ESTABLISHING DRLs in PEDIATRIC CT

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INTRODUCTION

• CT Dose Indices
  • CTDI
  • CTDI$_{100}$, CTDI$_{w}$, CTDI$_{vol}$
  • Displayed vs Measured CTDI$_{vol}$
  • DLP
  • E Dose and its limitations

• SSDE

• Applications of SSDE in the Clinic
Clinical Application

• 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.
CTDI = Integral under the radiation dose profile along the z-axis from a single axial scan of width nT.

Adapted from Frey
Computed Tomography Dose Index (CTDI)

- Represents the average integrated absorbed dose along the z axis from a series of contiguous irradiations.
- $\text{CTDI}_{100}$ represents accumulated multiple scan dose at center of 100 mm scan.
Calculation of CTDI Values

- **Weighted CTDI:** $\text{CTDI}_w$
  - Average CTDI across the FoV
  - $\text{CTDI}_w = \frac{1}{3} \text{CTDI}_{100,\text{center}} + \frac{2}{3} \text{CTDI}_{100,\text{edge}}$
  - $\text{CTDI}_w = 17 + 66 = 83 \text{ mGy}$
    for 32 cm CTDI phantom

- **Ave Dose over x & y direction**
Calculation of CTDI Values

- **Volume CTDI:** $\text{CTDI}_{\text{vol}}$
- $\text{CTDI}_{\text{vol}} = \frac{\text{CTDI}_w}{\text{pitch}}$

- Addresses dose when table motion occurs
CT SCANNER DOSE INDICES

Measurement of CT Radiation Dose

• Plastic cylindrical phantoms: CTDI Phantoms
  • (PMMA)
  • 16 & 32 cm diameter

• Pencil chamber moved into provided holes to measure radiation dose
  • Center of phantom

• Non measured holes plugged

Adapted from TG204
CURRENT ADULT PATIENT MODEL

B. \(\text{CTDI}_{100}\) measured with 100 mm pencil chamber in two standard phantoms

1. Sample 100 mm along the z-axis of patient
CT SCANNER DOSE INDICES

Measured $\text{CTDI}_{\text{vol}}$

- Measure $\text{CTDI}_{\text{vol}}$ with identical scan parameters
  - kVp
  - mA
  - Rotation time
  - Bow Tie Filter

- Use phantom 10, 16, and 32 cm diameter
Measured \(\text{CTD}I_{\text{vol}} = 47\)

Measured \(\text{CTD}I_{\text{vol}} = 37\)

Measured \(\text{CTD}I_{\text{vol}} = 18\)

10 cm Diameter

16 cm Diameter

32 cm Diameter

\textbf{Measured }\text{CTD}I_{\text{vol}} \text{ increases } 2.6 \text{ times as phantom size decreases!}
Displayed CTDI\textsubscript{vol}

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

\textbf{does not represent} . . .

\textbf{Patient dose!!}
**Measured**

CTDI$_{vol}$ = 47

47 mGy

38 mGy

**Measured**

CTDI$_{vol}$ = 37

35 mGy

21.6 mGy

**Measured**

CTDI$_{vol}$ = 18

10.8 mGy

**Displayed**

CTDI$_{vol16}$ = 37

CTDI$_{vol32}$ = 18

**Displayed**

CTDI$_{vol16}$ = 37

CTDI$_{vol32}$ = 18

**Displayed**

CTDI$_{vol16}$ = 37

CTDI$_{vol32}$ = 18
DISPLAYED CTDI SHORTCOMING

Same radiographic technique
Displayed CTDI$_\text{vol}$ based on 32 cm CTDI Phantom

18 mGy for both patients!
CLINICAL DILEMMA

- Displayed $\text{CTDI}_{\text{vol}}$ 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 Reports and CT scanner dose reports.
CLINICAL DILEMMA

• CTDI Phantoms are not clinical models
CLINICAL DILEMMA

- Anthropomorphic Phantoms only approximate the human body
<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
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<tbody>
<tr>
<td>20%</td>
<td>1. Is measured with a point, small volume ionization chamber.</td>
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<td>20%</td>
<td>2. Represents the radiation dose to the patient.</td>
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<td>20%</td>
<td>4. Can be determined with a single measurement.</td>
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1. CTDI\textsubscript{vol}:

