Personalized CT Imaging:
Decision support and optimization techniques for age, habitus, and diagnostic task

Sarah McKenney, Ph.D.
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No disclosures
Personalized CT Imaging: Decision support and optimization techniques for age, habitus, and diagnostic task

I. Pediatric Considerations

II. Bariatric Considerations

III. Size-Specific Dose Estimate

IV. Image Gently/Wisely and Choose Wisely
Pediatric considerations

I. Challenges
   a. Radiation Sensitivity
   b. Anatomic & Physiologic features
   c. “Uncooperative” Patients

II. Unique to pediatrics

III. Imaging Tips
Differences between Pediatrics & Adults

• Immature blood/brain barrier
• Larger body surface area
• Rapidly dividing cells
• Immature immune system
• Higher metabolic rate
• Thinner skin
• Higher respiratory rates

Cristina Dodge, Optimizing Pediatric CT in the ED. AAPM Annual Meeting, 2016

Challenges to Pediatric Imaging: Radiation Sensitivity

Based on the LNT model, per BEIR VII

Effect of Age At Exposure M&F

<table>
<thead>
<tr>
<th>Risk at 1 vs 30 yrs</th>
<th>Female Cancer Incidence</th>
<th>Male Cancer Incidence</th>
<th>Female Cancer Mortality</th>
<th>Male Cancer Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>~4.3</td>
<td>~3.3</td>
<td>3.2</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

Challenges to Pediatric Imaging: 
Radiation Sensitivity

Abdominal CT, 240 mAs

Estimated Lifetime Attributable Risk of Death from Cancer (%)

- Total
- Digestive
- Other
- Leukemia

Age at Time of CT Study (yr)

Natural Cancer Incidence: 22%
With an ABD CT at birth: 22.14%

Natural Cancer Mortality: 41%
With an ABD CT at birth: 41.14%

# Radiation Sensitivity: Carcinogenesis Risk for Children vs. Adults

<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>More</th>
<th>No Difference</th>
<th>Less</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>✓</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Brain</td>
<td>✓</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Thyroid</td>
<td>✓</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Leukaemia non-CL L</td>
<td>✓</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Stomach (mortality)</td>
<td>ERR</td>
<td>EAR</td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Lung</td>
<td>✓*</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Skin non-melanoma</td>
<td>✓</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Bladder</td>
<td>✓</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Colon (incidence)</td>
<td>EAR</td>
<td>ERR</td>
<td></td>
<td>Weak</td>
</tr>
<tr>
<td>Colon (mortality)</td>
<td>EAR &amp; ERR</td>
<td></td>
<td></td>
<td>Weak</td>
</tr>
<tr>
<td>Liver</td>
<td>✓</td>
<td></td>
<td></td>
<td>Weak</td>
</tr>
<tr>
<td>Myelodysplasia</td>
<td>✓</td>
<td></td>
<td></td>
<td>Weak</td>
</tr>
</tbody>
</table>

* Limited data on radon and lung cancer indicate approximately same risk after exposure at pre-adult and adult age.

Limited data on radon and lung cancer indicate approximately same risk after exposure at pre-adult and adult age

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<thead>
<tr>
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<th>Less</th>
<th>Level of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>ü</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Brain</td>
<td>ü</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Thyroid</td>
<td>ü</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Leukaemia non-CL L</td>
<td>ü</td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Stomach (mortality)</td>
<td></td>
<td></td>
<td>ERR</td>
<td>Moderate</td>
</tr>
<tr>
<td>Lung</td>
<td>ü</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Skin non-melanoma</td>
<td>ü</td>
<td></td>
<td></td>
<td>Moderate</td>
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<tr>
<td>Bladder</td>
<td>ü</td>
<td></td>
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<td>Moderate</td>
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<td></td>
<td></td>
<td>EAR</td>
<td>Weak</td>
</tr>
<tr>
<td>Colon (mortality)</td>
<td></td>
<td></td>
<td>ERR &amp;</td>
<td>Weak</td>
</tr>
<tr>
<td>Liver</td>
<td>ü</td>
<td></td>
<td></td>
<td>Weak</td>
</tr>
<tr>
<td>Myelodysplasia</td>
<td>ü</td>
<td></td>
<td></td>
<td>Weak</td>
</tr>
<tr>
<td>Kidney</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Myeloma</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Non-Hodgkin's lymphoma</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Oesophagus</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Ovary</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Parathyroid</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
<tr>
<td>Uterus</td>
<td></td>
<td></td>
<td></td>
<td>Strong</td>
</tr>
</tbody>
</table>

