Managing the Pediatric Patient’s CT Dose: the Role of SSDE

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INTRODUCTION
A. Image Gently Campaign
B. Pediatric CT Public Health Concerns
C. Affect of Patient Size on Dose Indices
D. Shortcomings of Dose Indices for CT
E. Clinical Dilemma
F. Interim Solution: AAPM TG204
G. Applications of SSDE
H. Managing Pediatric CT Patient Doses

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MISSION STATEMENT

Alliance for Radiation Safety in Pediatric Imaging is a coalition of health care organizations creating an education, awareness and advocacy campaign dedicated to providing safe, high quality pediatric imaging worldwide.

- 70 health care organizations/agencies
- 800,000 radiologists,
  radiology technologists,
  medical physicists
  worldwide

Adapted from Goske

Methods

Positive message
...resulting dose to population will lead to higher
cancer rates, accounting for as many as 2% of all cancers in the U.S.

Enroll key organizations
Increase awareness
  educate
  advocate
  change practice

Adapted from Goske

Founding Organizations

The Society for Pediatric Radiology

American Society of Radiologic Technologists

American Association of Physicists in Medicine

American College of Radiology

Alliance
For Radiation Safety in Pediatric Imaging

Adapted from Goske
Critical Triad
To act together for radiation protection for children

Image Gently
A. The ultimate goal of the Alliance is to accelerate the change of local practice.
1. Problem?
2. Scientific observation to local practice change ~ 17 years!¹

¹Greenberg SB. Trans Clin Climatol Assoc 119:245-261, 2008

Does Practice Need to Change?
How much do we really understand?

<table>
<thead>
<tr>
<th>Respondent Group</th>
<th>CT &lt; 10 × CR</th>
<th>CT &gt; 10 × CR</th>
<th>CT &gt; 100 × CR</th>
<th>CT &gt; 1000 × CR</th>
<th>CT &gt; 5000 × CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n = 47)</td>
<td>43 (64)</td>
<td>4 (7)</td>
<td>8 (13)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>ED Physicians (n = 45)</td>
<td>19 (42)</td>
<td>26 (58)</td>
<td>19 (42)</td>
<td>2 (4)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Radiologists (n = 59)</td>
<td>2 (5)</td>
<td>22 (37)</td>
<td>4 (13)</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
</tbody>
</table>

Note—Data are the number of respondents. Numbers in parentheses are percentages. χ² test: CR = chest radiograph.
* Accurate range.

Under estimation by 75% of MDs!
Lee et al. Radiology. 2004; 231:393-398
Does Practice Need to Change?  
How much do we really understand?

Which of the following provides a reasonable estimate of a child’s CT dose?

A. CTDI\text{vol} (mGy)  
B. DLP (mGy-cm)  
C. Effective Dose (mSv)  
D. Values in DICOM Structured Report  
E. None of the above!

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Preliminary estimate of changes in Medical radiation exposure to US population

US 1980\textsuperscript{*}  
Medical: 0.54 mSv per capita  
Total: 3.6 mSv per capita

US 2006  
Medical: 3.2 mSv per capita  
Total: 6.2 mSv per capita

\textsuperscript{*} NCRP 93  
Adapted from Mahesh
Procedures vs Effective Dose contributions

17% of All Exams Deliver 81% of Total Effective dose

PEDIATRIC CONSIDERATIONS

A. Radiation Induced Cancer Lifetime Risk From 1 Sv Dose
   1. Average
      a. 5% Males
      b. 6% Females
   2. First Decade
      13 - 15%
   3. Middle Age
      2 - 3 %
   4. Children 3 – 5 times more sensitive

Adapted from Hall

AFFECT of PATIENT SIZE on DISPLAYED CTDI\textsubscript{VOL} & DLP

1 HVL @ 120 kVp ~ 70 keV
AFFECT of PATIENT SIZE on DISPLAYED CTDI\textsubscript{VOL} & DLP

Real World ....

