Managing Pediatric CT Patient Doses

Keith J. Strauss, MSc, FAAPM, FACR
President
X-Ray Computations, Inc.
Boston, Massachusetts

Acknowledgements
Marilyn Goske, MD
John Boone, PhD
Cynthia McCollough, PhD
Michael McNitt-Grey, PhD
Dianna Cody, PhD
Tom Toth, PhD
Mahesh Mahadevappa, PhD
G. Donald Frey, PhD

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

MISSION STATEMENT
Alliance for Radiation Safety in Pediatric Imaging is a coalition of health care organizations dedicated to providing safe, high quality pediatric imaging worldwide.

The primary objective is to raise awareness in the imaging community of the need to adjust radiation dose when imaging children.

Adapted from Goske
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!


---

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

<table>
<thead>
<tr>
<th>Respondent Group</th>
<th>CT &lt; CR</th>
<th>CT &gt; CR</th>
<th>CT &gt; 10 × CR</th>
<th>CT &gt; 100 × CR</th>
<th>CT &gt; 1000 × CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n = 67)</td>
<td>19 (28)</td>
<td>43 (64)</td>
<td>5 (7)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>ED Physicians (n = 41)</td>
<td>3 (7)</td>
<td>20 (48)</td>
<td>10 (24)</td>
<td>10 (24)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Radiologists (n = 39)</td>
<td>2 (5)</td>
<td>22 (56)</td>
<td>6 (15)</td>
<td>5 (13)</td>
<td>4 (10)</td>
</tr>
</tbody>
</table>

Note.—Data are the number of respondents. Numbers in parentheses are percents. * χ² test; p < .001. CR = chest radiograph.

* Accurate range.

---

**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<sub>vol </sub>(mGy)
B. DLP (mGy-cm)
C. Effective Dose (mSv)
D. Values in DICOM Structured Report
E. None of the above!

---

**Under estimation by 75% of MDs!**

Lee et al. Radiology. 2004; 231:393-398
Founding Organizations

The Society for Pediatric Radiology
American Society of Radiologic Technologists
American Association of Physicists in Medicine
American College of Radiology

Adapted from Goske

Critical Triad
To act together for radiation protection for children

Adapted from Goske

What Is Image Gently
An education, awareness and advocacy campaign
To improve radiation protection for children worldwide

Alliance for Radiation Safety in Pediatric Imaging
- 58 health care organizations/agencies
- 800,000 radiologists,
  radiology technologists,
  medical physicists
  worldwide

Adapted from Goske

Objectives
Decrease radiation dose in children
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
Use internal communication of each member organization

Campaigns in
CT
CR / DR
Interventional Radiology
Flouroscopy
Nuclear medicine

Adapted from Goske

PEDIATRIC CONSIDERATIONS
CLINICAL EDUCATIONAL MATERIALS

1. CTDI_{vol} for Adults
   a. < 25 mGy Body
   b. < 75 mGy Head
2. Pediatric Patient Dose < Adult Dose
3. Conservatively high
4. Developed for adult department that images children occasionally

Adapted from Goske
CTDI\text{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!

TRAINING
Training is only as effective as the trainer’s understanding of their trainees
Each trainee may have a bit different perspective
Pediatric needs are different

YOUR HOUSE as seen by...
Yourself
Preliminary estimate of changes in Medical radiation exposure to US population

* Adapted from Mahesh

GROWTH OF MEDICAL RADIATION DOSE

C. General Radiography

1. 85% of dose from exams of Abdomen Pelvis/Hips, or Spine
2. 280,000 person Sv
3. ~ 0.62 mSv

