Establishing a Managed Radiation Dose for any Pediatric Exam on any CT Scanner

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Introduction
- Adult hospitals perform 80% of pediatric CT exams.
- Pediatric radiation doses and image quality should be managed.
- Both tube voltage and mAs should be altered for pediatric imaging.
- Minimalist approach (change mAs only) is preferred over doing nothing.

The Challenge
- Ideally, unique scan parameters should be established for each individual patient accounting for:
  - Patient size
  - Type of CT examination
  - Design of actual CT scanner
- This can be done in academic centers with diligent effort.
The Challenge

• Is this a practical solution for a community hospital that performs an occasional pediatric CT scan?

• Yet, majority of pediatric CT imaging in the US OCCURS in non-dedicated pediatric hospitals

A Solution: Patient Specific Technique on any CT Scanner

• Establish Diagnostic Reference Levels (DRL) for an examination for a given size patient

• Compare SSDE after the projection scan to department’s DRL

• Adjust the clinical technique to match the desired DRL

  • Manual mode

  • Automated tube current mode

  • Enlist the help of your qualified medical physicist (QMP)

Establish Department DRLs

• Adult Patient for Scanner #1

  • Use your measured dose data

  • Measured CTDIvol data

    • Head

    • Body

  • Associated technique factors which created measured CTDIvol
CT SCANNER DOSE INDICES

Measured CTDI<sub>vol</sub>

- Measure CTDI<sub>vol</sub> with identical scan parameters
  - kVp
  - mA
  - Rotation time
  - Bow Tie Filter
- Use phantom 10, 16, and 32 cm diameter

Measured CTDI<sub>vol</sub> increases 2.6 times as phantom size decreases!

Display CTDI<sub>vol</sub> varies.
DISPLAYED CTDI SHORTCOMING

Same radiographic technique

Displayed CTDI\textsubscript{vol} based on 32 cm CTDI Phantom

18 mGy for both patients!

CT SCANNER DOSE INDICES

Displayed CTDI\textsubscript{vol}

- Standardized method to estimate and compare the radiation output of two different CT scanners to same phantom.

\textbf{does not represent . . .}

\textbf{Patient dose!!}

CLINICAL DILEMMA

- Displayed CTDI\textsubscript{vol} on scanner is independent of patient size
- 16 cm CTDI phantom: adult dose over while pediatric dose under estimated.
- 32 cm CTDI phantom: adult and pediatric dose under estimated ~ 2.5 times!
- Propagated by DICOM Structured Dose Reports and CT scanner dose reports.
Establish Department DRLs

- Adult Patient for Scanner #1
  - Do your measured CTDI_{vol} results agree with published (national DRLs)?
  - ACR Accreditation submitted values without iterative reconstruction
  - Routine head CTDI_{vol16} < 75 mGy
  - Routine body CTDI_{vol32} < 25 mGy
  - Discuss with your site’s QMP

Establish Department DRLs

- Adult Patient for Scanner #1
  - Scale the mAs value if necessary to adjust CTDI_{vol} to desired level.
  - Calculate SSDE for routine abdomen
    - (28 & 38 cm AP & LAT dimensions)
  - DRL for Scanner #1

Establish Department DRLs

- Adult Patient DRL, Scanners #1, #2, #3, etc.
  - Scanner #1 (28 x 38 cm adult abdomen):
    - 120 kV, 250 mAs, pitch = 1, 25 mGy CTDI_{vol}
    - Site elects to reduce dose 20%
    - 120 kV, 200 mAs, pitch = 1, 20 mGy CTDI_{vol}
    - 120 kV, 250 mAs, pitch = 1.2, 20 mGy CTDI_{vol}
    - 20 mGy * 1.14 = 23 mGy SSDE
Establish Department DRLs

• Adult Patient DRL for Scanners #2, #3, etc.
  • Goal: similar image quality on all of site’s CT scanners
  • First step: match the patient’s radiation dose to the on all site’s scanners.
  • Similar image quality is not guaranteed.
  • Evaluate image quality any time patient doses are altered
  • Cooperative task between radiologists, technologists, and QMP