* Tumor not definitely shown to be increased by radiation exposure for:
  - Cervix
  - Hodgkin's lymphoma
  - Pancreas
  - Prostate
  - Rectum
  - Small intestine

Not enough sufficient data for cancer of:
  - Kidney
  - Myeloma
  - Non-Hodgkin's lymphoma
  - Oesophagus
  - Ovary
  - Parathyroid
  - Uterus

* Limited data on radon and lung cancer indicate approximately same risk after exposure at pre-adult and adult age.
Challenges to Pediatric Imaging: Anatomic & Physiologic Features

Wide spectrum of patient sizes
Low calcium content (flexible & lower con)
Small features & low body fat


Slide Courtesy of Cristina Dodge, Optimizing Pediatric CT in the ED. AAPM Annual Meeting 2016
Challenges to Pediatric Imaging:
The “Uncooperative Patient”

- Highly expressive
- Mistrust of health professionals
- Limited communication abilities
- Limited concentration & control

Pediatric considerations

I. Challenges

II. Unique to pediatrics
   a. Specialized protocols
   b. Patient Comfort
   c. When to use shielding

III. Imaging Tips
Unique to Pediatrics: Specialized Protocols

Ultra low-dose CT for boney congenital disease

- Craniosynostosis
  - Absent right coronal suture
  - Left coronal suture

- Pectus excavatum
  - Sunken chest wall

Resources:
- Craniosynostosis: https://neurosurgery.ufl.edu/patient-care/diseases-conditions/pediatric-craniosynostosis/
- Pectus excavatum: http://pedsurg.ucsf.edu/conditions--procedures/pectus-excavatum.aspx#a1
- Fused Suture: http://www.fetalultrasound.com/online/text/1-021.HTM
- Sunken Chest Wall: http://img.medscapestatic.com/pi/meds/ckb/89/26189tn.jpg
Ultra low-dose CT for bony congenital disease

- Craniosynostosis

https://neurosurgery.ufl.edu/patient-care/diseases-conditions/pediatric-craniosynostosis/

More at the ACR–ASER–SCBT-MR–SPR Practice Parameter for the Performance of Pediatric Computed Tomography

http://pedsurge.ucsf.edu/conditions--procedures/pectus-excavatum.aspx#a1

http://img.medscapestatic.com/pi/meds/ckb/89/26189tn.jpg
Unique to Pediatrics: Patient Comfort

Cooperation requires patience and age-appropriate...

- Education
- Communication
- Distraction tools
- Patient restraints

Improved with Child Life Specialists

http://elhardfamily.blogspot.com/2010/

Unique to Pediatrics:
Use of Shielding

AAPM statement for use of Bismuth shields

<table>
<thead>
<tr>
<th>POLICY NUMBER</th>
<th>POLICY NAME</th>
<th>POLICY DATE</th>
<th>SUNSET DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP 26-A</td>
<td>Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning</td>
<td>2/7/2012</td>
<td>12/31/2017</td>
</tr>
</tbody>
</table>

Policy source

AAPM Board Vote - Closed on February 7, 2012

Policy text

Bismuth shields are easy to use and have been shown to reduce dose to anterior organs in CT scanning. However, there are several disadvantages associated with the use of bismuth shields, especially when used with automatic exposure control or tube current modulation. Other techniques exist that can provide the same level of anterior dose reduction at equivalent or superior image quality that do not have these disadvantages. The AAPM recommends that these alternatives to bismuth shielding be carefully considered, and implemented when possible.
Outline

I. Pediatric considerations
   a. Challenges
   b. Unique to pediatrics
   c. Imaging Tips
      a. General considerations
      b. Technique considerations
      c. AD’s, DRR’s & DRL’s
Baseline Pediatric Protocols

Protocols for a spectrum of CT makes & models
http://www.aapm.org/pubs/CTProtocols/

- Head
- Chest
- Abdomen/Pelvis
Technique Tips: When to Reduce Tube Potential

- Lower tube potential improves contrast & lowers dose to small patients
- Educate before you implement!

