 64
  - 32 x 0.6 (19.2 mm) and 8 x 1.2 (28.8 mm total) (double sampled)
- Toshiba Aquilion 32, 64
  - 64 x 0.5, 32 mm



Time to cover heart

- Depends on
  - pitch, rotation time, detector acquisition length

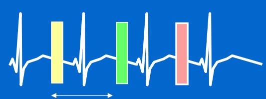
64 slice scanners	IGE	Philips	Siemens (1 tube)	Siemens (2 tube)	Toshiba
Acquisition width	0.625	0.625	0.6	0.6	0.5
Min rotation times (s)	0.35	0.42	0.33	0.33	0.4
Detector length (mm)	40	40	19.2	19.2	32
Time to cover 120 mm ^ (s)	5.3	6.3	10.3	5.1	7.5

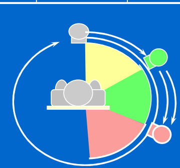
^assume pitch 0.2

Number of segments used

- Number of sectors available
- Automatic selection to varying degrees

	IGE	Philips	Siemens(1 tube)	Siemens (2 tube)	Toshiba
No of sectors	1, 2, 4	Up to 5	1 or 2	1 or 2	Up to 5





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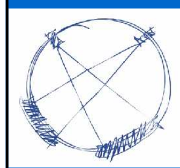
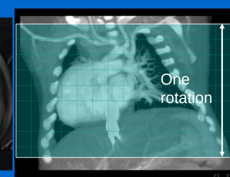
New Technologies

- Siemens Dual Tube
- Toshiba Aquilion One (160 mm coverage)
- Philips Brilliance iCT (80 mm coverage)





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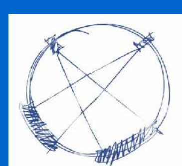
Siemens Definition Dual Tube

- Siemens Definition launched RSNA '05
- Two tubes at 90°
  - 2 x 1/4 scans in 83 ms



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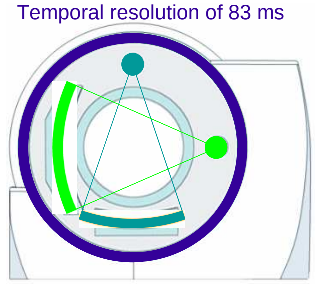
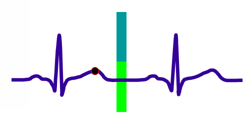
Siemens Definition Dual Tube

Temporal resolution of 83 ms





Temporal Resolution = $\frac{\text{Rotation Time}}{4}$ = **83 ms**

Courtesy Siemens

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Siemens Definition Dual Tube

- Half temporal resolution (½ of ½ rotation time)
  - Single segment (83 ms) or dual segment (42 ms)
- Array
  - 28.8 mm for 1.2 mm slices
  - 19.2 mm for 0.6 mm (z-axis flying fs => 0.3 mm)
- Claim no beta blockers and any heart rate
  - Applies to single segment recon
- Faster table speeds possible
  - only need to ‘hang around’ for one or two segments
- Dual energy imaging

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Toshiba Aquilion One

- 320 x 0.5 mm = 160 mm coverage

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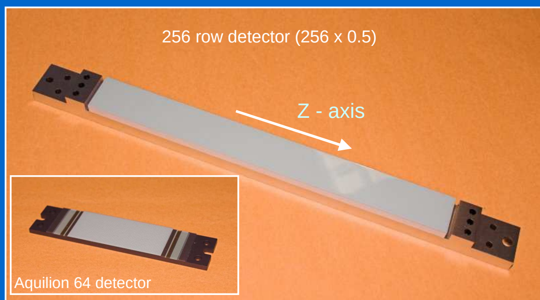
Courtesy of Toshiba

Toshiba AquilionOne

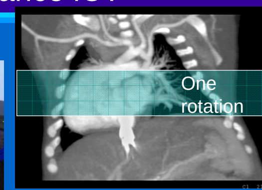
- Allow whole organ coverage in single rotation

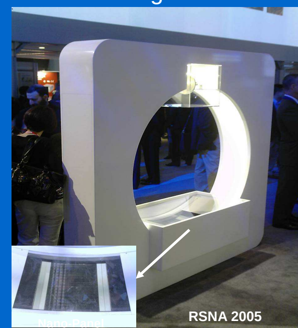


Detector mock-ups courtesy of Toshiba

Philips Brilliance iCT

8 cm coverage





Philips MDCT

Courtesy of Philips

Larger Detector Arrays

- Cover more of heart (or all) in one go
- Axial rotation 'step and shoot'
- Single segment 'one shot'
  - fastest image acquisition = ~half rotation time
- Dual segment
  - Better temporal resolution (with stable beat)
  - Two rotations -> higher dose
- Much lower dose than helical, retrospective gating
  - 3 – 5 mSv
- Only one phase of heart cycle (+/- 1/3 rotation time)
  - Can't do functional unless irradiate many times

Larger Detector Arrays

Scanner	Aquilion One	Philips Brilliance iCT	Siemens Definition AS+ (128 slices)	Siemens Definition Dual tube
Slices	320	256 (128)	128 (64)	64 (32), 24
Array length (Coverage)	160 mm (0.5 mm)	80 mm (0.625 mm)	38 mm (64 x 0.6 mm)	19. 2 mm (0.6 mm) 28.8 mm (1.2 mm)
Rotation time	0.35	0.27	0.3	0.33
Temporal resolution for 1 segment (ms)	180	130	160	83

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- Scanner technology
  - Existing 64 slice scanners
  - New technologies: dual source and wider arrays

Technical aspects of Cardiac CT

S. Edyvean

Imaging Performance Assessment of CT Scanners

St. Georges Hospital

www.impactscan.org

ImPACT

Scanner options to improve image quality

- Before the scan
  - Monitor pre-scan heart beat
  - Automatic determination of pitch, rotation time, number of sectors
- After the scan
  - ECG editing
  - Motion maps to determine optimum phase