What should we do to reduce radiation risks?

- Explore using Ultrasound and MRI prior to ordering CT
- Ensure CT exam is absolutely necessary and benefits outweigh risks always
  - Avoid repeat studies
  - Minimize multi-phase studies
  - Decrease frequency of follow-up imaging
- Coordinate efforts with radiation oncologists, radiologists, medical physicists and technologists to optimize modalities and protocols to minimize radiation exposure

**Radiation exposure to US population**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Adult dose (mSv)</th>
<th>Pediatric dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>2</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Neck</td>
<td>3</td>
<td>3 - 6</td>
</tr>
<tr>
<td>Chest</td>
<td>7</td>
<td>4.0 - 18.0</td>
</tr>
<tr>
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<td>8</td>
<td>3.5 - 25</td>
</tr>
<tr>
<td>Pelvis</td>
<td>6</td>
<td>3.3 - 10</td>
</tr>
<tr>
<td>Pediatric Head CT</td>
<td>3</td>
<td>1.9 - 3.7</td>
</tr>
<tr>
<td>Pediatric Chest CT</td>
<td>3</td>
<td>1.8 - 5.5</td>
</tr>
<tr>
<td>Pediatric Abdomen CT</td>
<td>5</td>
<td>5.0 - 15</td>
</tr>
</tbody>
</table>

**Effective Doses for Various CT Procedures**

<table>
<thead>
<tr>
<th>Examination</th>
<th>Effective dose (mSv)</th>
<th>Range in literature (mSv)</th>
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<tr>
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</tr>
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*IMV Benchmark Reports on CT*

**Number of CT procedures in US**

- 2007: 68.7 million
- 2008: 73.1 million
- 2009: 77.5 million
- 2010: 81.9 million
- 2011: 85.3 million
- 2012: 80.6 million
- 2013: 76.0 million

**Categories of CT procedures (62.0 million in 2006)**

- Adult dose (mSv) for various procedures
- Pediatric dose (mSv) for various procedures

**Effective Doses for Various CT Procedures in 2007**

<table>
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</tr>
</tbody>
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*Metzler FA, et al., Radiology, 248(1), 254-263, 2008*
RadiaHon Dose ReducHon Strategies

- Optimal tube current selection
  - Dose modulaHon strategies
- Reduce tube voltage in suitable paHents
- IteraHve ReconsHon
- Minimize scan range
- Technological advances

Scan Parameters and Image Quality in CT

Primary Factors
- Tube Current (mA)
- Tube Voltage (kVp)
- Scan Time
- Pitch
- Scan AcquisiHon Type

Secondary Factors
- Scan Field of View (SFOV)
- Display Field of View (DFOV)
- Beam CollimaHon
- ReconsHon Slice Width
- ReconsHon Interval
- ReconsHon AlgoHms

Other Factors
- PaHent Size
- PaHent MoHon
- Geometry and Detector Efficiency
- Training and experience

Tube Current (mA)

- Amount of x-rays produced in x-ray tube
- Indicate ‘Quantiy of x-rays’
- Radiation dose varies linearly with mA
- Decreasing tube current by 50%:
  - Decreases radiation dose by ½
  - Increases image noise by √2

CT Dose ModulaHon

Automatic Tube Current ModulaHon (ATCM)

- Spatial modulaHon: Based on modulaHng tube current (mA) at different spatial projecHons
- Utilized in most rouHne body CT protocols
- Temporal modulaHon: Based on modulaHng tube current (mA) at specified time points of an electrocardiographically gated (ECG) signal
- Utilized in cardiac CT protocols

CT dose reductions with tube current modulaHon

- X-ray attenuation lower in AP and higher in lateral projecHon
  - Higher attenuation high mA
  - Low attenuation low mA
- However, CT doses are uniform on the surface and decreases radially towards center
- Various dose reduction options are possible

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Dose modulation in z-direction

Automatic Exposure Control (AEC)


How effective is dose modulation?

- Dose modulations is effective for most adult and pediatric protocols
- Studies have shown to reduce radiation dose
  - Chest CT ~ 14% to 38%
  - Abdominal CT ~ 20% to 35%
  - Head CT ~ 35%

Singh S, et al. JACR, 2011

Temporal Dose Modulation

- Constant tube current through entire R-R cycle can be modulated
- Tube current is lowered outside diastolic region enabling dose reduction during cardiac CT


Caveats and Limitations of AEC

- Patient centering is key – specially for Pediatric subjects
- Obese patients
  - AEC techniques increases dose to maintain constant image quality
  - If low contrast detectability is not required, increase may be unnecessary

To modulate dose or not in certain patients?

