Purchasing a cardiac CT scanner: What the radiologist needs to know

Maria Lewis

ImPACT
St George’s Hospital, London
maria.lewis@stgeorges.nhs.uk
CT scanner development

- Increased z-coverage
- High temporal resolution
- General purpose

'Slice wars'

1998 → 2005

z-axis
Which scanner?
Top-of-the range CT scanners

- Philips Brilliance iCT
- Toshiba Aquilion ONE
- Siemens Definition Flash
- GE Discovery CT750 HD

*Improved performance with ‘difficult’ patients?*
What do you need on a cardiac scanner?

- High temporal resolution to ‘freeze’ cardiac motion
- Good 3-D spatial resolution to image narrow, tortuous arteries
- Fast volume coverage to minimise breathing and misregistration artefacts
- High dose efficiency for low dose scans
Conventional CCTA scan modes

• Helical
  – constant mA
  – mA modulated

• Axial (Step and Shoot)
  – with ‘padding’
  – single phase

Max
Min

Irradiation
Reconstruction
Cardiac CT: technical requirements (CCTA)

- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations
Cardiac CT: technical requirements (CCTA)

- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations
Temporal resolution

- To ‘freeze’ cardiac motion need short ‘imaging window’
  - time within one cardiac cycle over which data is acquired for image reconstruction
- Ideally imaging window < 15% R-R
  - at 60 bpm ~150 ms
  - higher heart rates – shorter times needed
Temporal resolution

- Reconstruct images in the most stationary phase of the cardiac cycle
  - best phase dependant on heart rate
How to improve temporal resolution

- Fast rotation times
  - currently 270 – 350 ms
  - 360° reconstruction not suitable

- Half-scan reconstruction method
  - temporal resolution (TR) ≈ ½ rotation time

60 bpm
R – R
~ 1000 ms

~ 150 ms

300 ms rotation

150 ms

UKRC 2010
How to improve temporal resolution

• Multi-segment reconstruction
  – uses multiple heart beats for image reconstruction
  – 2 segments: max TR ~ 1/4 rotation time
  – 3 segments: max TR ~ 1/6 rotation time ….etc

• Temporal resolution achieved dependent on heart rate
  – can be optimised by adjusting rotation time
How to improve temporal resolution

- Dual-source technology
  - two 90° segments acquired simultaneously in single heart beat
  - Temporal resolution \( \approx \frac{1}{4} \) rotation time
  - heart rate independent
  - high temporal resolution allows more flexibility in reconstruction phase

Temporal resolution \( \approx 75 \text{ ms} \)

Diagram showing two tubes (Tube A and Tube B) with a 280 ms rotation time.
## Temporal resolution

<table>
<thead>
<tr>
<th>Scanner model</th>
<th>Tubes (#)</th>
<th>Rotation (ms)</th>
<th>Temporal resolution (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE Discovery CT750 HD</td>
<td>1</td>
<td>350</td>
<td>175</td>
</tr>
<tr>
<td>Philips Brilliance iCT</td>
<td>1</td>
<td>270</td>
<td>135</td>
</tr>
<tr>
<td>Siemens Definition Flash</td>
<td>2</td>
<td>285</td>
<td>75</td>
</tr>
<tr>
<td>Toshiba Aquilion ONE</td>
<td>1</td>
<td>350</td>
<td>35 - 175</td>
</tr>
</tbody>
</table>
Cardiac CT: technical requirements

• Temporal resolution
• Spatial resolution
• Volume coverage
• Dose
• Other considerations
Spatial resolution

• Ability to discern small, high contrast structures

• Isotropic spatial resolution required
  – equal resolution in all planes

Voxel size: $x = y = z$

10 line pairs/cm $\equiv 0.5$ mm
Spatial resolution

- Spatial resolution dependent on
  - focal spot and detector size
  - sampling density
- Also dependent on
  - reconstruction parameters e.g. reconstruction filter
  - temporal resolution

Scan axis
(z)

Scan plane
(x-y)

40 mm (64 x 0.625 mm)
How to improve spatial resolution

- Flying (dynamic) focal spot (FFS)
  - improves sampling density
  - reduces artefacts

<table>
<thead>
<tr>
<th>Manufacturer*</th>
<th>FFS availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x-y plane</td>
</tr>
<tr>
<td>GE</td>
<td>Yes</td>
</tr>
<tr>
<td>Philips</td>
<td>Yes</td>
</tr>
<tr>
<td>Siemens</td>
<td>Yes</td>
</tr>
<tr>
<td>Toshiba</td>
<td>No</td>
</tr>
</tbody>
</table>

* Not available on all scanner models
How to improve spatial resolution

• Double slice reconstruction – volume axial mode

ConeXact reconstruction
Standard Mode

Volume Parameters

- Tube focus
- Detector position 2
- Cone beam projection 1
- 3D matrix reconstruction
- Cone beam projection 2
- Slice reconstruction
- Slice interval 0.50 mm
- Detector position 1
- Standard slices in z-direction