Radiation distribution crosses the imaged volume

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

Adapted from Frey
CT SCANNER DOSE INDICES

B. Measurement of CT Radiation Dose

1. Plastic cylindrical phantoms: CTDI Phantoms
   a. (PMMA)
   b. 16 & 32 cm diameter

2. Pencil chamber moved into provided holes to measure radiation dose
   a. 1 cm under surface
   b. Center of phantom
   c. Non measured holes plugged

C. Measure CTDI_{vol}

1. Measure CTDI_{vol} with identical scan parameters
   a. kVp
   b. mA
   c. Rotation time
   d. Bow Tie Filter

2. Use phantom 10, 16, and 32 cm diameter
CT SCANNER DOSE INDICES

D. Displayed CTDI$_{vol}$
1. Dose that represents distribution of dose given to cross-sectional area of a slab of the CTDI phantom (16 or 32 cm diameter)
2. Reflects changes in:
   a. High voltage to x-ray tube (kVp)
   b. X-ray tube current (mA)
   c. Rotation time (sec)
   d. Bow tie filter shape, thickness, material
   e. Pitch
   f. Source to detector distance

CT SCANNER DOSE INDICES

D. Displayed CTDI$_{vol}$
3. Standardized method to estimate and compare the radiation output of two different CT scanners to same phantom.
CT SCANNER DOSE INDICES

E. Displayed Dose Length Product (DLP)

1. DLP (mGycm) = $CTD_{vol} \times$ Scan Length
   a. Scan length is the length of phantom irradiated.
   b. ‘Represents’ energy transferred.

2. DLP is not a patient dose index because $CTD_{vol}$ does not represent patient dose.

So how do we represent the greater biologic risk?

Adapted from Frey

DLP = 200 mGy cm

So, DLP represents the greater biologic risk!
CT SCANNER DOSE INDICES

E. Displayed Dose Length Product (DLP)

1. Previous example: radiation doses equal.

2. Second patient at greater risk because a larger length of body was scanned.

3. While DLP is the dose to a standard phantom, increases in DLP indicate increases in risk to patient.

<table>
<thead>
<tr>
<th>Measured CTDI_{vol} = 47</th>
<th>Measured CTDI_{vol} = 37</th>
<th>Measured CTDI_{vol} = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>47 mGy</td>
<td>38 mGy</td>
<td>21.6 mGy</td>
</tr>
<tr>
<td>Displayed CTDI_{vol16} = 18</td>
<td>Displayed CTDI_{vol16} = 18</td>
<td>Displayed CTDI_{vol32} = 18</td>
</tr>
<tr>
<td>35 mGy</td>
<td>35 mGy</td>
<td>10.8 mGy</td>
</tr>
</tbody>
</table>

CLINICAL DILEMMA

A. Displayed CTDI_{vol} is independent of the patient size; displayed CTDI_{vol} assumes either 16 or 32 cm CTDI phantom.

B. 16 cm CTDI phantom: adult dose over while pediatric dose under estimated.

C. 32 cm CTDI phantom: adult and pediatric dose under estimated ~ 2.5 times!

D. Propagated by DICOM Structured Reports and CT scanner dose reports.
CT SCANNER DOSE INDICES

D. Displayed CTDI_{vol}

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

4. Dose index of CT scanners if the fan beam width in z direction of the patient is small (< 1 cm)
   a. AAPM TG111 addresses these shortcomings
   b. Beyond scope of this presentation.

CT SCANNER DOSE INDICES

D. Displayed CTDI_{vol}

5. does not represent . . .

Patient dose!!

