Automated CT Protocol Design
Advantages and Pitfalls of Algorithm-Based Technique Selection in Pediatrics

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Disclosures

Learning Objectives

1. Justification and Basics of Automatic Exposure Control (AEC)
2. Review of Two Commercial Products
3. Building Pediatric Protocols with AEC
4. The Boston Children’s Hospital Experience
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1. Justification and Basics

Dose Adaption to Patient:

Size
Anatomy
Shape

If all patients were perfect cylinders, this would be easy!
1. Justification and Basics

Learning Objectives

1. Justification and Basics of Automatic Tube Current Modulation (AEC)
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Learning Objectives

2. Review of Two Commercial Products
   a) GE Auto mA
   b) Siemens CareDose 4D and Care kV
2a. GE Auto mA

- Noise Index: Image Noise (SD) in uniform water phantom with same attenuation ($D_w$) as patient*
2a. GE Auto mA

• Noise Index: Image Noise (SD) in uniform water phantom with same attenuation ($D_w$) as patient*

* NOT reference patient

2a. GE Auto mA

Noise Index = 5

SD = 5 HU
CTDI = 3 mGy

Noise Index = 5

SD = 5 HU
CTDI = 12 mGy

2a. GE Auto mA

• Noise Tolerance is size dependent!
2a. GE Auto mA:

- GE FeatherLight Protocols

<table>
<thead>
<tr>
<th>Weight Range (lbs)</th>
<th>Minimum mA</th>
<th>Maximum mA</th>
<th>Maximum mA</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-89 lbs or 27-40 kg</td>
<td>5</td>
<td>65</td>
<td>130</td>
<td>150</td>
</tr>
<tr>
<td>100-109 lbs or 45-50 kg</td>
<td>7</td>
<td>85</td>
<td>160</td>
<td>180</td>
</tr>
<tr>
<td>110-120 lbs or 51-54 kg</td>
<td>10</td>
<td>115</td>
<td>200</td>
<td>215</td>
</tr>
<tr>
<td>&gt;120 lbs or &gt;54 kg</td>
<td>12</td>
<td>135</td>
<td>220</td>
<td>230</td>
</tr>
</tbody>
</table>


Learning Objectives

2. Review of Two Commercial Products
   a) GE Auto mA
   b) Siemens CareDose 4D

2b. Siemens CareDose 4D:
Define desired noise level for standard adult patient (70 – 80 kg, DW ~ 33 cm)

Dose Saving Optimizer: Selects level of subject contrast in order to optimize kVp according to image quality metric

2b. Siemens CareDose 4D:

Semi Mode:

*Set kVp, Effective mAs optimized based on Dose Optimizer*

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2b. Siemens CareDose 4D:

CareDose “Strength”:

*Determines mA-Modulation Strength for large and small patients*
What is our target (e.g. SSDE or Noise Eff)

\[ mAs = \text{QRM} \cdot \exp\left(25 - \text{D}_{\text{Ref}}\right) \]
2b. Siemens CareDose 4D:
• Image Quality Metrics defined for REFERENCE PATIENT

• i.e. We are dependent on CareDose 4D algorithm to optimize IQ/Dose for all patient sizes

• Still need size based protocols if we want to customize IQ/Dose curve

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3a. Building Pediatric Protocols with GE Auto mA
3a. Building Pediatric Protocols with GE Auto mA

3. Building Pediatric Protocols

3. Building Pediatric Protocols with AEC
What is our target (e.g. SSDE or Noise Tolerance)?


\[ N_b = 11.5 \]

\[ N_b = N_a \left( \frac{SSDE_a}{SSDE_b} \right)^{0.5} = 11.5 \left( \frac{9}{12} \right)^{0.5} = 9.95 \]
• GE Auto mA: Straight-forward to customize Dose Curve with size based protocols by modifying Noise Index

• kVp is fixed based on patient size and tube mA limits
Learning Objectives

3. Building Pediatric Protocols with AEC
   a) GE Auto mA
   b) Siemens CareDose 4D

3b. Building Pediatric Protocols with Siemens CareDose 4D

Table 1

<table>
<thead>
<tr>
<th>3D Group</th>
<th>No. of scanner</th>
<th>Mean</th>
<th>Standard Dev</th>
<th>Lower 25th Percentile</th>
<th>Median</th>
<th>Upper 25th Percentile</th>
<th>Upper 75th Percentile</th>
<th>SSDE/CTDI Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;17.5cm</td>
<td>21</td>
<td>8.6</td>
<td>3.9</td>
<td>5.7</td>
<td>12.0</td>
<td>15.9</td>
<td>20.4</td>
<td>0.92</td>
</tr>
<tr>
<td>17.5-30cm</td>
<td>35</td>
<td>30.5</td>
<td>11.4</td>
<td>15.7</td>
<td>47</td>
<td>63</td>
<td>86</td>
<td>0.94</td>
</tr>
<tr>
<td>30.1-45cm</td>
<td>30</td>
<td>35.1</td>
<td>10.3</td>
<td>20.4</td>
<td>54</td>
<td>71</td>
<td>94</td>
<td>0.90</td>
</tr>
</tbody>
</table>