1. Is measured with a point, small volume ionization chamber.
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3. Estimates and compares the radiation output of two different CT scanners to the same phantom.
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5. Is measured with a pencil ionization chamber with a length of 90 mm

CT SCANNER DOSE INDICES

Displayed Dose Length Product (DLP)

- DLP (mGycm) = $\text{CTDI}_{\text{vol}} \times \text{Scan Length}$
- Scan length is the length of phantom irradiated.
- ‘Represents’ energy transferred.
- DLP is **not** a patient dose index because $\text{CTDI}_{\text{vol}}$ does not represent patient dose.
Effective Dose (E)

- Whole body uniform radiation dose that reflects the same risk to the patient as the larger radiation dose delivered to a fraction of the patient’s body during a CT scan.

\[ E \text{ (mSv)} = k \times \text{DLP} \]

Units of \( k \): mSv / mGy-cm

- \( k \) values depend on:
  - Patient size
  - Body region
  - CTDI phantom assumed by vendor (16 or 32)
Effective Dose Limitations

• ‘SSDELP’ = SSDE * Scan Length
• Better estimate of energy transferred.

Caution:

• SSDE can NOT be substituted in place of $CTD_{vol}$ when using k-factors to estimate Effective Doses from CT exam.
Effective Dose Limitations

• Can Effective Dose be used to estimate:
  • An individual patient’s radiation dose?
  • Organ doses?

• ABSOLUTELY NOT, despite the fact that one can find numerous published papers that make this error!!
Effective Dose Limitations

- Effective Dose was originally defined to address radiation protection concerns of occupationally exposed workers.

- Effective dose can be used to facilitate a comparison of biological effects between diagnostic exams of different types.
Effective Dose Limitations

Effective Dose Recommended Reading

• ICRP 103 Executive Summary
• CJ Martin, “Effective dose: How should it be applied to medical exposures?”, BJR 2007
• “Rational approach to the clinical use of effective dose estimates”, AJR 2011.

Effective Dose:

1. Compares biological effects between diagnostic exams of different types.
2. Accuracy is improved when SSDE is multiplied times the appropriate k-factor instead of CTDI_{vol}.
3. Can be used to estimate an individual patient’s radiation dose.
4. Can be used to estimate organ doses.
5. Is defined to address radiation protection concerns of medically exposed patients.
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AAPM Report No. 204

Size Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, in collaboration with the International Commission on Radiological Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging.
Clinical Applications of SSDE

So what is SSDE?:

- Estimates the peak soft tissue dose of the patient at the center of the scan length.
- Adjusts for patient size and varying attenuation from overlying tissue thickness.
- Uses average scan radiation output: $\text{CTDI}_{\text{vol}}$
- Useful first approximation of organ dose?

Adapted from McCollough
Data from four independent investigators studying patient size correction factors.

- Physical measurements on phantoms
  
  A. Anthropomorphic Phantoms (McCollough Laboratory “Mc”)
  
  B. Cylindrical PMMA phantoms (Toth / Strauss Collaboration “T-S”)

- Monte Carlo computer modeling
  
  C. Monte Carlo Voxelized Phantoms (McNitt-Gray Laboratory “MG”)
  
  D. Monte Carlo Mathematical Cylinders (Boone Laboratory “Z-B”)

Adapted from TG 204
Patient trunk dose > CTDI$_{vol}$ by 2.5 x for smallest patients

$y = 3.7044e^{-0.0367x}$

$R^2 = 0.9429$
Patient head dose $\geq$ CTDI$_{vol}$ for smallest patients by only 20%

$y = 1.8748e^{-0.0387x}$

$R^2 = 0.9673$
TG 204
What about scans performed at 80, 100, or 140 kV?

1. 5% difference overall
2. 3% difference between 1 yr old (15 cm) & adult (32 cm)

Combined TS / ZB: 80-140 kV from 120 kV only
What is an effective diameter?