Establish Department DRLs

• Adult Patient DRL, Scanners #1, #2, #3, etc.
  • ‘Same’ adult DRL for each scanner
  • SSDEs are equal
  • CTDI<sub>vol</sub> values are equal
  • Unique technique for each scanner
  • mAs alone cannot be used to compare patient dose between two CT scanners

Establish Department DRLs

• Adult Patient DRL, Scanners #1, #2, #3, etc.
  • Scanner #1 (28 x 38 cm adult abdomen):
    • 120 kV, 200 mAs, pitch = 1, 20 mGy CTDI<sub>vol</sub>
  • Scanner #2 (28 x 38 cm adult abdomen):
    • 120 kV, 250 mAs, pitch = 1, 13 mGy CTDI<sub>vol</sub>
    • 120 kV, 385 mAs, pitch = 1, 20 mGy CTDI<sub>vol</sub>
    • 120 kV, 250 mAs, pitch = 0.65, 20 mGy CTDI<sub>vol</sub>
    • 23 mGy SSDE for both scanners
Establish Department DRLs

• Select Pediatric Patient DRL (without iterative reconstruction)

<table>
<thead>
<tr>
<th>ADULT DRL</th>
<th>PEDIATRIC DRL</th>
<th>KAPPA</th>
<th>nML</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 12 13</td>
<td>10 11 12</td>
<td>0.95 1</td>
<td>0.95 1</td>
</tr>
<tr>
<td>14 15 16</td>
<td>13 14 15</td>
<td>0.96 1</td>
<td>0.96 1</td>
</tr>
<tr>
<td>17 18 19</td>
<td>16 17 18</td>
<td>0.97 1</td>
<td>0.97 1</td>
</tr>
</tbody>
</table>

AP & LAT thicknesses are average values from study of 360 random patients
• Kleinman PL et al. AJR June 2010, pp. 1611 – 19.

Establish Department DRLs

AGE vs PATENT SIZE

Same age patients vary dramatically in size.
• Abdomens of:
  • Largest 3 year olds and smallest adults are the same size.
  • Patient cross section size, not age, should be used.
Establish Department DRLs

- AP & LAT thicknesses are average values from study of 360 random patients
  

- Effective Diameter = \((\text{AP Thk} \times \text{LAT Thk})^{0.5}\)
  
  Boone JM et al. TG204, AAPM website

- Average mass of boys & girls
  
  National Center for Health Statistics 2000

Establish Department DRLs

- Select Pediatric Patient DRL (without iterative reconstruction)

  A. Use adult techniques
     
     - Newborn (10 x 14 cm) dose = 2.4 * adult dose
     
     - Common practice prior to 2001

  B. Limited reduced pediatric techniques
     
     - Newborn SSDE = adult SSDE
     
     - Basis of CT protocols on Image Gently Website posted in 2008

Establish Department DRLs

- Select Pediatric Patient DRL (without iterative reconstruction)

  D. Aggressive pediatric techniques
     
     - Newborn SSDE = 0.5 * adult SSDE
     
     - Results of QuICRC published research
Establish Department DRLs

- Select Pediatric Patient DRL (without iterative reconstruction)

C. Moderate pediatric techniques
   - Newborn SSDE = 0.75 * adult SSDE

D. Aggressive pediatric techniques
   - Newborn SSDE = 0.5 adult SSDE
   - Results of QuIRCC published research

Establish Department DRLs

D. QuIRCC published research?
   - Six pediatric hospitals submitted CT patient CTDIvol dose data from late 2009; prior to iterative reconstruction reductions
   - Image quality was evaluated
   - SSDE/SSDE_{adult} = 0.14 + 0.025*LAT size
     \[ = 0.14 + 0.025*14 = 0.49 \]

   - NB dose is half of adult dose in Aggressive model

Establish Department DRLs

- Pediatric Patient DRL (without iterative reconstruction) SSDE
Establish Department DRLs

- **Pediatric Abdominal DRL (without iterative reconstruction)** Required mAs

<table>
<thead>
<tr>
<th>Age</th>
<th>Limited Info Reduction</th>
<th>Moderate Info Reduction</th>
<th>Aggressive Info Reduction</th>
<th>Adult Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>70</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>1y</td>
<td>70</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>2y</td>
<td>70</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>3y</td>
<td>70</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

With respect to reduction of mAs when developing abdominal CT technique factors for a newborn patient:

1. Newborn (NB) dose = adult dose (AD) if adult mAs is unchanged.
2. NB dose = half of AD if adult mAs cut in half.
3. NB dose = AD if adult mAs divided by 3.
4. NB dose = half of AD if adult mAs divided by 4.
5. NB dose = half of AD does not provide clinically useful images.

