Coronary CT Angiography: Protocols -- Radiation Dose

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Yale University School of Medicine
## 2006

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Procedures (millions)</th>
<th>%</th>
<th>Collective dose (Person-Sv)</th>
<th>%</th>
<th>Per capita (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>276</td>
<td>52</td>
<td>182,000</td>
<td>19</td>
<td>0.6</td>
</tr>
<tr>
<td>Interventional</td>
<td>13</td>
<td>2</td>
<td>112,000</td>
<td>12</td>
<td>0.4</td>
</tr>
<tr>
<td>CT</td>
<td>67</td>
<td>12</td>
<td>440,000</td>
<td>46</td>
<td>1.45</td>
</tr>
<tr>
<td>Mammography</td>
<td>34</td>
<td>6</td>
<td>3,300</td>
<td>&lt;0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Dental</td>
<td>125</td>
<td>23</td>
<td>2,300</td>
<td>&lt;0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Nuclear Medicine</td>
<td>21</td>
<td>4</td>
<td>230,000</td>
<td>23</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>~ 544</strong></td>
<td><strong>100</strong></td>
<td><strong>~ 970,000</strong></td>
<td><strong>100</strong></td>
<td><strong>3.2</strong></td>
</tr>
</tbody>
</table>

Fred Mettler, MD: “Magnitude of Radiation Uses and Doses in the US: NCRP Scientific Committee 6-2 Analysis of Medical Exposures”
Medical Radiation Exposure: 600% increase
Adapted from Pierce, D.A. and Preston, D.L.

Excess Relative Risk for Cancer Mortality (1950-1990) in A-bomb Survivors (all ages)

Dose (mSv)

Dose Range for CT

1 in 2000

Adapted from Pierce, D.A. and Preston, D.L.
Risks

X-rays, gamma rays, and neutrons--labeled as known carcinogens by NIEHS on January 2005

A CT examination with an effective dose of 10 mSv may be associated with an increase in the possibility of fatal cancer of approx. 1 chance in 2000. USFDA
## Cardiac CT

<table>
<thead>
<tr>
<th></th>
<th>Dose (mSv)</th>
<th>Relative Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest x-ray</td>
<td>0.02</td>
<td>1</td>
</tr>
<tr>
<td>Coronary Calcium:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBT/MDCT</td>
<td>0.8/1-4</td>
<td>40/50-200</td>
</tr>
<tr>
<td>Annual Background Rad.</td>
<td>3.6</td>
<td>180</td>
</tr>
<tr>
<td>Coronary angiogram</td>
<td>3-10</td>
<td>150-500</td>
</tr>
<tr>
<td>Coronary CTA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBT</td>
<td>1.2</td>
<td>60</td>
</tr>
<tr>
<td>MDCT(16)</td>
<td>9-14</td>
<td>450-700</td>
</tr>
<tr>
<td>MDCT(64)</td>
<td>16</td>
<td>800</td>
</tr>
<tr>
<td>MDCT(64 ”Triple”)</td>
<td>35</td>
<td>1,750</td>
</tr>
</tbody>
</table>

*Adapted from Morin et al., Circ. 2003;107:917-922 and McCullough Herz 2003;28:1-6*
Retrospective Gating
Pitch

Pitch 1.5:1

Pitch 1

Pitch 0.5:1

Ella A. Kazerooni, AJR 2003
Cancer Risk from CCTA

- Phantom Data and Monte Carlo Simulation
  - BEIR VII report from atomic bomb survivors
  - Lungs: 42 - 91 mSv (greatest LAR)
  - Breasts: 50 - 80 mSv
  - Lifetime Cancer Risks: w/ gating
    » Male, age 80 1 in 3261 1 in 5017
    » Female, age 20 1 in 143 1 in 219

Technique

- Tube Current (mA)
- Tube Voltage (kVp)
- Beam Pitch
- Recon. Algorithm
- Dose Monitoring
Tube Current Modulation

AEC: Automatic Exposure Control

Radiation Dose Savings of up to 50%
ECG gating (Retrospective) + Tube Current Modulation

Radiation Dose Savings of 30-50%
Prospective Cardiac Gating

Retrospective Gated Helical Acquisition

Multiphase Data
Functional analysis

6-15 mSv

Prospective Gated Axial Acquisition

X-ray on time
Target Phase range

Table move

Table move

Single phase or phase range
Low dose acquisition

3-6 mSv

Diagnostic Cath: 3 - 5 mSv
Prospective (Step and Shoot) ECG Gating

• 41 CCTA patients
  – GE 64DCT, prospective gating
  – Effective dose: 1.1-3.0 mSv (mean = 2.1)
  – Non-diagnostic image quality in 5%
    » Step artifacts from lack of overlap
    » May require some overlap, dose increase

Husmann L, et al. (Univ. Hospital Zurich), Eur Heart J, 12/07
Women

• Breast Shields (?)
  – Bismuth latex
  – Several sizes
  – Attenuates primary beam
  – Little effect on image quality
Breast Shields

• Reduced dose to:
  – breasts by 30%
  – lungs by 15%

• Increase in image noise

• “Reduction in organ dose could be realized more efficiently with a reduction in tube current”

