Technical Principles of ECG-gated CT and Radiation Dose Reduction

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OBJECTIVE

- review two fundamentals of CT technology
  - detector banks in multidetector (multislice) CT
  - pitch
- prospective and retrospective ECG gating
- explain how heart-rate influences selection of gating technique, ...
- and how this affects radiation exposure

3rd Generation Computed Tomography
Tube-Fanbeam-detector array rotating around patient

Gantry rotation times (modern scanners): 500ms → 300ms

Fastest Gantry Rotation Times for Different Scanners

<table>
<thead>
<tr>
<th>System</th>
<th>Gantry Rotation Time (ms)</th>
<th>(sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE-C1 (8 row)</td>
<td>500</td>
<td>0.5</td>
</tr>
<tr>
<td>GE-C3 (16-row)</td>
<td>400</td>
<td>0.4</td>
</tr>
<tr>
<td>GE-VCT (64-row)</td>
<td>350</td>
<td>0.35</td>
</tr>
<tr>
<td>Siemens S 64 (Blake)</td>
<td>330</td>
<td>0.33</td>
</tr>
<tr>
<td>Siemens DualSource (SMIC)</td>
<td>330</td>
<td>0.33</td>
</tr>
<tr>
<td>Siemens AS+ (SMOC)</td>
<td>300</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Multiple Detector Row Systems
Exposed detector-rows

- 1 row
- 4 rows
- 8-16-32-64 rows .....
**Examples of Detector bank Configurations**

<table>
<thead>
<tr>
<th>Detector configuration</th>
<th>Total detector bank width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE–CT1 (8 row)</td>
<td>10 mm</td>
</tr>
<tr>
<td>GE–CT3 (16-row)</td>
<td>20 mm</td>
</tr>
<tr>
<td>GE–VCT (64-row)</td>
<td>40 mm</td>
</tr>
<tr>
<td>Siemens S 64 (Blake)</td>
<td>19.2 mm</td>
</tr>
<tr>
<td>Siemens DualSource (SMIC)</td>
<td>19.2 mm</td>
</tr>
<tr>
<td>Siemens AS+ (SMOC)</td>
<td>38.4 mm</td>
</tr>
</tbody>
</table>

**What is the definition of Pitch ?**

Spiral / Helical Acquisition

- **Pitch**: table translation (for one gantry rotation) relative to total width of exposed detector rows

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**CT and Cardiac Motion**

**Problem:**

- fast Motion !!!
- Cardiac cycle ~ 1 s (1000 ms)
- Ideal temporal resolution: <50 msec
What is Temporal Resolution in CT?

- Time it takes to acquire all x-ray projections needed to reconstruct one CT image.
- Half-scan reconstruction needs only projections from ~180° gantry rotation. Temporal resolution ≈ 1/2 gantry rotation time.
- With two x-ray tube/detector systems, temporal resolution ≈ 1/4 gantry rotation time.

Temporal Resolution (2009)

<table>
<thead>
<tr>
<th></th>
<th>Gantry Rotation (ms)</th>
<th>Temporal Resolution (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE – VCT (CT2)</td>
<td>350</td>
<td>175 ms</td>
</tr>
<tr>
<td>Siemens S 64 (Blake)</td>
<td>330</td>
<td>165 ms</td>
</tr>
<tr>
<td>Siemens AS+ (SMOC)</td>
<td>300</td>
<td>150 ms</td>
</tr>
<tr>
<td>Siemens DualSource (SMIC)</td>
<td>330</td>
<td>85 ms</td>
</tr>
<tr>
<td>GE – HD750 (SMIC)</td>
<td>350</td>
<td>175 ms</td>
</tr>
<tr>
<td>Siemens FLASH (SMIC/SMOC)</td>
<td>280</td>
<td>75 ms Oct '09</td>
</tr>
</tbody>
</table>

CT and Cardiac Motion

Solution:
- (a) Scan much faster
- (b) Synchronize scan (or reconstruction) with EKG signal
- (a) + (b)

Coronary Angiography (Catheter angiography)

RAO of right coronary artery

Cardiac CT basics

Heart rate vs duration of diastole/systole

Low heart rate (~60): best images in Diastole
Medium heart rate (~70): best images Diastole or Systole
Higher heart rates (~80): best images in Systole
**ECG synchronized CT**
(coronary CTA, gated chest)

- Prospective triggering (step and shoot)
  - every other R-peak triggers (80-175ms) scan
  - no (minimal) radiation dose overlap
  - NEEDS slow and STABLE heart rate

- Retrospective gating (low pitch helical)
  - redundant helical data acquisition (pitch ~0.2)
  - coregistration of ECG
  - selecting only projection samples which fall into desired phase of cardiac cycle

- Prospectively triggered high-pitch helical
  - dual source only

**Prospective Triggering**
for Coronary CTA

- step- and- shoot (every other heart beat)
  - 3 scans (~12cm): 5 heartbeats → ~5 sec
  - 4 scans (~16cm): 7 heartbeats → ~7 sec

- acquisition as fast as helical
  - substantially less radiation dose
  - (as low as 2–3 mSv) *

- need low and steady heart rate !!
  (≤60 bpm; ±5)

- no dynamic information (no 4D)

