Translating Protocols Across Patient Size: Babies to Bariatric

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Disclosures

Research Support:

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     DK 083007
     DK 059933
     EB 004898
     RR 018898

Siemens Healthcare

Off Label Usage
None
Since no CT image looked “over-exposed,” the community lost the sense of needing to adjust the mAs or kVp for patient size, as was inherent to film/screen imaging.
January 22, 2001

• “CT scans in children linked to cancer”
  – USA Today News

• "Each year, about 1.6 million children in the USA get CT scans to the head and abdomen--and about 1,500 of those will die later in life of radiation-induced cancer, according to research out today."
January 22, 2001

• “CT scans in children linked to cancer”
  – USA Today News

• "Each year, about 1.6 million children in the USA get CT scans to the head and abdomen--and about 1,500 of those MAY die later in life of radiation-induced cancer, according to research out today."
February 2001 Issue of AJR

- Brenner DJ, et al. *Estimated Risks of Radiation-Induced Fatal Cancer from Pediatric CT*
While the benefits of computed tomography are well known ... those benefits are not without risks.

... emphasize the importance of keeping radiation doses ... as low as reasonably achievable, especially for pediatric and small adult patients, who may sometimes receive more radiation than needed to obtain diagnostic images.

... stress the importance of adjusting CT scanner parameters appropriately for each individual’s weight and size, and for the anatomic region being scanned.
Dose management is about getting the right dose for the specific patient and the specific diagnostic task.

For large patients, this can indeed mean a dose* increase.

*Doubling the mAs on an obese patient to achieve the same image noise as standard patient results in only an approximately 30% increase in effective dose due to the extra layers of fat tissue “shielding” many of the sensitive internal organs.
“Right-sizing” the dose

mAs works - IF all else constant
Technique charts

- Adapt the scan parameters to
  - specific patient
  - specific diagnostic task
- Reduce dose for pediatric and small patients
- Improve image quality for large patients
- Ensure consistency across practice
  - dose and image quality
What mA is required to match image noise as patient thickness varies?
What mA is required to image a newborn?
What mA is required to image obese patients?
Exponential relationship between patient thickness, mAs, and measured photons

\[ N_o = N \cdot \exp\left(0.693 \cdot \frac{t}{HVL}\right) \]

To achieve same image noise (N)
Estimating Patient Attenuation

- Lateral width (skin to skin) at the level of the liver
  - from the A/P CT radiograph
- For patients with very large upper chest or hips
  - use measurement from the level of the liver
  - If in doubt, go up up a size
- Reconstruction (display) FOV chosen as usual
  - may be different from the width used to determine mAs.
## Generalized Technique Chart (fixed slice width)

<table>
<thead>
<tr>
<th>Lateral patient (cm)</th>
<th>Width (relative to standard Adult)</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.1 - 26</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>26.1 - 30</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>30.1 - 35</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>35.1 - 40</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>40.1 - 45</td>
<td></td>
<td>1.4*</td>
</tr>
<tr>
<td>45.1 - 50</td>
<td></td>
<td>2.0*</td>
</tr>
</tbody>
</table>
## Abdomen & Pelvis technique for Adults (> 22 cm)

<table>
<thead>
<tr>
<th>Lateral patient width (cm)</th>
<th>mAs (relative to standard Adult protocol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.1 - 26</td>
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<td>45.1 - 50</td>
<td>2.0*</td>
</tr>
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</table>

* If desired mAs is unavailable, options are:
  - increase exposure time (per rotation)
  - increase kVp
  - decrease pitch
  - increase slice thickness

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Guiding principles

- All decisions made in the direction of conservative dose reduction
  - wanted no non-diagnostic exams
  - can iteratively reduce further as staff gain comfort
- Involve pediatric and adult radiologists and lead techs
- ER, inpatient and outpatient scans
- Get leadership buy-in
- Provide mandatory education with roll out
- Aim for consistency, staff must use chart
## Example

<table>
<thead>
<tr>
<th>Abd/Pelvis Technique Chart (pediatric and adult)</th>
<th>Lightspeed (QX/i and Plus)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary slice thickness (mm)</strong></td>
<td><strong>Mode</strong></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>3.75</td>
<td>HQ</td>
</tr>
<tr>
<td>3.75</td>
<td>HQ</td>
</tr>
<tr>
<td>3.75</td>
<td>HQ</td>
</tr>
<tr>
<td>5</td>
<td>HQ</td>
</tr>
<tr>
<td>5</td>
<td>HQ</td>
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</tr>
</tbody>
</table>

* mA limit reached - use the 0.8 sec option unless otherwise indicated.