Strauss KJ. Pediatr Radiol Supplement 2014 (in press)
Establish Department DRLs

- **Pediatric Chest DRL (without iterative reconstruction)** Required mAs
  - **Scanner 1 (28 x 38 cm adult abdomen):**
    - 120 kV, 200 mAs, pitch = 1, 20 mGy CTDI_{vol}
    - 20 mGy * 1.14 = 23 mGy SSDE
    - 120 kV, 160 mAs, pitch = 1, 16 mGy CTDI_{vol}
    - 16 mGy * 1.14 = 18 mGy SSDE

<table>
<thead>
<tr>
<th>kVp</th>
<th>mA</th>
<th>Time (sec)</th>
<th>Pitch During Measured CTDI_{vol}</th>
<th>Pitch During Clinical Exam</th>
<th>Adult SSDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>200</td>
<td></td>
<td>20 mGy</td>
<td></td>
<td>23 mGy</td>
</tr>
<tr>
<td>120</td>
<td>160</td>
<td></td>
<td>16 mGy</td>
<td></td>
<td>18 mGy</td>
</tr>
</tbody>
</table>

**Establish Department DRLs**

- **Pediatric Chest DRL (without iterative reconstruction)** Required mAs
  - **BE CAREFUL:**
    - Data has not been published to date for the chest where pediatric radiologists have evaluated image quality and dose.
    - Consider using **Moderate** as opposed to **Aggressive** mAs reduction until more data is published

**Establish Department DRLs**

- **Pediatric Head Exams w/o iterative recon**
  - Have validated adult head doses by ACR.
  - **Limited:** ped doses = adult dose (75 mGy max)
Establish Department DRLs

- **Pediatric Head Exams w/o iterative recon**
  - Have validated adult head doses by ACR.
  - **Limited**: ped doses = adult dose (75 mGy max)
  - **Moderate**: 16 vs 20 cm AP: 35 mGy vs 75 mGy
  - Maximum ACR reference values

<table>
<thead>
<tr>
<th>Head Dose</th>
<th>Head Dose</th>
<th>Head Dose</th>
<th>ISL</th>
<th>ISL</th>
<th>Fish</th>
<th>Fish</th>
<th>Fish</th>
<th>Fish</th>
<th>Scanner</th>
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</thead>
<tbody>
<tr>
<td>AP Thickness (cm)</td>
<td>LAT Thickness (cm)</td>
<td>Effective Diameter (cm)</td>
<td>Age</td>
<td>Age</td>
<td>Head</td>
<td>Adult</td>
<td>Adult</td>
<td>Adult</td>
<td>Head</td>
</tr>
<tr>
<td>16</td>
<td>13</td>
<td>14.8</td>
<td>12</td>
<td>3</td>
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<tr>
<td>17</td>
<td>16</td>
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<td>4</td>
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<tr>
<td>19</td>
<td>15</td>
<td>17</td>
<td>21</td>
<td>6</td>
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<td>0.8</td>
<td>0.78</td>
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<tr>
<td>20</td>
<td>14</td>
<td>16</td>
<td>(65 mGy)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

With respect to managing pediatric head CT doses:

1. Calculate the SSDE to estimate patient dose.
2. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 35 mGy CTDIvol.
3. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 75 mGy CTDIvol.
4. 35 mGy CTDIvol is recommended by Image Gently for 1 yr old patient head.
5. 35 mGy CTDIvol is recommended by ACR for a newborn head.