Courtesy J. Blobel, Toshiba

UKRC 2010
How to improve spatial resolution

- Double slice reconstruction – volume axial mode

ConeXact reconstruction
Double Slice Mode

Volume | MultiView
---|---
Volume Parameters
Scan Slice Thickness: 0.5 mm
Slice Thickness: 0.5 mm
Interval: 0.25 mm

0.35 mm

2,572 views/s

How to improve spatial resolution

- Double slice reconstruction – volume axial mode

ConeXact reconstruction
Double Slice Mode

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ConeXact reconstruction
Double Slice Mode

Volume | MultiView
---|---
Volume Parameters
Scan Slice Thickness: 0.5 mm
Slice Thickness: 0.5 mm
Interval: 0.25 mm

0.35 mm
Spatial resolution

- Limiting spatial resolution:
  - up to 15 - 25 lp/cm (0.3 - 0.2 mm) in scan plane
  - up to ~13 lp/cm (0.4 mm) in z-axis

- Sharpest reconstruction filters result in high noise

- Generally for standard cardiac scans
  - x-y plane resolution ~ 8 lp/cm (0.6 mm)
  - z-axis resolution ~ 13 lp/cm (0.4 mm)

- For reduced ‘blooming’ e.g. stents, calcium
  - sharper filters may be used ~ 10 lp/cm (0.5 mm)

Images from Lin, EC et al; http://emedicine.medscape.com/article/1603072-overview

Courtesy Siemens
Cardiac CT: technical requirements

- Temporal resolution
- Spatial resolution
- Volume coverage
- Dose
- Other considerations
Volume coverage

• Aim to cover heart within a breath-hold and with a minimum number of heart beats

• Ideally, single heart beat
  – less chance of arrhythmia & breathing artefacts
Volume coverage

- z-axis detector configuration of top-of-the-range CT scanners

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Detector Configuration</th>
<th>Data Channels</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens Somatom Definition Flash – ‘128 slice scanner’</td>
<td>64 x 0.6 mm</td>
<td>128</td>
<td>38.4 mm</td>
</tr>
<tr>
<td>GE Discovery CT750 HD – ‘64 slice scanner’</td>
<td>64 x 0.625 mm</td>
<td>64</td>
<td>40 mm</td>
</tr>
<tr>
<td>Philips Brilliance iCT – ‘256 slice scanner’</td>
<td>128 x 0.625 mm</td>
<td>256</td>
<td>80 mm</td>
</tr>
<tr>
<td>Toshiba Aquilion ONE – ‘640 slice scanner’</td>
<td>320 x 0.5 mm</td>
<td>320</td>
<td>160 mm</td>
</tr>
</tbody>
</table>

* 64 detector banks double-sampled
** 128 detector banks double-sampled
*** 640 slices from one axial acquisition
Volume coverage

- Consider detector length NOT ‘no. of slices’
- Number of heart beats required to cover volume depends on
  - detector length
  - scan mode

No. of heart beats required: 140 mm length, single segment

<table>
<thead>
<tr>
<th>Scan mode</th>
<th>Detector length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Axial (step and shoot)</td>
<td>7</td>
</tr>
<tr>
<td>Helical – low pitch</td>
<td>4</td>
</tr>
<tr>
<td>Helical – high pitch</td>
<td>1</td>
</tr>
</tbody>
</table>
Volume coverage – ‘single beat’

• Single heart beat coverage can be achieved in two ways:
  
  – full organ coverage
  
  – high helical pitch

[Diagram showing full organ coverage and high helical pitch with a 160 mm field of view and dual source flash mode (Pitch 3.4).]
Volume coverage – ‘single beat’

- Full organ coverage
  - cardiac scanning: triggered axial mode, no table movement
- Single beat, single rotation
  - standard CCTA
- Single beat, multiple rotations
  - increased flexibility
- Single beat, modulated
  - CCTA + functional
- Multi-beat, pulsed
  - CCTA, multi-segment
- Multi-beat, continuous
  - perfusion

Irradiation
Volume coverage

- Wide detector coverage
  - cone beam artefact: 3D reconstruction method
  - scatter: software corrections
  - roof-top effect: software corrections available on some systems
Volume coverage

- Reduced roof-top effect – Toshiba Aquilion ONE

Version 4.51

Version 4.61
Volume coverage – ‘single beat’

- High pitch helical (Siemens ‘Flash’ mode)
  - prospectively triggered helical mode
  - couch speed ~ 135 mm per rotation
  - cardiac volume acquired within single heartbeat
Volume coverage

- High pitch helical
  - limited to lower heart rates (<65 bpm)
  - images acquired at range of R-R phases (but high temp res)
  - scatter from two tubes: reference detector corrections
  - helical artefacts?