- Circle with area of patient’s cross section
- Effective diameter can be estimated if the patient’s AP or lateral dimension is known.
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.
What if I am doing retrospective dose analysis and I only know age of patient?

- Corrections based on patient size are more accurate.
TG 204

Determining patient size

• Measure Lateral dimension with mechanical calipers.

• Measure Lateral or AP dimension from AP or Lateral projection scan.
  • **Magnification Error**

• Measure AP or LAT dimension from axial scan view.
SSDE Calculations

• Failure to identify correct CTDI phantom, 16 or 32 cm: systematic error of up to 100%.
• No standard exists: depends on:
  • Selected protocol: adult or pediatric
  • Selected scan field of view
  • Year of manufacture
  • Software rev
• Make no assumptions: contact manufacturer
SSDE Accuracy

• 20%

• Product is an *estimate* of patient dose

• Significant digits?
  
  • SSDE $\geq 5$ mGy: integers only, 7 or 23 mGy

  • SSDE $< 5$ mGy: one decimal point, 2.7 or 4.5 mGy
SAMPLE CALCULATION: POST SCAN

- Determine size of patient
  - AP = 9.9 cm; LAT = 12.3 cm
  - AP + LAT = 22.2 cm
- 32 cm CTDI phantom assumed
- Displayed CTDI$_{vol}$ = 5.4 mGy
- 5.4 mGy x 2.5 = 13 mGy SSDE

Adapted from TG 204
SAMPLE CALCULATION: POST SCAN

- Determine size of patient
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Adapted from TG 204
SSDE:

1. Calculation has an estimated error of 10%.
2. Accounts for both the radiation output of the scanner and patient size.
3. Cannot be estimated until after the CT examination is completed.
4. Is more accurate if patient size is estimated based on the patient’s age.
5. Should not be used for CT examinations of the thorax.
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Clinical Application

• 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 CTDI_{vol} data
    • Head
    • Body
    • Associated technique factors which created measured CTDI_{vol}
Establish Department DRLs

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

• Adult Patient for Scanner #1
• Scale the mAs value if necessary to adjust $\text{CTDI}_{\text{vol}}$ 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
    - $\text{CTDI}_{\text{vol}}$ 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\textsubscript{vol}
  - **Scanner #2** (28 x 38 cm adult abdomen):
    - 120 kV, 250 mAs, pitch = 1, 13 mGy CTDI\textsubscript{vol}
    - 120 kV, **385 mAs**, pitch = 1, **20 mGy** CTDI\textsubscript{vol}
    - 120 kV, 250 mAs, pitch = 0.65, 20 mGy CTDI\textsubscript{vol}
  - 23 mGy SSDE for both scanners
Establish Department DRLs

- **Select Pediatric Patient DRL (without iterative reconstruction)**

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<tr>
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<th>Pitch During Clinical Exam</th>
<th>Adult SSDE</th>
<th>Scanner #1: Limited NB = Adult SSDE Estimated mAs</th>
<th>23 mGy Moderate NB = 0.75 * Adult SSDE Estimated mAs</th>
<th>Aggressive NB = 0.5 * Adult SSDE Estimated mAs</th>
<th>Adult SSDE</th>
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<tbody>
<tr>
<td>AP Thickness (cm)</td>
<td>LAT Thickness (cm)</td>
<td>Effective Diameter (cm)</td>
<td>Mass (kg)</td>
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Establish Department DRLs

- AP & LAT thicknesses are average values from study of 360 random patients
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 = (AP Thk * 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 = $2.4 \times \text{adult dose}$
   - 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

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Establish Department DRLs

• Select **Pediatric** Patient DRL (without iterative reconstruction)

D. **Aggressive** pediatric techniques

• Newborn SSDE = 0.5 * adult SSDE

• Results of QuIRCC published research

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• 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 CTDI\textsubscript{vol} dose data from late 2009; prior to iterative reconstruction reductions

- **Image quality was evaluated**

- \(\frac{\text{SSDE}}{\text{SSDE}_{\text{adult}}} = 0.14 + 0.025 \times \text{LAT size}\)

\[= 0.14 + 0.025 \times 14 = 0.49\]