Establish Department DRLs

• **Iterative Reconstruction Required mAs**
  • Scans with iterative reconstruction should deliver significantly less dose than DRL values of ACR
  • Degree of iterative reconstruction
  • Vendor recommendation?
  • Site’s radiologists and QMP should evaluate degree of iterative reconstruction that provides desired image quality.

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Establish Department DRLs

• **Iterative Reconstruction Required mAs**
  • **Scanner 1 (28 x 38 cm adult abdomen):**
    • Scale adult patient mAs to reflect the reduction in adult patient SSDE
    • Plug technique and SSDE values into table.
    • Consider moderate as opposed to aggressive mAs reduction until more data is published

<table>
<thead>
<tr>
<th>kVp</th>
<th>mA</th>
<th>Time (sec)</th>
<th>Pitch During Measured CTDIvol</th>
<th>Pitch During Clinical Exam</th>
<th>Adult SSDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>80</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>80</td>
<td>100</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

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Establish Department DRLs

• **Tube Voltage < 120 kV: Required mAs?**
  • Any size patient: Less voltage, same dose
  • Set size dependent mAs at 120 kV
  • Note displayed CTDI_{vol120}
  • Reduce voltage to desired value on scanner
  • Increase mAs until CTDI_{vol} = CTDI_{vol120}
  • Increased Contrast at ~ same dose

<table>
<thead>
<tr>
<th>kVp</th>
<th>mA</th>
<th>Time (sec)</th>
<th>Pitch During Measured CTDIvol</th>
<th>Pitch During Clinical Exam</th>
<th>Adult SSDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>60</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>80</td>
<td>80</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

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Establish Department DRLs

- Voltage < 120 kV: Required mAs?
  - 10 yr patient: **Less voltage, same image quality**
  - Set size dependent mAs at 120 kV
  - Note displayed CTDI<sub>vol120</sub>
  - Measure increased contrast at kV<sub>ref</sub> compared to 120 kV.
  - Place 'roi' over 1 cm disk & background region

<table>
<thead>
<tr>
<th>KVP</th>
<th>mA</th>
<th>Time [sec]</th>
<th>DQE During Measured CTDIvol</th>
<th>DQE During Clinical Exam</th>
<th>Adult SSDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>50</td>
<td>30</td>
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<td>120</td>
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<tr>
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<td>50</td>
<td>30</td>
<td>120</td>
<td>120</td>
<td>50</td>
</tr>
</tbody>
</table>

Establish Department DRLs

- Voltage < 120 kV: Required mAs?
  - 10 yr patient: **Less voltage, same image quality**
    - Noise increase: CTDI<sub>vol120</sub> vs CTDI<sub>vol80</sub>
    - Assume contrast up 20% / Noise up 40%
  - **Increase mAs** at 80 kV until Noise increases only 20%
  - CNR<sub>120kV</sub> = CNR<sub>80kV</sub>
  - **Same image quality; Reduced patient dose**

Establish Department DRLs

Previous analysis: Reduced mAs @ 120 kV

- Voltage < 120 kV: Required mAs?
  - 120 vs 100, 90, 80, & 70 kV
  - Affect on:
    - Contrast
    - Noise
    - Artifacts
    - Scanning speed: **Motion Unsharpness**
When reducing the high voltage of the CT scanner in an effort to improve image quality and reduce the radiation dose to pediatric patients, one can ignore the effect on:

1. Contrast.
2. Noise.
3. Sharpness.
4. Artifacts.
5. Scanning speed

When reducing the high voltage of the CT scanner in an effort to improve image quality and reduce the radiation dose to pediatric patients, for each type of clinical examination one can ignore the effect on:

1. Contrast.
2. Noise.
3. Sharpness.
4. Artifacts.
5. Scanning Speed


Scan Progression

• Complete projection Scan
• Setup voltage and mAs as previously determined to achieve department DRLs or
• Calculate SSDE
• Compare calculated SSDE to reference SSDE
• Adjust mAs or kV as necessary
Conclusions

Due to variations in:
• Patient size,
• Type of CT examinations, and
• Design of actual CT scanners,

Patient’s CT dose should be appropriately
• Estimated and
• Managed during the examination, regardless of patient size!