Table 2: Hounsfield Unit values as a function of CT X-ray tube voltages (kV) [Relative HU values normalized to unity at 120 kV]

<table>
<thead>
<tr>
<th>Tube voltage (kV)</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal average photon energy (keV)</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Fat</td>
<td>−152</td>
<td>−111</td>
<td>−89</td>
<td>−69</td>
</tr>
<tr>
<td>[1.70]</td>
<td>[1.25]</td>
<td>[1.00]</td>
<td>[0.77]</td>
<td></td>
</tr>
<tr>
<td>Brain</td>
<td>47</td>
<td>43</td>
<td>39</td>
<td>37</td>
</tr>
<tr>
<td>[1.20]</td>
<td>[1.08]</td>
<td>[1.00]</td>
<td>[0.93]</td>
<td></td>
</tr>
<tr>
<td>Soft tissue</td>
<td>62</td>
<td>58</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>[1.14]</td>
<td>[1.06]</td>
<td>[1.00]</td>
<td>[0.96]</td>
<td></td>
</tr>
<tr>
<td>Cortical bone</td>
<td>3760</td>
<td>2590</td>
<td>1940</td>
<td>1330</td>
</tr>
<tr>
<td>[1.94]</td>
<td>[1.34]</td>
<td>[1.00]</td>
<td>[0.69]</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>9,570</td>
<td>5,960</td>
<td>3,950</td>
<td>2,090</td>
</tr>
<tr>
<td>[2.42]</td>
<td>[1.51]</td>
<td>[1.00]</td>
<td>[0.53]</td>
<td></td>
</tr>
<tr>
<td>Iodine</td>
<td>405,000</td>
<td>267,000</td>
<td>180,000</td>
<td>93,200</td>
</tr>
<tr>
<td>[2.24]</td>
<td>[1.48]</td>
<td>[1.00]</td>
<td>[0.52]</td>
<td></td>
</tr>
</tbody>
</table>

Technique Tips: When to Use AEC & TCM

Automatic Exposure Control & Tube Current Modulation

- Greater dose savings for mid-sized patients
- Greatest gains if AEC changes with size-dependent protocols

Greater patient positioning effects observed at low kV

Positioning at the “center of mass” (attenuation) not the geometric center of a patient

Technique Tips:
Methods to Reduce Scan time

<table>
<thead>
<tr>
<th>Collimation</th>
<th>Rotation Time</th>
<th>Pitch</th>
<th>Tube Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>
AD’s, DRR’s, & DRL’s

- Achievable Dose: Median Dose
- Dose Reference Levels: 75\textsuperscript{th} percentile
- Dose Reference Ranges: 25\textsuperscript{th} - 75\textsuperscript{th} percentile

<table>
<thead>
<tr>
<th>Effective Diameter (cm)</th>
<th>No. of Examinations</th>
<th>Mean SSDE (mGy)</th>
<th>Standard Error of the Mean (mGy)</th>
<th>Median (mGy)*</th>
<th>PDRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>20</td>
<td>2.7</td>
<td>0.34</td>
<td>2.1 (1.8–3.9)</td>
<td>&lt;0.44</td>
</tr>
<tr>
<td>15–19</td>
<td>147</td>
<td>3.4</td>
<td>0.15</td>
<td>3.0 (2.2–4.5)</td>
<td>0.44–0.60</td>
</tr>
<tr>
<td>20–24</td>
<td>165</td>
<td>4.3</td>
<td>0.20</td>
<td>3.4 (2.7–5.1)</td>
<td>0.64–0.80</td>
</tr>
<tr>
<td>25–29</td>
<td>134</td>
<td>5.3</td>
<td>0.21</td>
<td>4.7 (3.6–6.6)</td>
<td>0.84–1.0</td>
</tr>
<tr>
<td>≥30</td>
<td>52</td>
<td>7.4</td>
<td>0.43</td>
<td>6.3 (5.5–8.4)</td>
<td>≥1.0</td>
</tr>
</tbody>
</table>

* Data in parentheses are the DRR (25th and 75th percentiles).

