Pediatric CT Protocol Development
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Disclosures
No disclosures

Outline: Pediatric CT Protocol Development
I. Challenges
II. Unique to pediatrics
III. Protocol Development & Optimization Tips
IV. Resources

https://goo.gl/kyfUxf
Pediatric considerations

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

II. Unique to pediatrics

III. Protocol Development & Optimization Tips

IV. Resources

Pediatrics & Adults are Physiologically Different

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


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

Challenges to Pediatric Imaging: Anatomic & Physiologic Features

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


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

Challenges to Pediatric Imaging: Radiation Sensitivity

Based on the LNT model, per BEIR VII.


### 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>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>Leukemia 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>EAR</td>
<td>✓</td>
<td>Weak</td>
</tr>
<tr>
<td>Colon (mortality)</td>
<td>EAR</td>
<td>ERR</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.

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### Radiation Sensitivity: UNSCEAR 2013 Annex B

**Not enough sufficient data for cancer of...**
- Kidney
- Myeloma
- Non-Hodgkin’s lymphoma
- Oesophagus
- Ovary
- Parathyroid
- Uterus

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

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### Radiation Sensitivity: UNSCEAR 2013 Annex B

**Prioritize efforts to reduce dose to...**
- Breast
- Brain
- Thyroid
- Leukemia
Pediatric considerations

I. Challenges

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

III. Protocol Development & Optimization Tips

IV. Resources

Unique to Pediatrics: Specialized Protocols

Ultra low-dose CT for boney congenital disease

• Craniosynostosis
  - http://www.neurosurgery.ufl.edu/patient-care/diseases-conditions/pediatric-craniosynostosis

• Pectus excavatum
  - http://pedsurg.ucsf.edu/conditions-procedures/pectus-excavatum.aspx#a1

More at the ACS-AAPR-SCBID-MI-APR Performance Parameter for the Tomography of Pediatric Computed
Unique to Pediatrics: Patient Comfort

Cooperation requires patience and age-appropriate...

- Education
- Communication
- Distraction tools
- Patient restraints

Improved with Child Life Specialists

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>DURATION</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>2/26/2012</td>
<td>12/31/2017</td>
</tr>
</tbody>
</table>

Policy Expiry

AAPM board vote - Closed on February 3, 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.

Pediatric considerations

I. Challenges
II. Unique to pediatrics

III. Protocol Development & Optimization Tips
   a. General considerations
   b. Variable patient size
   c. AD’s, DRR’s & DRL’s

I. Resources
Why bother?

Dedicated pediatric facilities consistently outperform adult facilities:
- SSDE is 65% less
- Higher concordance w/ final diagnosis

Evaluating Image Noise

- Protocol optimization must be based on image quality.
- Ideally the metric is independent of patient size & condition

General Considerations:
When to Reduce Tube Potential

- Lower kV lowers dose at matched iodine CNR
- Lower kV may decrease dose at matched noise levels
Tube Potential & TCM: Modest Dose Reductions

<table>
<thead>
<tr>
<th>Relative effective dose (mSv) for Chest CT</th>
<th>80 kV</th>
<th>100 kV</th>
<th>120 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>New born</td>
<td>88%</td>
<td>96%</td>
<td>100%</td>
</tr>
<tr>
<td>1 yo</td>
<td>75%</td>
<td>91%</td>
<td>100%</td>
</tr>
<tr>
<td>5 yo</td>
<td>81%</td>
<td>91%</td>
<td>100%</td>
</tr>
</tbody>
</table>


Relative effective dose (mSv) for Chest CT

<table>
<thead>
<tr>
<th>Tube Potential &amp; TCM: When to Use AEC &amp; TCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Exposure Control (AEC) &amp; Tube Current Modulation (TCM)</td>
</tr>
<tr>
<td>• Greater dose savings for mid-sized patients</td>
</tr>
<tr>
<td>• Greatest gains if AEC adapts with size-dependent protocols</td>
</tr>
</tbody>
</table>

Greater patient positioning effects observed at low kV

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


https://goo.gl/kyfUxf

General Considerations: Methods to Reduce Scan time & Maintain Image Quality

<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>


General Considerations: What About > 40 mm Beam Widths?