Last modified 12/09/01
### Example

<table>
<thead>
<tr>
<th>Primary slice thickness (mm)</th>
<th>Mode (pitch)</th>
<th>Table speed (mm/rot)</th>
<th>Retro recon thickness available (mm)</th>
<th>Lateral patient width (cm)</th>
<th>mA (at 0.8s)</th>
<th>kVp (at 0.8s)</th>
<th>mA (at 0.5s)</th>
<th>kVp (at 0.5s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.75</td>
<td>HQ</td>
<td>7.5</td>
<td>2.5 5.0</td>
<td>up to 14</td>
<td>50</td>
<td>120</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>3.75</td>
<td>HQ</td>
<td>7.5</td>
<td>2.5 5.0</td>
<td>14.1 - 18</td>
<td>70</td>
<td>120</td>
<td>110</td>
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AEC: Automatic Exposure Control

- Radiographic – phototiming
- Fluroscopy - automatic brightness control
X-ray attenuation

- Varies over **body region** and with **projection angle**
- Image noise is primarily determined by noisiest projections (thick body parts)
- More photons (dose) to thinner body parts is unnecessary radiation dose
Three Levels of AEC

- For a single cross section, automatically adjust the mA along different directions
  - (x-y modulation)
- For a single patient, automatically adjust the mA for different body parts
  - (z modulation)
- For different patients, automatically adjust the mA based upon the patient size
  - “Right sizing” dose for each patient
Technology Assessment Initiative: Summit on CT Dose

**Z modulation**

**Angular modulation**

Without modulation

**mAs per rotation**

Without modulation

Thorax

Liver

Shoulder
Example: 6 year old child

Scanned with adult protocol
(but using AEC dose reduction strategy)

Reference eff. mAs = 165

Mean eff. mAs = 38

mA variation
Routine Abd/Pelvis (5 mm)
Reference eff. mAs = 240
61 y.o. female
30 cm lateral width -> 120
88 eff. mAs

122 eff. mAs
Routine Chest/Abdomen/Pelvis (5 mm)
Reference eff. mAs = 240
71 y.o. male
43 cm lateral width -> 340

Sensation 16
Ex: CT2003112507145
Topogram 1.0 T20s
Se: 1/2
Im: 1/4
Cor: 1.0
512 x 512
T20s
Mag: 1.0x

120.0 kV
35.0 mA
Routine Abdomen/Pelvis (5 mm)
Reference eff. mAs = 240

51 y.o. male
48 cm lateral width -> 350 @ 140 kVp
What to do when you see this (or similar)

Scan Controller

Peak exposure demand exceeds system limit. Locally increased image noise may result.

You may
- increase the kV
- increase the Rotation time
- decrease Pitch
Don’t proceed until you try ...

- Decrease the pitch (gives same effective mAs will less mA, may be within limits)
  - Increases scan time, which may invoke other tube loading limits, so make sure CTDI doesn’t start to drop
- Use wider collimation
  - Decreases scan time again
  - Limits thinnest slices that you can reconstruct
- Increase kV
  - Decreases iodine contrast
  - MUST change threshold for bolus tracking trigger
  - Must set a new target mA value (e.g. quality reference mAs)
Don’t proceed until you try ...

- Increase rotation time
  - Increases scan time
  - Can affect contrast media timing
- AND-
- Be sure to make sure timing and slice width trade offs are acceptable for the exam type (e.g. angiography)
- Wider image width and smoother reconstruction kernels may be needed
- Use extended FOV option if available
  (minimizes truncation artifacts – streaks and white regions at edge of FOV)
191 eff. mAs

351 eff. mAs

340 eff. mAs
Effective mAs decreases relative to our technique charts

- Exam average 21.0%
- Upper lung 29.7%
- Breast 54.8%
- Liver 13.2%
- Pelvis 23.2%
Eff. mAs decreases relative to a single eff. mAs value (i.e. no technique charts)