PEDIATRIC CONSIDERATIONS

CLINICAL EDUCATIONAL MATERIALS

1. CTDI_{vol} for Adults
   a. < 25 mGy Body (CTDI_{32})
   b. < 75 mGy Head (CTDI_{16})
   c. < 20 mGy Pediatric Body (CTDI_{16})
### PEDIATRIC CONSIDERATIONS

**CLINICAL EDUCATIONAL MATERIALS**

#### IMAGE GENTLY BODY

<table>
<thead>
<tr>
<th>Patient Age</th>
<th>mAs Reduction Factor (RF)</th>
<th>Estimated mAs = BL x RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 newborn</td>
<td>0.43</td>
<td>0.42</td>
</tr>
<tr>
<td>12 1 yr</td>
<td>0.51</td>
<td>0.49</td>
</tr>
<tr>
<td>14 5 yr</td>
<td>0.59</td>
<td>0.57</td>
</tr>
<tr>
<td>16 10 yr</td>
<td>0.66</td>
<td>0.64</td>
</tr>
<tr>
<td>19 15 yr</td>
<td>0.76</td>
<td>0.73</td>
</tr>
<tr>
<td>22 small adult</td>
<td>0.90</td>
<td>0.82</td>
</tr>
<tr>
<td>25 med adult</td>
<td>1.0</td>
<td>fill in</td>
</tr>
<tr>
<td>31 large adult</td>
<td>1.27</td>
<td>1.16</td>
</tr>
</tbody>
</table>

---

**PEDIATRIC CONSIDERATIONS**

**CLINICAL EDUCATIONAL MATERIALS**

1. CTDI\textsubscript{vol} for Adults
   - a. < 25 mGy Body (CTDI\textsubscript{32})
   - b. < 75 mGy Head (CTDI\textsubscript{16})
   - c. < 20 mGy Pediatric Body (CTDI\textsubscript{16})

2. Pediatric Patient Dose < Adult Dose
   - a. Up to 2.6 times greater if do nothing

3. Conservatively high

4. Developed for adult department that images children occasionally

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**Image Gently Vendor Summit**

August 20, 2008

CTDI\textsubscript{vol} is not an indication of patient dose

Pediatric Radiologists and Technologists have been asking for a reasonable estimate of CT radiation dose in children for over 10 years.

You need to provide better training on pediatric applications of your images!
TG 204

E. Report does not:

1. Address correction factors for heads
2. Correct small (< 1%) doses from scanned projection images
3. Correct for variation (~ 5%) in attenuation of thorax vs abdomen
4. Correct small variation in pre and post contrast scans

TG 204

E. Report does not address:

5. Changes in dose as a function of fan beam
   a. 20 cm: relative dose ~ 2
   b. 30 cm: relative dose ~ 2.3
   c. Dose Profiles vs Fan Beam Width

Adapted from J. Boone
F. Data from four independent investigators studying patient size correction factors.

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

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

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**TG 204**

**32 cm 120 kVp**

![Graph](image1.png)

Adapted from TG 204

\[ y = 3.7446e^{0.0885x} \]

\[ R^2 = 0.9423 \]

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**TG 204**

**16 cm 120 kVp**

![Graph](image2.png)

Adapted from TG 204

\[ y = 1.8706e^{0.0893x} \]

\[ R^2 = 0.9673 \]
TG 204

G. What about scans performed at 80, 100, or 140 kVp?

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

Combined TS / ZB: 80-140 kV

adapted from TG 204

TG 204

H. What about scans performed in the thorax?

1. Thorax data from Huda et al.
2. 16% dif @ 12 cm
3. 7% dif @ 17 cm
4. < 3% dif > 17 cm

adapted from Boone

TG 204

I. What is an effective diameter?

1. Circle with area of patient’s cross section
2. Effective diameter can be estimated if the patient’s AP or lateral dimension is known.
J. Fitted equations calculate the effective diameter from either AP or LAT dimension of patient based on published data of actual patient sizes.

AGE vs PATENT SIZE

A. Same age patients vary dramatically in size. Abdomens of:
   1. Largest 3 year olds and
   2. Smallest adults are the same size.

Patient cross section size, not age, should be used.

