Optimization Strategies for Pediatric CT Imaging

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Educational Objectives

Pediatric CT Protocol Development

- Image Quality
- Radiation Dose
- Contrast Dose
- Sedation
- Brain & Body CT

Brain CT

- Brain CT (one of the more tricky protocols to optimize)
  - Two biggest limitations
    - Skull (especially the posterior fossa)
    - Minimum inherent differentiation between structures in brain

Gray matter: 34 HU
White matter: 26 HU

Beam Hardening
Brain CT

- The head grows logarithmically
  - In diameter & bone density

Kleinman, et al. AJR 2010; 194:1611-1619

Brain CT

- The head grows logarithmically
  - In length (S/I)
  - Volumetric CT (160 mm) is limited by cone artifact (~140 mm)

Brain CT

- Established 5 protocols
  - 0-6 mon
  - 7-24 mon
  - 2-5 years
  - 6-13 years
  - > 13 years

Kleinman, et al. AJR 2010; 194:1611-1619
**Brain CT**

- **100 kV**: better gray/white differentiation
- **CTDI**: dose and noise balanced
- **Fixed mA**: not sensitive to misalignment issues with TCM
- **Speed**: volume mode < 2yr old

<table>
<thead>
<tr>
<th>Protocol</th>
<th>kV</th>
<th>mA</th>
<th>Rot (s)</th>
<th>Coll (mm)</th>
<th>CTDIvol (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6 m (V)</td>
<td>100</td>
<td>200</td>
<td>0.75</td>
<td>0.5x30</td>
<td>21.7</td>
</tr>
<tr>
<td>7-24 m (V)</td>
<td>100</td>
<td>280</td>
<td>0.75</td>
<td>0.5x30</td>
<td>27.6</td>
</tr>
<tr>
<td>24m-5y (H)</td>
<td>120</td>
<td>180</td>
<td>0.75</td>
<td>0.5x40</td>
<td>32.7</td>
</tr>
<tr>
<td>6-13y (Y)</td>
<td>120</td>
<td>170</td>
<td>0.75</td>
<td>0.5x40</td>
<td>34.7</td>
</tr>
<tr>
<td>≥13y (H)</td>
<td>120</td>
<td>170</td>
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</tbody>
</table>

**Body CT**

- **Proper protocol**
- **Organ dose modulation**
- **Iterative reconstruction**
- **Metal Artifact reduction software**

**Keys to success:**

- Simplify protocol tree
  - Myth: you need lots of protocol variations for pediatrics
  - 5 will cover the range from 0 to > 100 kg

**Acquisition Time**

- Faster acquisition may lead to lower sedation rates
  - E.g. 5yr; 30 cm scan length
  - Pitch 1.5 @ 0.28 sec rotation
  - Total exposure time = 0.7 sec

- Single acquisition
  - ~0.28 sec
  - Great for head, chest, cardiac, or limited FOV (e.g., kidneys)
Acquisition Time

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- Single acquisition
  - ~0.28 sec
  - Great for head, chest, cardiac, or limited FOV (e.g., kidneys)
  - Can almost freeze even cardiac motion

Body CT

- Proper protocol
- Organ dose modulation
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- Weight/size based adjustments
  - kVp
  - Develop good contrast timing schemes

Image Quality Optimization-kV

- Why decrease kV?
  - Enhance iodine or bone contrast
    - 120 vs. 80 kV = 42% contrast
  - Soft tissue vs. bone
    - 120 vs. 80 kV = 100% contrast
Image Quality Optimization-kV

- Why decrease kV?
  - Lower IV/oral contrast dose
  - Compensate contrast intensity w/ lower kV
  - Only valid in small patients

Image Quality Optimization-kV

- How to decrease kV clinically?
  - Don’t match noise, match CNR!
  - Calculate target CNR in phantom
    \[ \alpha = \frac{\ln \left( \frac{m_{AS2}}{m_{AS1}} \right)}{\ln \left( \frac{kV1}{kV2} \right)} \]
    \[ \alpha = \frac{\ln \left( \frac{120}{80} \right)}{\ln \left( \frac{120}{80} \right)} = 3.8 \]
  - Apply \( \alpha \) value towards patient protocols
    - Use avg TCM mA value
    - \( m_{AS2} = m_{AS1} \cdot \left( \frac{kV2}{kV1} \right)^{\alpha} \)