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number</th>
<th>%</th>
<th>Collective Person Sv</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis/Hips</td>
<td>20</td>
<td>5</td>
<td>45,700</td>
<td>24.8</td>
</tr>
<tr>
<td>Upper GI</td>
<td>4</td>
<td>1</td>
<td>38,000</td>
<td>20.7</td>
</tr>
<tr>
<td>Spine</td>
<td>17</td>
<td>4</td>
<td>57,000</td>
<td>31.0</td>
</tr>
<tr>
<td>Abdomen</td>
<td>15</td>
<td>4</td>
<td>16,000</td>
<td>8.7</td>
</tr>
<tr>
<td>Head Face</td>
<td>2.4</td>
<td>0.6</td>
<td>2,300</td>
<td>1.2</td>
</tr>
<tr>
<td>Chest</td>
<td>126</td>
<td>31</td>
<td>6,500</td>
<td>3.5</td>
</tr>
<tr>
<td>WP</td>
<td>1.2</td>
<td>0.3</td>
<td>3,700</td>
<td>2.0</td>
</tr>
<tr>
<td>Barium enema</td>
<td>0.65</td>
<td>0.2</td>
<td>8,500</td>
<td>4.6</td>
</tr>
<tr>
<td>Extremities</td>
<td>56</td>
<td>14</td>
<td>1,900</td>
<td>1.0</td>
</tr>
<tr>
<td>Mammography</td>
<td>34</td>
<td>9</td>
<td>2,200</td>
<td>1.2</td>
</tr>
<tr>
<td>Dental</td>
<td>125</td>
<td>31</td>
<td>2,300</td>
<td>1.2</td>
</tr>
<tr>
<td>Total</td>
<td>~401</td>
<td></td>
<td>~184,000</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Mahesh

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
**Pediatric Considerations**

**Radiation Risk based on Effective Dose?**

<table>
<thead>
<tr>
<th></th>
<th>Somatic risk %/Sv</th>
<th>Hereditary risk %/Sv</th>
<th>Total risk %/Sv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children Aged 0-9</td>
<td>14.5</td>
<td>2.5</td>
<td>17</td>
</tr>
<tr>
<td>Children Aged 10-19</td>
<td>8.5</td>
<td>2.5</td>
<td>11</td>
</tr>
<tr>
<td>Whole population</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>


**PEDIATRIC CONSIDERATIONS**

**Real World ....**

Radiation distribution *crosses* the imaged volume

- Peak dose
- "Tails" of dose distribution

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

**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

Adapted from Frey

Adapted from TG204

Adapted from Frey
CT SCANNER DOSE INDICES

C. Measure CTDI\textsubscript{vol}

1. Measure CTDI\textsubscript{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

CTDI\textsubscript{vol} = \left[2 \times \text{surface dose} / 3 + \text{central dose} / 3\right] / \text{Pitch}

Measured CTDI\textsubscript{vol} = 47

Measured CTDI\textsubscript{vol} = 37

Measured CTDI\textsubscript{vol} = 18

Measured CTDI\textsubscript{vol} increases 2.6 times as phantom size decreases!
CT SCANNER DOSE INDICES

D. Displayed CTDI\textsubscript{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

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\textsubscript{vol}

5. does not represent . . .

   Patient dose!!

E. Displayed Dose Length Product (DLP)

1. DLP (mGycm) = CTDI\textsubscript{vol} * Scan Length
   a. Scan length is the length of phantom irradiated.
   b. 'Represents' energy transferred.

2. DLP is not a patient dose index because CTDI\textsubscript{vol} does not represent patient dose.
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.

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

A. Patients of a given age vary dramatically in size. Abdomens of the largest 3 year olds are approximately the same size as the abdomens of the smallest adults.

Size of patient, not age should be used,
AFFECT of PATIENT SIZE on DISPLAYED CTDI\textsubscript{VOL} & DLP

**Measured**
- \(\text{CTDI}_\text{vol} = 47\) mGy
- \(\text{CTDI}_\text{vol} = 37\) mGy
- \(\text{CTDI}_\text{vol} = 18\) mGy

**Displayed**
- \(\text{CTDI}_\text{vol16} = 37\) mGy
- \(\text{CTDI}_\text{vol16} = 37\) mGy
- \(\text{CTDI}_\text{vol32} = 18\) mGy

**CLINICAL DILEMMA**

A. Displayed CTDI\textsubscript{vol} is independent of the patient size; displayed CTDI\textsubscript{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 \(\sim 2.5\) times!
D. Propagated by DICOM Structured Reports and CT scanner dose reports.
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

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")
   C. Monte Carlo Voxelized Phantoms
   D. Monte Carlo Mathematical Cylinders (Boone Laboratory "Z-B")

2. Monte Carlo computer modeling

Adapted from TG 204
Adapted from J. Boone
TG 204

32 cm 120 kVp
Adapted from TG 204

16 cm 120 kVp
Adapted from 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 kVp
from 120 kVp only

H. What about scans performed in the thorax?

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

Adapted from Boone
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.