What is our target (e.g. SSDE or Noise)
What is our target (e.g. SSDE or Noise...
3c. Modeling CareDose 4D

The effect of following parameters on SSDE and CNR were modeled:

1. Patient Size
2. CareDose Strength
3. Quality Reference mAs
4. Dose Saving Optimizer Position
5. Semi Mode
3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.
3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.

- Effect of Dose Optimizer is a fixed ratio across all patient size when same kV is used
e.g. \( S7/S3 = 1.22 \)

- Effect of QRM is fixed across all patient sizes
e.g. \( 200/150 = 1.33 \)
3c. Modeling CareDose 4D

- CD4D Strength affects kVp selection.
  - Effect of Dose Optimizer is a fixed ratio across all patient size when same kV is used e.g. S7/S3 = 1.22
  - Effect of QRM is fixed across all patient sizes e.g. 200/150 = 1.33
  - Semi Mode has no effect on curve shape
3a. Based on Diagnostic Reference Ranges

<table>
<thead>
<tr>
<th>Age (weeks)</th>
<th>AP (cm)</th>
<th>LAT (cm)</th>
<th>Dv (cm)</th>
<th>VIP</th>
<th>Child Strength</th>
<th>Dose Optimizer</th>
<th>QRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>8.9</td>
<td>13.4</td>
<td>9.6</td>
<td>80</td>
<td>Weak</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>13.3</td>
<td>15.8</td>
<td>13.5</td>
<td>80</td>
<td>Weak</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>15.8</td>
<td>20.4</td>
<td>17.9</td>
<td>100</td>
<td>Weak</td>
<td>7</td>
<td>175</td>
</tr>
<tr>
<td>5</td>
<td>18.5</td>
<td>23.8</td>
<td>20.9</td>
<td>100</td>
<td>Weak</td>
<td>7</td>
<td>175</td>
</tr>
<tr>
<td>10</td>
<td>21.3</td>
<td>27.3</td>
<td>23.5</td>
<td>120</td>
<td>Weak</td>
<td>7</td>
<td>175</td>
</tr>
<tr>
<td>15</td>
<td>24.7</td>
<td>30.9</td>
<td>28.2</td>
<td>150</td>
<td>Weak</td>
<td>7</td>
<td>185</td>
</tr>
</tbody>
</table>
Learning Objectives

1. Justification and Basics of Automatic Tube Current Modulation (ATCM)
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4. The BCH Experience

- Size based AEC Techniques operated with Fixed kV (Semi Mode with CD4D)
- Patient Size measured on PA localizer
- Size-Based Protocol Selected
- Three Image Quality “Classes”
4. The BCH Experience


21.7 cm

Abdomen/Pelvis: Measure at Iliac Crest

Chest: Measure at Xyphoid Tip

21.7 cm
4. The BCH Experience

Dose Class determined by QRM or Noise Index

e.g. DC₁ = 100%, DC₂ = 75%, DC₃ = 50%
QRM/QRM₄₅₆ = 1, 0.75, 0.5
NI/NI₄₅₆ = 1, 1.15, 1.4

To achieve an acceptable level of image noise across all patient sizes using GE auto mA and constant image thickness, Noise Index (NI) should:

1. Increase with increasing patient size
2. Decrease with increasing patient size
3. Remain fixed for increasing patient size
4. Be disabled and a fixed mA used
5. Be disabled and a fixed kV used

Noise Index (NI) should increase with patient size:

NI = 5, SD = 5 HU

NI = 8, SD = 8 HU
The following is the most reliable metric to estimate patient attenuation and selection of a size-based CT protocol:

1. Patient Weight (kg) 23%
2. Patient Age (years) 13%
3. Body Mass Index (BMI) 23%
4. Patient Girth (Calipers or e-Calipers) 23%
5. Technologist best guess 17%

4. Patient Girth Measured with Calipers or e-Calipers

3c. Advantages of AEC protocols

- Adapts to changing anatomy (Lung/Pelvis)
- Adapts to patient geometry (AP/LAT)
- CareDose 4D: Less Risk of Error adapting to patient size (-10% to +15%)
3c. Disadvantages of AEC protocols

- Takes extensive testing to optimize protocols
- Without phantoms, process is iterative and time consuming
- Dependent on localizer position
3c. Disadvantages of AEC protocols (2)

- Diminishing returns on very small patients
- Still need size based protocols

Thank You!