* Earls (2008) Radiology 246
Scheffel (2008) Heart 94
Stolzmann (2008) Radiology 249

**56 yo man with chest pain (ER)**

prospectively gated coronary CTA
(betablocker, HR 62 bpm)

**ECG synchronized CT**
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**Multislice CT**
Spiral Acquisition

Focus

T1 table increment
Pitch 1.0
Multislice CT
Spiral Acquisition

Focus

TI table increment
Pitch 1.5

Focus

TI table increment
Pitch 0.25

**retrospective ECG – gating**

4 x 1mm spiral
1.5 mm TI
(pitch: 0.375)
1.2 mm $S_{eff}$

ECG synchronized CT
(coronary CTA, gated chest)

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• Retrospective gating (low pitch helical)
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  redundant radiation $\rightarrow$ increased dose
  $\rightarrow$ EKG based tube current modulation

Aortic Root Aneurysm, Mitral Valve Prolapse and Mitral Anulus Disjunction

33 yo woman, Marfan’s
 gated chest

(64x0.6mm)
Dual-Source Scanner
Lowest Dose Coronary Protocol(s) possible with low heart rates

Siemens Scanners

- retrospective gating (heart rate < 65 bpm)
- with 'min–dose' tube current modulation and pulsing window of 70% RR
- (if heart rate > 65 bpm, pulsing window 30–70%)

GE: VCT

- prospective gating (heart rate ≤ 60 bpm ± 5)
- (if heart rate > 60 bpm or irregular, retro–gating)

100 kVp for slim patients (< 65kg)

Radiation Exposure Reduction in Cardiac CT

**Retrospective Gating**
- no EKG dose modulation: 100%
- EKG mod. 20% mA: 30–70% RR: ~ 70%
- EKG mod. 20% mA: 70% RR: ~ 50%
- EKG mod. 4% mA: 30–70% RR: ~ 50%
- EKG mod. 4% mA: 70% RR: ~ 25%

**Prospective Gating**
- prospective std. padding: ~ 25%

100kV

- dose proportional to square of kV:
  - iodine signal incr.; noise increases too; subtract
  - 120–100kV: ~30% dose (at same mA): ~ 30%

3–5mSv

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MinDose 30 0%

42.13 mGy (592 mGy·cm) [10mSv]

54 yom

5’11” (180cm)
185 lbs (84kg)
2.04 BSA
100 atenolol
HR 69

CLINICAL CASE EXAMPLES
MinDose 30% 42.13 mGy (592 mGy/cm) [10mSv]

54 yom
5'11" (180cm) 185 lbs (84kg) 2.04 BSA
100 atenolol HR 69

CTDI (CT Dose index): mGy (milligray)
DLP (dose length product): mGy x cm

MinDose 30% 42.13 mGy (592 mGy/cm) [10mSv]

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5'11" (180cm) 185 lbs (84kg) 2.04 BSA
100 atenolol HR 69

CTDI (CT Dose index): mGy (milligray)
DLP (dose length product): mGy x cm

prospective gating: 24.84 mGy (338 mGy/cm) [5.75mSv]

59 yo man
6'1" (190cm) 185 lbs (86 kg) BSA 2.11
HR: 50 bpm

prospective gating: 24.84 mGy (338 mGy/cm) [5.75mSv]

59 yo man
6'1" (190cm) 185 lbs (86 kg) BSA 2.11
HR: 50 bpm

CLINICAL CASE

56 yo physician
5'6" (168cm) 133 lbs (60kg) 1.68 BSA
HR: 48 bpm
**Practical Dose Reduction Strategies in Cardiac CT**

**SUMMARY**

- very effective dose-reduction strategies for cardiac CT available
- slightly different on different scanners
  - prospective: GE-VCT, Siemens AS+
  - retrospective: minDose: Dual Source
- individually tailored to
  - patient size
  - heart rate
  - clinical indication

<table>
<thead>
<tr>
<th>Scan Type</th>
<th>kV</th>
<th>mAs / ref.</th>
<th>CTDI (mGy)</th>
<th>DLP (mGy*cm)</th>
<th>mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>no pulsing</td>
<td>120</td>
<td>438</td>
<td>110.60</td>
<td>1593</td>
<td>~27</td>
</tr>
<tr>
<td>mindose 30–70</td>
<td>120</td>
<td>214/438</td>
<td>42.13</td>
<td>592</td>
<td>~10</td>
</tr>
<tr>
<td>mindose 70–70</td>
<td>120</td>
<td>119/438</td>
<td>26.19</td>
<td>426</td>
<td>~7.2</td>
</tr>
<tr>
<td>mindose 70–70</td>
<td>100</td>
<td>68/350</td>
<td>11.49</td>
<td>192</td>
<td>~3.3</td>
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<tr>
<td>prospective</td>
<td>120</td>
<td>385/400</td>
<td>24.48</td>
<td>338</td>
<td>~5.7</td>
</tr>
<tr>
<td>XXL</td>
<td>120</td>
<td>438</td>
<td>61.61</td>
<td>890</td>
<td>~15</td>
</tr>
<tr>
<td>gated chest 30–70</td>
<td>100</td>
<td>203/438</td>
<td>27.01</td>
<td>667</td>
<td>~11</td>
</tr>
</tbody>
</table>

**THANK YOU ...**

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