Flash mode (Pitch 3.4)

Tube 1
Tube 2

Scan direction

~300 ms

120 mm scan length

75 ms

R

Radiation on
Cardiac phase of acquired slices
Cardiac CT: technical requirements

- Temporal resolution
- Spatial resolution
- Volume coverage
- Image noise
- Dose
- Other considerations
Dose in cardiac CT

- Dose primarily dependent on:
  - scan mode
  - scan protocol
  - dose reduction features

- Choice of scan mode and protocol dependent on patient
  - heart rate
  - heart rate variability
  - patient size
Dose in cardiac CT

- Scan mode
  - Helical: constant mA
  - Axial: modulated mA

  - full cycle
  - narrow window
**Dose in Cardiac CT**

**Variation of dose with scan mode: Siemens Definition Flash**

Helical – low pitch scan – no ECG modulation: 10 mSv

<table>
<thead>
<tr>
<th>Scan mode</th>
<th>Effective dose (mSv)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximal mA window</strong></td>
<td>Narrow (Single phase)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose outside max mA window</td>
<td>0</td>
<td>4%*</td>
<td>25%</td>
</tr>
<tr>
<td>Axial (step and shoot)</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helical – low pitch</td>
<td>1.7</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Helical – high pitch (Flash mode)</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wide (40% phase range)</strong></td>
<td></td>
<td>4%*</td>
<td>25%</td>
</tr>
<tr>
<td>Dose outside max mA window</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial (step and shoot)</td>
<td></td>
<td></td>
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<tr>
<td>Helical – low pitch</td>
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</tr>
<tr>
<td>Helical – high pitch (Flash mode)</td>
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</table>

* Siemens MinDose

**Doses obtained using Siemens’ Cardiac Dose Calculator (Accuracy ±10%)**

Assuming: 60 bpm, BMI 25; 0.014 mSv/DLP
Scan parameters: 100 kV, 160 mAs/rot/tube, 140 mm scan length
Scanner software version VA 34
Dose in cardiac CT

• Selection of appropriate mA and kV
  – automatic selection of mA may be available

• Use of small FOV bow-tie filter
  – reduces peripheral dose

• Use of iterative reconstruction
  – less noise at same dose
  – ~ 50% dose reduction for same image quality claimed

From Silva et al AJR Jan 2010
Dose in cardiac CT

- All manufacturers offer iterative reconstruction

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Iterative reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>Adaptive Statistical Image Reconstruction (ASIR)</td>
</tr>
<tr>
<td>Philips</td>
<td>iDOSE</td>
</tr>
<tr>
<td>Siemens</td>
<td>Iterative Reconstruction in Image Space (IRIS)</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Adaptive Iterative Dose Reduction (AIDR)</td>
</tr>
</tbody>
</table>

- Second generation iterative reconstruction methods currently in development
  - e.g. GE: Model-based Iterative Reconstruction (Veo)
  - Siemens: Sinogram Affirmative Iterative Reconstruction (SAFIRE)

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Dose in cardiac CT

- Optimisation of scan length:
  Dose increase ~10% per cm\(^1\)
  - ‘adaptive collimation’ for wide beam axial scans
  - ‘dynamic collimation’ to reduce over-ranging in helical scans

- Partial irradiation to reduce surface organ dose
  - breast dose reduction up to 40%\(^2\)

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\(^1\) With a base scan length of 10 cm

\(^2\) Kalender W. et al. Reduction of dose to the female breast in thoracic CT; European Society of Radiology 2008; 18: 1674-1682
Cardiac CT: technical requirements

- Temporal resolution
- Spatial resolution
- Volume coverage
- Image noise
- Dose
- Other considerations
Other considerations

• User-friendliness
  – automated scan parameter optimisation
  – applications software / post-processing

• Additional features
  – dual energy for e.g. myocardial perfusion, direct bone removal, virtual non-contrast, plaque differentiation....
Other considerations

- Dual energy approaches

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Dual energy method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens</td>
<td>Dual source technology</td>
</tr>
<tr>
<td>GE</td>
<td>Rapid kV switching with ‘flying-focal spot’</td>
</tr>
<tr>
<td>Philips</td>
<td>Dual-layer detector</td>
</tr>
</tbody>
</table>

Philips dual-layer detector

Low energy x-rays

High energy x-rays
Conclusions

• Cardiac CT scans benefit particularly from a high temporal and spatial resolution as well as fast volume coverage

• Cardiac doses depend largely on scan mode – choice of mode is mainly patient determined

• Optimal parameters and dose saving features should be used

• Manufacturers have moved in different directions in scanner development

• The ‘best’ scanner is dependent on local needs – dedicated cardiac, dedicated A&E, general purpose scanner…

• …and also £££££
Market review

Market review: Advanced CT scanners for coronary angiography
CEP10043, March 2010
www.dh.gov.uk/cep
www.impactscan.org