Axial Mode

Helical Mode

83% Dose Increase
### General Considerations: Iterative Reconstruction

<table>
<thead>
<tr>
<th>Patient Age</th>
<th>Original CTDIvol</th>
<th>Reduced CTDIvol</th>
<th>Difference</th>
<th>Noise Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1y</td>
<td>54.2 ± 5.7</td>
<td>33.3 ± 4.4</td>
<td>-30%</td>
<td>-4.6%</td>
</tr>
<tr>
<td>2-5y</td>
<td>34.1 ± 3.4</td>
<td>24.6 ± 3.3</td>
<td>-30%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>6-11y</td>
<td>26.1 ± 3.1</td>
<td>19.3 ± 2.6</td>
<td>-30%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>12-18y</td>
<td>20.4 ± 2.5</td>
<td>15.1 ± 2.2</td>
<td>-30%</td>
<td>-2.6%</td>
</tr>
</tbody>
</table>

**On average...**
- 40% reduction in CTDIvol
- 0.2% reduction in phantom noise

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### Scaling Radiation Output: TG204, Size-Specific Dose Estimate

\[
\text{SSDE} = \text{CTDI}_{\text{vol}} \times \text{SCALING FACTOR}
\]

Effective diameter is highly correlated to water equivalent diameter.

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**References**


Scaling Radiation Output: TG204, Size-Specific Dose Estimate

Ave. water equivalent diameter is more strongly correlated to SSDE

Binning Pediatric Protocols

- Head: Age
  - 0 - 1 yr
  - 1 – 2 yr
  - 2 – 6 yr
  - 6 – 16 yr
  - 16 yr+

- Body: Effective Diameter
  - 7 – 13 cm
  - 14 – 16 cm
  - 17 – 22 cm
  - 23 – 27 cm
  - 28 – 32 cm

AD’s, DRR’s, & DRL’s

<table>
<thead>
<tr>
<th>Metric</th>
<th>Definition</th>
<th>How to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achievable Dose [AD]</td>
<td>Median Dose</td>
<td>Sanity check</td>
</tr>
<tr>
<td>Dose Reference Level (DRL)</td>
<td>75th Percentile</td>
<td>Review exams that are overdosed</td>
</tr>
<tr>
<td>Dose Reference Ranges (DRR)</td>
<td>25th - 75th Percentile</td>
<td>Review exams that are over/under dosed</td>
</tr>
</tbody>
</table>
**Chest CT:**
AD’s, DRR’s, & DRL’s

<table>
<thead>
<tr>
<th>Effective Diameter (cm)</th>
<th>No. of Examinations</th>
<th>AD (DRR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>20</td>
<td>2.1 (1.8-3.9)</td>
</tr>
<tr>
<td>15-19</td>
<td>147</td>
<td>3.0 (2.2-4.5)</td>
</tr>
<tr>
<td>20-24</td>
<td>165</td>
<td>3.4 (2.7-5.1)</td>
</tr>
<tr>
<td>25-29</td>
<td>134</td>
<td>4.7 (3.6-6.6)</td>
</tr>
<tr>
<td>&gt;30</td>
<td>52</td>
<td>6.3 (5.5-8.4)</td>
</tr>
</tbody>
</table>

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


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**Abdomen CT:**
AD’s, DRR’s, & DRL’s

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Scans</th>
<th>Lower DRR, 25th Percentile</th>
<th>Median, 50th Percentile</th>
<th>Upper DRR, 75th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15cm</td>
<td>21</td>
<td>5.8</td>
<td>8.0</td>
<td>12.0</td>
</tr>
<tr>
<td>15-19</td>
<td>153</td>
<td>7.3</td>
<td>8.7</td>
<td>12.2</td>
</tr>
<tr>
<td>20-24</td>
<td>386</td>
<td>7.6</td>
<td>9.6</td>
<td>13.4</td>
</tr>
<tr>
<td>25-29</td>
<td>326</td>
<td>9.8</td>
<td>13.0</td>
<td>16.4</td>
</tr>
<tr>
<td>&gt;30cm</td>
<td>168</td>
<td>13.1</td>
<td>15.6</td>
<td>19.0</td>
</tr>
</tbody>
</table>


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**Building DRL’s In-House**

For each binned demographic:
1. Collect patient data
2. Identify 95th percentile dose metric
3. Add a 10% buffer
Pediatric considerations

I. Challenges
II. Unique to pediatrics
III. Protocol Development & Optimization Tips

I. Resources
   I. AAPM CT Protocols
   II. Image Gently

Baseline Pediatric Protocols

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

- Head
- Chest
- Abdomen/Pelvis

Image Gently: Pediatric Protocol Generation Tools