AD’s, DRR’s, & DRL’s

- Achievable Dose: Median Dose
- Dose Reference Levels: 75\textsuperscript{th} percentile
- Dose Reference Ranges: 25\textsuperscript{th} - 75\textsuperscript{th} percentile

<table>
<thead>
<tr>
<th>BW Group</th>
<th>No. of Scans</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Lower DRR, 25th Percentile</th>
<th>Median, 50th Percentile</th>
<th>Upper DRR, 75th Percentile</th>
<th>SSDE/SSDE\textsubscript{std} Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15 cm</td>
<td>21</td>
<td>8.6</td>
<td>0.9</td>
<td>5.8</td>
<td>8.0</td>
<td>12.0</td>
<td>0.52</td>
</tr>
<tr>
<td>15–19 cm</td>
<td>153</td>
<td>10.0</td>
<td>0.5</td>
<td>7.3</td>
<td>8.7</td>
<td>12.2</td>
<td>0.61</td>
</tr>
<tr>
<td>20–24 cm</td>
<td>286</td>
<td>11.4</td>
<td>0.7</td>
<td>7.6</td>
<td>9.8</td>
<td>13.4</td>
<td>0.69</td>
</tr>
<tr>
<td>25–29 cm</td>
<td>326</td>
<td>13.5</td>
<td>0.3</td>
<td>9.8</td>
<td>13.0</td>
<td>16.4</td>
<td>0.82</td>
</tr>
<tr>
<td>$\geq$30 cm</td>
<td>168</td>
<td>16.5</td>
<td>0.4</td>
<td>13.1</td>
<td>15.6</td>
<td>19.0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

I. Bariatric Considerations
   a. Challenges
      a. Table limits
      b. Bore limits
      c. Radiation output limits
   b. Technique Tips
## Challenges to Bariatric Imaging: Table Limits

- **Label weight limits on all imaging tables during acceptance.**

<table>
<thead>
<tr>
<th>CT scanners</th>
<th>Internal bore diameter</th>
<th>Weight capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td><strong>Model</strong></td>
<td><strong>CT scanners</strong></td>
</tr>
<tr>
<td>GE Healthcare</td>
<td>LightSpeed RT 4</td>
<td>80 cm</td>
</tr>
<tr>
<td></td>
<td>LightSpeed RT 16</td>
<td>80 cm</td>
</tr>
<tr>
<td></td>
<td>LightSpeed CT750 HD, VCT, VCT XT</td>
<td>70 cm</td>
</tr>
<tr>
<td>Philips Healthcare</td>
<td>Brilliance CT (Big Bore system), ICT</td>
<td>85 cm</td>
</tr>
<tr>
<td></td>
<td>Brilliance CT (other)</td>
<td>70 cm</td>
</tr>
<tr>
<td>Siemens Healthcare</td>
<td>Somatom Sensation 40, 64</td>
<td>70 cm</td>
</tr>
<tr>
<td></td>
<td>Somatom Definition AS and Somatom Dual Source</td>
<td>78 cm</td>
</tr>
<tr>
<td></td>
<td>Somatom Sensation Open</td>
<td>82 cm</td>
</tr>
<tr>
<td>Toshiba America Medical Systems</td>
<td>Aquilion 16</td>
<td>72 cm</td>
</tr>
<tr>
<td></td>
<td>Aquilion 32, 64</td>
<td>72 cm</td>
</tr>
<tr>
<td></td>
<td>AquilionOne</td>
<td>72 cm</td>
</tr>
</tbody>
</table>

More limits available at: [https://www.itnonline.com](https://www.itnonline.com)

Challenges to Bariatric Imaging: Bore Diameter & Field of View

Aperture Specification: 70 cm
Useable Vertical Diameter: 60 cm
Scan FOV: 50 cm

Challenges to Bariatric Imaging: Truncation Artifacts

Incomplete lateral data collection

Challenges to Bariatric Imaging: Patient Bundling

Outline

I. Bariatric Considerations
   a. Challenges
   b. Technique Tips
      a. How to increase tube output
      b. When to use AEC
Challenges to Bariatric Imaging: Radiation Output & Photon Starvation