Low kVp -- Rationale

- K-edge of Iodine: 32 keV
- Mean photon energy:
  - 80 kVp: 44 keV
  - 100 kVp: 52 keV
  - 120 kVp: 57 keV
  - 140 kVp: 62 keV

Effect of kV on Dose

Courtesy of Marilyn Siegel, MD
Effective of kV on Image Noise

Courtesy of Marilyn Siegel, MD
Effect of kV on Iodine Contrast

Courtesy of Marilyn Siegel, MD
Low kV

• CT Angio: Phantom/Human Study
  – 80, 100, 120, 140 kVp
    » 91-94% increase in signal w/ 80 kVp
    » Reduced radiation dose by 25-50%
    » Equivalent 3-D renderings

Low kV

• Chest CT: Improved detection of PE
  – 100 vs. 140 kVp
  – Reduced radiation dose by 3x
    » 140 kVp -- 10.4 mGy
    » 100 kVp -- 3.4 mGy

Low kV

• Coronary CTA: 100 patients (≤ 85 kg)
  – Siemens Dual Source 64DCT
  – Retrospective gating
  – 120 kVp / 330 mAs: 12.7 mSv
  – 100 kVp / 330 mAs: 7.8 mSv
  – No significant impact on image quality

Pflederer T, et al. AJR 2009; 192:1045-1050
<table>
<thead>
<tr>
<th>Scan Mode</th>
<th>Thorax Time</th>
<th>Thorax Dose</th>
<th>Triple Rule-out Time</th>
<th>Triple Rule-out Dose</th>
<th>Pediatric Time</th>
<th>Pediatric Dose</th>
<th>Whole Body Time</th>
<th>Whole Body Dose</th>
<th>4D Dynamic Scans Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSCT Spiral</td>
<td>5 s</td>
<td>20 s</td>
<td>20 s</td>
<td>&lt; 5 mSv</td>
<td>&gt; 4 s</td>
<td>&lt; 1 s</td>
<td>&gt; 10 s</td>
<td></td>
<td>48 cm</td>
</tr>
<tr>
<td>Siemens Dual Source Flash</td>
<td>0.6 s</td>
<td>Breath Hold Optional</td>
<td>0.6 s</td>
<td>&lt; 5 mSv</td>
<td>&lt; 1 s</td>
<td>No Sedation</td>
<td>4 s</td>
<td></td>
<td>48 cm</td>
</tr>
</tbody>
</table>
Dual Source Flash - Cardiac

Temp Res. 75 ms
Spat Res. 0.33 mm
0.35 s for 149 mm
Rotation 0.28 s
100 kV; 290 mAs
0.9 mSv
<table>
<thead>
<tr>
<th>Single Source</th>
<th>Dual Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Single Source Image" /></td>
<td><img src="image2" alt="Dual Source Image" /></td>
</tr>
<tr>
<td>120 kV Attenuation</td>
<td>80 kV Attenuation B, 140 kV Attenuation A</td>
</tr>
<tr>
<td>Selective Photon Shield</td>
<td></td>
</tr>
</tbody>
</table>
$S_1$: 80 kV  \quad S_2$: 140 kV  \quad + SPS

Dose equivalent to 120 kV scan
Adaptive Statistical Iterative Recon. (ASIR)

Dose reduction of 35% to 65%

GE Healthcare, Inc.
ASIR: DLP=136 mGy-cm (2.0 mSv)

Noise: 23.2

ASIR 50 % – Noise: 13.7
Coronary CTA; 100 kVp

2008 – Retrospective Gating; No ASIR
CTDIvol = 21.6 mGy
Eff. Dose = 28 mSv

2009 – Prospective Gating; 60% ASIR
CTDIvol = 6.8 mGy
Eff. Dose = 4.5 mSv
Dose Monitoring
Gated; No Tube Current Modulation

Exam Description: CT CHEST/ABD DISSECTION

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy·cm)</th>
<th>Phantom cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>53.250–1271.750</td>
<td>17.42</td>
<td>591.82</td>
<td>Body 32</td>
</tr>
<tr>
<td>202</td>
<td>Axial</td>
<td>1100.000–1100.000</td>
<td>10.41</td>
<td>5.22</td>
<td>Body 32</td>
</tr>
<tr>
<td>3</td>
<td>Cardiac Helical</td>
<td>12.000–1218.250</td>
<td>68.21</td>
<td>1713.89</td>
<td>Body 32</td>
</tr>
<tr>
<td>3</td>
<td>Cardiac Helical</td>
<td>1219.000–1399.000</td>
<td>50.58</td>
<td>1087.53</td>
<td>Body 32</td>
</tr>
</tbody>
</table>

Total Exam DLP: 3398.46

Effective Dose = DLP x 0.016 mSv/mGy-cm
= 54.4 mSv
**Effective Dose**

Estimate effective dose from DLP

<table>
<thead>
<tr>
<th>Region</th>
<th>mSv / (mGy cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>0.0023</td>
</tr>
<tr>
<td>Chest</td>
<td>0.017</td>
</tr>
<tr>
<td>Abdomen</td>
<td>0.015</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Jessen KA. Applied Radiation and Isotopes, 1999; 165-172
(This method is used in the ACR CT Accreditation Program)