K. What if I am doing retrospective dose analysis and I only know age of patient?
   1. Corrections based on patient size are more accurate.
L. Determining patient size

1. Measure Lateral dimension with mechanical calipers.
2. Measure Lateral or AP dimension from AP or Lateral projection scan.
3. Measure AP or LAT dimension from axial scan view.
4. In #2 & #3 patient must be centered in gantry.
   a. Magnification Error

M. Determining size of CTDI phantom your CT scanner used to estimate CTDIvol

1. Failure to identify correct phantom, 16 or 32 cm leads to a systematic error of 100%.
2. No standard exists. Choice may depend on:
   a. Selected protocol: adult or pediatric
   b. Selected scan field of view
   c. Year of manufacture
   d. Software level
3. Make no assumptions: contact manufacturer of your unit through its service organization.

O. Correction Factor based on 32 cm CTDI Phantom

Adapted from TG 204
TG 204

Q. SSDE Accuracy

1. 20%
2. Product is an estimate of patient dose
3. Report dose estimates with proper number of significant digits
   a. SSDE > 5 mGy: integers only, e.g. 7 or 23 mGy
   b. SSDE < 5 mGy: one decimal point, e.g. 2.7 or 4.5 mGy

SAMPLE CALCULATION: PRESCAN

A. Determine size of patient
   1. AP Projection Scan: 16.8 cm

B. 16 cm CTDI phantom used by scanner to calculate CTDI<sub>vol</sub>

C. Displayed CTDI<sub>vol</sub> = 9.29 mGy

D. 9.29 mGy x 1.08 = 10 mGy SSDE

SAMPLE CALCULATION: POST SCAN

A. Determine size of patient
   1. AP = 9.9 cm; LAT = 12.3 cm
   2. AP + LAT = 22.2 cm

B. 32 cm CTDI phantom assumed

C. Displayed CTDI<sub>vol</sub> = 5.4 mGy

D. 5.4 mGy x 2.5 = 13 mGy SSDE
SAMPLE CALCULATION: POST SCAN

A. Determine size of patient
   1. $AP = 9.9$ cm; $LAT = 12.3$ cm
   2. $AP + LAT = 22.2$ cm

B. 16 cm CTDI phantom assumed

C. Displayed CTDI$_{vol}$ = 10.8 mGy

D. 10.8 mGy $\times$ 1.24 = 13 mGy

SSDE

R. Dose Reporting by Radiologists

The CTDI$_{vol}$ value reported on the scanner for the [32 or 16] PMMA phantom was used with correction factors obtained from AAPM Report 204. The correction factor for this patient was based on the patient's [AP, LAT, AP + LAT, or effective dimension] This method is thought to produce dose estimates with accuracy to within 20%. For this patient, the size corrected (SSDE) estimate for this CT scan is _____ mGy.

T. Caution:

SSDE can NOT be substituted in place of CTDI$_{vol}$ when using k-factors to estimate Effective Doses from CT exam
F. Can Effective Dose be used to estimate:
1. An individual patient's radiation dose?
2. Organ doses?

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

G. Effective Dose is NOT:
1. A patient dose
2. To be used for an individual
3. Defined for children
4. For estimating cancer risk; it assesses more than just cancer risk.

H. Effective Dose Recommended Reading
1. ICRP 103 Executive Summary
CLINICAL CHALLENGE

A. Child imaged on GE CT on Tuesday followed by second examination on Wednesday on Siemens CT in same department.
   1. GE: Displayed CTDI\textsubscript{vol(16)} = 10.8 mGy
   2. Siemens: Displayed CTDI\textsubscript{vol(32)} = 5.4 mGy

B. Mom & Dad were not happy campers!

C. SSDE = 13 mGy for both studies!

Clinical Applications of SSDE

D. SSDE
   1. Is useful as a first approximation of some organ doses
      a. Soft tissues only
      b. Organ completely in scan volume in z direction.