- **NB dose is half of adult dose in Aggressive model**
Establish Department DRLs

- **Pediatric Patient DRL (without iterative reconstruction) SSDE**

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<td>11.8</td>
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<td>0.52</td>
<td>0.39</td>
<td>0.25</td>
<td>23</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>16</td>
<td>13.3</td>
<td>10</td>
<td>1 yr</td>
<td>0.55</td>
<td>0.42</td>
<td>0.29</td>
<td>23</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>20</td>
<td>16.7</td>
<td>18</td>
<td>5 yr</td>
<td>0.62</td>
<td>0.50</td>
<td>0.39</td>
<td>23</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>25</td>
<td>20.0</td>
<td>33</td>
<td>10 yr</td>
<td>0.70</td>
<td>0.62</td>
<td>0.53</td>
<td>23</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>19</td>
<td>29</td>
<td>23.5</td>
<td>54</td>
<td>15 yr</td>
<td>0.80</td>
<td>0.74</td>
<td>0.68</td>
<td>23</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>22</td>
<td>32</td>
<td>26.5</td>
<td>65</td>
<td>20 yr</td>
<td>0.89</td>
<td>0.86</td>
<td>0.83</td>
<td>23</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>25</td>
<td>35</td>
<td>29.6</td>
<td>75</td>
<td>md adult</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>31</td>
<td>41</td>
<td>35.7</td>
<td>110</td>
<td>lg adult</td>
<td>1.25</td>
<td>1.31</td>
<td>1.43</td>
<td>23</td>
<td>25</td>
<td>27</td>
</tr>
</tbody>
</table>
Establish Department DRLs

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

| Age       | mA  | Time (sec) | Pitch During Measured CTDIvol | Pitch During Clinical Exam | Adult SSDE | Limited mAs Reduction Factor | Moderate mAs Reduction Factor | Aggressive mAs Reduction Factor | Limited mAs SSDE (mGy) | Moderate mAs SSDE (mGy) | Aggressive mAs SSDE (mGy) | Scanner #1: Limited NB = Adult SSDE Estimated mAs | Scanner #2: 23 mGy Limited NB = 0.75 * Adult SSDE Estimated mAs | Scanner #2: 23 mGy Moderate NB = 0.5 * Adult SSDE Estimated mAs |
|-----------|-----|------------|-------------------------------|-----------------------------|------------|------------------------------|-------------------------------|-----------------------------|-------------------------|-------------------------|--------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| newborn   | 200 | 1          | 1.0                          | 1.0                         | 23         | 23                           | 17                           | 11                         | 23                      | 200                     | 230                      | 104                             | 110                             | 23                             | 104                             | 110                             | 23                             | 104                             | 110                             |
| 1 yr      |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| 5 yr      |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| 10 yr     |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| 15 yr     |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| 20 yr     |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| md adult  |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |
| lg adult  |     | 1.0        |                               |                             |            |                              |                               |                             |                         |                         |                         | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             | 201                             | 212                             | 204                             |

Note: mAs values are estimated for different age groups, considering limited, moderate, and aggressive mAs reduction factors and different scanning conditions.
Reduction of mAs for abdominal CT for a newborn patient:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Rule Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>1. Newborn (NB) dose = adult dose (AD) if adult mAs is unchanged.</td>
</tr>
<tr>
<td>20%</td>
<td>2. NB dose = half of AD if adult mAs cut in half.</td>
</tr>
<tr>
<td>20%</td>
<td>3. NB dose = AD if adult mAs divided by 3.</td>
</tr>
<tr>
<td>20%</td>
<td>4. NB dose = half of AD if adult mAs divided by 4.</td>
</tr>
<tr>
<td></td>
<td>5. NB dose = half of AD does not provide clinically useful images.</td>
</tr>
</tbody>
</table>
Reduction of mAs for abdominal CT 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.

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\textsubscript{vol}
    - 20 mGy $\times$ 1.14 = 23 mGy SSDE
    - 120 kV, **160 mAs**, pitch = 1, 16 mGy CTDI\textsubscript{vol}
    - 16 mGy $\times$ 1.14 = 18 mGy SSDE
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.