Effective Diameter as a function of age per ICRU 74

J. Fitted equations calculate the effective diameter from either AP or LAT dimension of patient based on published data of actual patient sizes.

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

Adapted from TG 204
M. Determining size of CTDI phantom your CT scanner used to estimate CTDI\_vol

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. Adapted from TG 204

P. Adapted from 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 $\geq 5$ mGy: integers only, e.g. 7 or 23 mGy
   b. SSDE $< 5$ mGy: one decimal point, e.g. 2.7 or 4.5 mGy
R. Dose Reporting by Radiologists

The CTDI<sub>vol</sub> 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.

SAMPLE CALCULATION: PRESCAN
A. Determine size of patient
   1. AP Projection Scan: 16.8 cm
   2. 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<sub>vol</sub> = 10.8 mGy
   D. 10.8 mGy x 1.24 = 13 mGy SSDE
**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!

**Applications of SSDE**

A. Understand difference between SSDE and CTDI\textsubscript{vol}
   1. SSDE may be useful as a first approximation of average organ dose to organs completely contained in scan volume.
   2. SSDE can NOT be substituted in place of CTDI\textsubscript{vol} when using k-factors to estimate Effective Doses from CT exam

B. Start calculating SSDEs
   1. More accurate estimates of patient dose than CTDI\textsubscript{vol}
   2. Recorded values of SSDE in patient medical record have more applications than CTDI\textsubscript{vol}
   3. DRLs could be based on SSDE values
   4. Recorded SSDE values will lead to department dose standards.

**Correction Factors for Heads**

D. 1. Will be published in the future
   2. Correction factor not as large
Applications of SSDE

B. Start calculating SSDEs
   5. SSDE values can be used as a tool to manage patient doses from CT.
   6. Work ongoing to get CT manufacturers to calculate and display SSDE values.

Managing Pediatric CT Patient Doses

A. CTDI_{vol} Measurements
   1. 32 cm adult body measurement
   2. 16 cm adult head measurement

B. Compare/adjust wrt ACR Reference Values
   Establish reasonable adult doses
   Are they high, moderate, or low?
   1. < 25 mGy
   2. < 75 mGy

C. Establish Appropriate Pediatric Dose Levels by reducing mAs appropriately
   1. Reduce mAs until pediatric SSDE < adult SSDE for department.
      a. 10 cm AP
      b. 1 / 2.5 = 40% original mAs
   2. IG website model of mAs reduction
      a. 10 cm AP dimension
      b. ~ 45% original mAs
Managing Pediatric CT Patient Doses

D. Dose reduction of IG website results in conservatively high doses

E. Doses in a pediatric department might be:

1. 10 cm (Newborn) ~ 0.6 x adult SSDE
2. 11 cm (1 yr old) ~ 0.7 x adult SSDE
3. 14 cm (5 yr old) ~ 0.8 x adult SSDE
4. 17 cm (15 yr old) ~ 0.9 x adult SSDE
5. 23 cm (Adult) adult SSDE

Managing Pediatric CT Patient Doses

F. Should voltages < 120 kVp be used for Children?

1. Reduced high voltage at same dose
   a. Dial up reduced mAs technique
   b. Note displayed CTDI\textsubscript{vol 120}
   c. Reduce kVp
   d. mAs up until CTDI\textsubscript{vol 80} = CTDI\textsubscript{vol 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\textsubscript{vol 120}
   c. Measure increased contrast at 80 kVp compared to 120 kVp.
      i. ACR accreditation phantom
      ii. Clinical FoV / Bow tie Filter
Managing Pediatric CT Patient Doses

2. Reduced high voltage; reduced dose
   d. Estimate increase in noise by comparing CTDI_{vol 120} & CTDI_{vol 80}
   e. Contrast Up 40% / Noise Up 60%
   f. Increase mAs at 80 kVp until CNR_{80 kVp} = CNR_{120 kVp}
   g. Same image quality; reduced dose

Conclusions

A. Adult hospitals performing 80% of all pediatric patients should manage pediatric radiation doses.
   1. Use adult protocols and calculate adult SSDE.
   2. SSDE of pediatric patients prior to scan < SSDE for adult patient.
   3. Changing kVp in addition to mAs is more involved, but allows both image quality improvement and/or dose reduction.