Image Quality Optimization-kV

- Apply \( \alpha \) value towards patient protocols
  - Use avg TCM mA value
  - \( m_{AS2} = m_{AS1} \cdot \left( \frac{kV2}{kV1} \right)^{\alpha} \)
  - e.g., \( \left( \frac{120}{80} \right)^{3.8} \approx 85 \ mAs \)
  - CNR improves with lower kV even though noise increases
  - Noise can be higher at lower kV

Same Patient

- 120 kV
  - 100 kV
  - 31% dose reduction

*Bushberg et al, The essential physics of medical imaging, 3rd Ed, LWW*
Dose and Image Quality Optimization-CT

- **Why decrease kV?**
  - Caveat: you can get good dose reduction at 120 kV
- **Rule of thumb (trunk)**
  - Routine imaging @ 80 kV
    - ≤ 15 cm dia. (CCHMC, <15 kg)
    - ≤ 36 cm lat dim (Mayo)*
  - Routine imaging @ 100 kV
    - ≤ 26 cm dia.dia. (CCHMC, <71 kg)
    - ≤ 41 cm lat dim (Mayo)*

- **120 kV; 1.81 mGy**
- **100 kV; 2.83 mGy**

*Fletcher, AAPM 2010
Yu et al. Med Phys 57(1) 2010; 234-243

Image Quality Optimization-kV

- **Why increase kV?**
  - Penetration
    - Larger patients, generally, require higher kV (i.e., 120 kV)
    - Brain imaging ~> 4 yr old (use 120 kV)
  - Focal spot consideration
    - For high resolution (small structure imaging) use smallest focal spot
    - Small focal spot (~0.6 mm) is available ~≤ 350 mA

Body CT

- **Proper protocol**
- **Organ dose modulation**
- **Iterative reconstruction**
- **Metal Artifact reduction software**
- **Weight/size based adjustments**
- **kVp**
- **Develop good contrast timing schemes**
IV Contrast

- Develop good contrast timing schemes
  - Poor contrast management may mask pathology
- Popular approaches
  - Bolus tracking
  - Fixed time

### IV Contrast

**Protocol (kg)**  | **ID (sec)**  | **Volume (mL)**  | **Rate (mL/sec)**  | **Tpeak enhancement** (sec)  | **Delay** (sec)  |
---|---|---|---|---|---|
9-14.9 | 20 | <30 | 1.6-1.8 | 50 | 10-20
15-31.4 | 30 | 30-62 | 1.0-2.0 | 40 | 30-60
>31.5-65 | 40 | 63-110 | 1.0-2.0 | 50 | 70-90
>65-100 | 60 | 110-150 | 1.0-2.5 | 70 | 90-110
>100 | 60 | 150 | 2.5 | 70-90


### Dose Dose and Image Quality Optimization-CT

- Proper protocol
- Proper set up
- Organ dose modulation
- Iterative reconstruction
- Metal Artifact reduction software

Dose and Image Quality Optimization-CT

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Dose and Image Quality Optimization-CT - CT

• Iterative reconstruction limitations:
  - “Plastic” or “soft” look
  - No matter the level of iterative recon there will be losses in edge definition
  - Mostly affecting soft tissue kernels

Dose Reduction 20-70%
Future Directions of CT Reconstruction

• Deep learning models
  – 1000’s of CT images used to train a reconstruction algorithm
  – Reconstruction will only be as good as the data used to train
    • Must include adults & peds
  – Performs well in sinogram space at “filling in” missing data
    • e.g., fixing metal artifact
    • e.g., cleaning up noisy data

Future Directions of CT Reconstruction

• Low dose reconstruction
  – Full dose ~230-430 mA
  – ¼ dose ~60-110 mA
  – Recon time 1.6 sec/slice
    • Total: 2-3 min (MATLAB)


Image Quality Optimization-kV

• Use metal artifact reduction software
  – Increasing kV and mAs does NOT improve metal artifacts!
Thank you

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