- Average of all patients: 18.5%
- Slim patients: 44.9%
- Large patients: 3.1%
Percent eff. mAs reduction relative to our technique charts
Automated exposure control

- Analogous to photo-timing
- User determines IQ (noise) requirements (hard)
  - don’t need “pretty” pictures for all diagnostic tasks
  - need to choose low noise, standard, or low dose dependent on the diagnostic task
- System determines the right mAs (easy)
- Will adjust mA
  - during rotation (x,y)
  - along z-direction
  - x, y and z
IQ (noise) Selection Paradigms

• **GE: Noise Index**
  - Referenced to std. deviation of pixel values in a water phantom
  - mA per rotation calculated based on Scout
  - Tries to maintain constant noise over all images

• **Philips: Reference Image**
  - Automatic Current Setting (ACS)
  - Save an acceptable patient exam (including SurView)
  - Raw data and noise saved, used as later reference

• **Siemens: Quality Reference Effective mAs**
  - Enter the effective mAs site uses in standard (approx. 80 kg) patient
  - Noise target varied on basis of patient size (empirical algorithm)
  - Topogram used to predict mA curve, on-line feedback fine tunes it

• **Toshiba: Std. Deviation**
  - Referenced to std. deviation of pixel values in an attenuation-equivalent water phantom, which is created from Scanogram

• **All allow reference value to be stored with protocols**
Thorax phantoms
Lateral dimension of 30, 35, and 40 cm
Empirically, matched noise is:

- Not well-accepted clinically
- Not achievable over range of patient sizes
  - Presented constant noise images to radiologists
  - Pediatric to obese patients
  - Pediatric images were found unacceptable, even though they contained the same level of image noise
Equal noise is not acceptable because ...

- Children don’t have the fat planes between tissues and organs that adults do (fat planes enhance contrast and tissue differentiation)
- Details of interest are smaller in children, so greater CNR required
- Radiologists are accustomed to “reading through the noise” on large patients
- Radiologists require higher image quality in children to ensure high diagnostic confidence
Clinical Impact

- AEC systems that prescribe a fixed noise level systematically
  - increase dose more than clinically required for **obese patients** (potentially causing tube heating problems or longer scan times)
  - increase noise more than is clinically acceptable for **pediatric patients** (potentially yielding non-diagnostic exams)
**Recommendations**

- Use of a noise target technique chart
- Use of min and max mA values to prevent excessive decrease or increase of tube current
### Noise Index Technique Chart for body CT exams

<table>
<thead>
<tr>
<th>Lateral Patient Width (cm)</th>
<th>Noise Index (at 0.5 s)</th>
<th>Minimum mA</th>
<th>Maximum mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.1 – 30</td>
<td>9</td>
<td>150</td>
<td>280</td>
</tr>
<tr>
<td>30.1 – 40</td>
<td>11.5</td>
<td>220</td>
<td>500</td>
</tr>
<tr>
<td>40.1 – 45</td>
<td>14.5</td>
<td>400</td>
<td>720</td>
</tr>
<tr>
<td>45.1 – 50+</td>
<td>17 (0.7 s)</td>
<td>450</td>
<td>770</td>
</tr>
</tbody>
</table>
Beyond right-sizing the scanner output

• Children generally benefit from
  – High pitch (short scans)
  – Shortest rotation times (stop motion)
  – Lower tube potentials (increases contrast/decreases dose)
  – Thin detector collimations (need higher resolution)

• Obese patients generally benefit from
  – Low pitch (allows adequate dose)
  – Longer rotation times (allows higher mAs)
  – Higher tube potentials (to penetrate thicker body parts)
  – Thicker detector collimations (avoid electronic noise/artifacts)
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Non-uniform “wavy” streaks due to detector-level averaging of very low signal levels ("adaptive filtering")
Dual Source CT
Pitch 3.2
0.28 sec rotation time
75 ms resolution

Single Source CT
Pitch 0.9
0.28 sec rotation time
280 ms resolution
Case Example:

Male child scanned at 15 and 24 months
No sedation, no breath hold

Dual-source CT at pitch 3.4, 2009

Courtesy of Friedrich-Alexander University Erlangen-Nuremberg and IMP / Erlangen, Germany
Thank you

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http://mayoresearch.mayo.edu/CTCIC