<table>
<thead>
<tr>
<th>Age</th>
<th>Limited mAs Reduction Factor</th>
<th>Moderate mAs Reduction Factor</th>
<th>Aggressive mAs Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>newborn</td>
<td>0.52</td>
<td>0.39</td>
<td>0.25</td>
</tr>
<tr>
<td>1 yr</td>
<td>0.55</td>
<td>0.42</td>
<td>0.29</td>
</tr>
<tr>
<td>5 yr</td>
<td>0.62</td>
<td>0.50</td>
<td>0.39</td>
</tr>
<tr>
<td>10 yr</td>
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</tr>
<tr>
<td>20 yr</td>
<td>0.89</td>
<td>0.86</td>
<td>0.83</td>
</tr>
<tr>
<td>md adult</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>lg adult</td>
<td>1.25</td>
<td>1.31</td>
<td>1.43</td>
</tr>
</tbody>
</table>
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
### Managing Pediatric Head CT Doses:

| 20% | 1. Calculate SSDE to estimate patient dose. |
| 20% | 2. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 35 mGy CTDI$_{vol}$. |
| 20% | 3. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 75 mGy CTDI$_{vol}$. |
| 20% | 4. 35 mGy CTDI$_{vol}$ is recommended by Image Gently for 1 yr old patient head. |
| 20% | 5. 35 mGy CTDI$_{vol}$ is recommended by ACR for a newborn head. |
Managing Pediatric Head CT Doses:

1. Calculate SSDE to estimate patient dose.

2. Cut adult head mAs in half, for 1 yr old technique to deliver ~ 35 mGy CTDI$_{vol}$.

3. Cut the adult head mAs in half, for 1 yr old technique to deliver ~ 75 mGy CTDI$_{vol}$.

4. 35 mGy CTDI$_{vol}$ is recommended by Image Gently for 1 yr old patient head.

5. 35 mGy CTDI$_{vol}$ 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.
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
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 $\text{CTDI}_{\text{vol120}}$
  - Reduce voltage to desired value on scanner
  - Increase mAs until $\text{CTDI}_{\text{vol}} = \text{CTDI}_{\text{vol120}}$
  - **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>fill in</td>
<td>fill in</td>
<td>fill in</td>
<td>fill in</td>
<td>fill in</td>
<td>fill in</td>
</tr>
</tbody>
</table>
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_{vol120}
  - Measure increased contrast at kV_{ref} compared to 120 kV.
    - Place ‘roi’ over 1 cm disk & background region
Establish Department DRLs

- **Voltage < 120 kV**: Required mAs?
  - 10 yr patient: Less voltage, same image quality
    - Noise increase: \( \text{CTDI}_{\text{vol120}} \) vs \( \text{CTDI}_{\text{vol80}} \)
    - Assume contrast up 20% / Noise up 40%

- **Increase mAs** at 80 kV until Noise increases only 20%

- \( \text{CNR}_{120kV} = \text{CNR}_{80kV} \)

- **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 to improve image quality and reduce radiation dose for pediatric patients, one can ignore the effect on:

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When reducing the high voltage to improve image quality and reduce radiation dose for pediatric patients, one can ignore the effect on:

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

Ref: Yu L, Bruesewitz MR, Thomas KB, Fletcher JG, Kofler JM, McCollough CH. Radiographics 2011 May-Jun;31(3):835-48, p 835
Automatic Mode

• Adjust provided parameters to result in desired SSDE based on voltage choice
  • Image quality index is not constant for all sized patients
    • Radiologists demand greater CNR in images of smaller patients
  • GE: Noise Index
    • Maintain constant noise in all images
    • Doubling Noise index quarters dose and doubles noise in images
Automatic Mode

• Adjust provided parameters to result in desired SSDE based on voltage choice

• **Image quality index typically** is not constant for all sized patients

• **Toshiba:** Standard Deviation
  • Doubling Std Dev quarters dose and doubles noise in images

• **Siemens:** Quality Reference Effective mAs for ~ 80 kg standard patient

• **Philips:** Automatic Current Setting (ACS)
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!