   1. Is useful as a first approximation of some organ doses
      c. Radial dose profiles
      d. Range dependent on patient diameter
      e. Single estimated average (83)
Clinical Applications of SSDE

D. SSDE

1. Is useful as a first approximation of some organ doses
   f. Increased error for small organs

Adapted from McCullough

Clinical Applications of SSDE

I. Ideally, unique scan parameters should be established for each individual patient accounting for:
   1. Patient size
   2. Type of CT examination
   3. Design of actual CT scanner

J. This can be done in academic centers with diligent effort.

Clinical Applications of SSDE

K. What are the odds this will happen for the occasional pediatric CT scan completed at a good community hospital?
   SLIM & NONE!
   Yet, majority of pediatric CT imaging in US DOES NOT occur in dedicated pediatric hospitals?
Clinical Applications of SSDE

L. What is a solution?
   1. Calculate SSDE after scan projection image of patient is complete.
      a. Measured patient width
      b. Size of CTDI phantom used by imager
      c. $\text{CTD}_\text{vol}$
   2. Compare calculated SSDE to reference SSDE
   3. Adjust scan parameters as necessary.

Managing Pediatric CT Patient Doses

M. Starting Reference Doses (SSDE) in an adult department might be:
   1. 10 cm (Newborn) $\sim$ adult SSDE
   2. 11 cm (1 yr old) $\sim$ adult SSDE
   3. 14 cm (5 yr old) $\sim$ adult SSDE
   4. 17 cm (15 yr old) $\sim$ adult SSDE
   5. 23 cm (Adult) $\sim$ adult SSDE

Managing Pediatric CT Patient Doses

M. Reference Doses (SSDE) in a pediatric department might be:
   1. 10 cm (Newborn) $\sim$ 0.6 x adult SSDE
   2. 11 cm (1 yr old) $\sim$ 0.7 x adult SSDE
   3. 14 cm (5 yr old) $\sim$ 0.8 x adult SSDE
   4. 17 cm (15 yr old) $\sim$ 0.9 x adult SSDE
   5. 23 cm (Adult) $\sim$ adult SSDE
## Managing Pediatric CT Patient Doses

### N. Should voltages < 120 kVp be used for Children?

1. Reduced high voltage; same dose
   - a. Set appropriate reduced mAs
   - b. Note displayed CTDI$_{vol}$\textsubscript{120}
   - c. Reduce kVp
   - d. mAs up until CTDI$_{vol}$\textsubscript{80} = CTDI$_{vol}$\textsubscript{120}
   - e. Increased Contrast at ~ same dose

### Managing Pediatric CT Patient Doses

2. Reduced high voltage; reduced dose
   - a. Dial up reduced mAs technique
   - b. Note displayed CTDI$_{vol}$\textsubscript{120}
   - c. Measure increased contrast at 80 kVp compared to 120 kVp.
     - i. ACR accreditation phantom or
     - ii. CTDI phantom with Iodine Pin(s)
   - ii. Clinical FoV / Bow tie Filter
   - d. Estimate increase in noise by comparing CTDI$_{vol}$\textsubscript{120} & CTDI$_{vol}$\textsubscript{80}
   - e. Contrast Up 40% / Noise Up 60%
   - f. Increase mAs at 80 kVp until Noise increases only 40%
   - g. CNR$_{80 \text{ kVp}}$ = CNR$_{120 \text{ kVp}}$
   - h. Same Image Quality; Reduced Dose
Conclusions

A. Due to variations in:
   1. Patient size,
   2. Type of CT examinations, and
   3. Design of actual CT scanners,
   Patient’s CT dose should be appropriately
   1. Estimated,
   2. Managed during the examination, and
   3. Recorded,
   regardless of patient size!
   SSDE can help with all three tasks!

Conclusions

B. Adult hospitals performing 80% of all pediatric CT Examinations should manage their pediatric radiation doses.
   1. Use adult protocols and calculate adult SSDE.
   2. SSDE of pediatric patient prior to scan <
      a. SSDE for adult patient.
      b. Established reference SSDE by Dept.
   3. Changing kVp is more involved, but addresses:
      a. Image quality improvement and/or
      b. Dose reduction.