Scan date: 6-25-2012
Scan without dose modulation
Manual tube current: 300 eff mAs
CTDIvol (ave) = 20.34 mGy
DLP: 626 mGy-cm

Scan date: 10-11-2010
Scan with dose modulation
Tube current (eff mAs): 748/200 ref
CTDIvol (ave): 10.90 mGy
DLP: 1412 mGy-cm

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Caveats and Limitations of AEC

- Patients with prosthesis
- For very low dose CT protocols (screening)
  - manual selection of low mA may be advantageous and easier to implement
- Users should be familiar with limitations of AEC techniques

Tube Potential Selection

Tube Voltage (kV)

- Potential difference between anode and cathode of x-ray tube
- Quality of x-rays - affects image contrast
- 120 kV – most common
  - Others – 140/135, 100/110, 80 and even 70 kV
  - 100 kV or 80 kV – thin patients
- CTDI increases with tube voltage (kV²)

Tube Voltage Modulation

- Lower tube voltage improves image contrast and reduce dose for small and medium size

Radiology 2012; 264(2): 567-580

Iterative Reconstruction

- Objective is to enable user to acquire CT data at dose and improve image quality with iterative process
- Most iterative reconstruction algorithms due to manufacturer proprieties act as ‘BLACK BOX’
**Abdominal CT:**
Filtered Back Projection (FBP) vs Iterative Reconstruction

- Standard FBP yielded relatively noisy image
- SAFIRE® – Iterative reconstruction
- Less Noisy

---

**Contrast to Noise Ratio (CNR)**
Tube Voltage 120 KV vs 100 KV
- CNR improves with SAFIRE at each tube voltage
- Compared to 120 KV FBP images, CNR increased by 25% for 100 KV images with SAFIRE 3, at the same time radiation dose decreased by 40%

<table>
<thead>
<tr>
<th></th>
<th>120 KV</th>
<th>100 KV</th>
<th>SAFIRE 3 (120 vs 100 KV)</th>
<th>FBP vs SAFIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTDIvol (mGy)</td>
<td>9.2</td>
<td>5.53</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>FBP</td>
<td>0.74</td>
<td>0.68</td>
<td>-8%</td>
<td></td>
</tr>
<tr>
<td>SAFIRE-1</td>
<td>0.78</td>
<td>0.71</td>
<td>-4%</td>
<td></td>
</tr>
<tr>
<td>SAFIRE-2</td>
<td>0.95</td>
<td>0.84</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>SAFIRE-3</td>
<td>1.57</td>
<td>1.39</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>SAFIRE-4</td>
<td>1.15</td>
<td>1.1</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>SAFIRE-5</td>
<td>1.74</td>
<td>1.37</td>
<td>38%</td>
<td></td>
</tr>
</tbody>
</table>

**120 KV FBP vs 100 KV SAFIRE 3**
40% dose reduction
25% higher CNR

---

**Cardiac CTA – submSv studies**
- 107 patients
  - 27.2 BMI
  - 100 kVp for 97 patients
- Wide volume coverage (320 * 0.5 mm - Toshiba 320)
- Iterative Reconstruction
- Automatic Exposure control
- Radiation dose – 0.93 mSv (0.58 – 1.74 mSv)

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**Other initiatives aimed at reducing dose**
- Adopting appropriateness criteria into physician decision making
- Increased awareness
  - Such as *Image Gently* and *Image Wisely* campaign
  - Education and Radiation awareness

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**Over-ranging in MDCT**

- Over-ranging is specific to reconstruction-algorithm
- Generally increases with collimation and pitch
- Over-ranging may lead to substantial but unnoticed exposure to radiosensitive organs


**Conventional and Adaptive Collimation**

Deak, P. D. et al. Radiology 2009;252:140-147

**CT & Fetal Irradiation**

- Fetus not directly in the x-ray beam as in Chest CT or Head CT
- Very few scattered x-rays reach fetus
- Mostly internal scatter

**Organ or Tissue Weighting Factors (wT)**

<table>
<thead>
<tr>
<th>Organ or Tissue</th>
<th>Weighting factor*</th>
<th>ICRP 60</th>
<th>ICRP 103</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>0.05</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Red bone marrow, Colon, Lung, Stomach</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Remained tissues</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>0.20</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Bladder, Liver, Thyroid &amp; Esophagus</td>
<td>0.05</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Skin &amp; Bone surface</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Brain &amp; Salivary glands</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ICRP 103, 2007

\[\text{Organ or Tissue Weighting Factor} = \text{ICRP 60} \times \text{ICRP 103} \]

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