Radiation output depends on

1. Generator power
   - Ranges from 50-100 kW

2. Technique selection

### Technique Tips: How to Increase Tube Output

<table>
<thead>
<tr>
<th>Tube Current</th>
<th>Rotation Time</th>
<th>Pitch</th>
<th>kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

For BMI >40, increase tube potential to 140 kV

*Improve image noise with increased thickness & iterative reconstruction*

---

Slide from Mannudeep Kalra, *CT in Obesity: Tips and Tricks*. 3rd CT Dose Summit, 2013
Technique Tips: Use AEC with Care!

- Review maximum tube current for bariatric protocols
- Manual techniques may be adequate

Unique to Bariatric Imaging: Dose Distribution

- Decreased radiation dose to internal organs
- Increased radiation dose to skin, breast tissue, and thyroid

TG204: The Size-Specific Dose Estimate

The same CT output results in different dose distributions

Useful for

- Prospective evaluation of CT technique
- Size-specific protocol development

I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely
      1. Description of coalition and goals
      2. Educational material
   b. Image Gently
   c. Choosing Wisely
Image Wisely offers resources and information to radiologists, medical physicists, other imaging practitioners, and patients to:

1. Lower the amount of radiation used in medically necessary imaging studies
2. Eliminate unnecessary procedures
Image Wisely: Educational Material

Optimization Cases

Medical Physicists

- How to Understand and Calculate Dose
  - Download PDF
  - An overview of the risks associated with radiation

- Manufacturer and Model-Specific
  - The AAPM is publishing a set of scan protocols for frequently used CT equipment and offering several model-specific examples

- CT Protocol Design and Optimization
  - Download PDF
  - Resources for CT protocol design and optimization

- U.S. Department of Health and Human Services
  - The study of CT is most commonly seen in adults and children

- Image Reconstruction
  - Download PDF
  - The study of CT is most commonly seen in adults and children

- The Pregnant CT Dose
  - CT dose calculation

- Diagnostic Referrals
  - Discussion of using diagnosis levels to reduce the overall dose and the range of doses observed in clinical practice

Society Recommendations

- American Podiatric Medical Association
  - Don’t routinely use MRI to diagnose bone infection

- American Academy of Pediatrics
  - Don’t routinely use MRI to diagnose bone infection

- American Urological Association
  - Don’t routinely order a head CT to assess for shunt failure in children with hydrocephalus.

Physicist, Physician, & Technologist Resources

Links to Decision Support & Appropriateness Criteria

Unnecessary radiation.
Outline

I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely
   
   b. Image Gently
      1. Description of alliance and goals
      2. Educational material
   
   c. Choosing Wisely
To change practice by raising awareness of the opportunities to lower radiation dose in the imaging of children via information and free educational materials to every member of the care team.
The Image Gently Alliance: How far we have come together!

2008 –
• 13 Alliance Organizations reaching
  ~ 400,000
• 200 pledges on the Campaign’s 1st day

2015 –
• 91 Alliance Organizations – reaching millions
• ~35,000 pledges to date

Thanks to the Founding Organizations representing the members of the Image Team: SPR, ACR, ASRT and AAPM
I. Image Gently/Wisely and Choose Wisely
   a. Image Wisely

   b. Image Gently

   c. Choosing Wisely
      1. Description of foundation and goals
      2. Resources
Choosing Wisely: Appropriateness Criteria & Decision support

To promote conversations between clinicians and patients by helping patients choose care that is:

- Supported by evidence
- Not duplicative of other tests or procedures already received
- Free from harm
- Truly necessary
Choosing Wisely:
ACR Recommendations

Ever-growing list of indications
• Narrative & Rating Table
• Evidence Table
• Literature Search
What happens with Gently/Wisely education?

What happens with Gently/Wisely education?

**Before Education**

<table>
<thead>
<tr>
<th>% of total imaging</th>
<th>Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
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</tr>
<tr>
<td>MRI</td>
<td>0.1</td>
</tr>
<tr>
<td>US</td>
<td>0.1</td>
</tr>
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</table>

**After Education**

Thank You