Estimating Patient Dose

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Learning Objectives:

- Limitations for estimating patient dose for CT
- Methods for estimating patient dose for CT
- Potential future options?
What is reported?

- Volume CT Dose Index (CTDI_{vol}) and Dose Length Product (DLP)
- Both specific to cylindrical plastic phantom
- Both are metrics for CT scanner output

- NOT PATIENT DOSE METRICS

- McCollough et al. CT Dose Index and Patient Dose: They are *NOT* the same thing. Radiology 259:311-416, 2011.
NOT patient dose?

- Does not adjust for:
  - Patient SIZE
  - Organs partially irradiated
  - Presence of contrast enhancement
  - Tissue composition (instead of plastic)
  - Energy absorbed by patient (presence or absence of naturally occurring attenuator layer – FAT)
What do we mean by patient dose?

- Absorbed dose (energy) by individual subject
- What about effective dose? Is that dose to a patient?
- Maybe organ dose would be a better measure?
Convert to effective dose...

- k-factor approach (AAPM Report 96)
- ImPACT CT Dosimetry Tool
- CT-Expo
- Commercial dose database packages

- Research facilities (also organ dose)
  - UCLA [Michael McNitt-Gray]
  - University of Florida [Wes Bolch]
  - Rensselaer Polytechnic Institute [George Xu]
  - Duke [Ehsan Samei and Xiang Li]
  - Others...
Effective dose definition

\[ E(Sv) = \sum [w_T \times H_T(Sv)] \]

- \( w_T \) = tissue weighting factors
- \( H_T \) = organ dose

Applies to population, NOT individual
Effective dose?

- Specific to standard man size or geometric model
- May be automatically calculated by database
- But useful in what context?
  - Population studies
  - Overall practice patterns
  - Protocol quality assurance (outliers)
Effective dose?

- NOT suitable for individual patient histories
  - Only when patient size exactly matches modeling approach used to calculate effective dose
    - “Standard Man”
What would be most useful for our patients???

- ORGAN DOSE (relevant to size & scan details)
- Would help us understand risk to organ systems
- Would allow more useful cumulative analyses

- VERY complicated
- LOTS of values to track
- MUST be automated!!
So what can we do???

- AAPM Report 204
- Chair: John Boone, Ph.D., FAAPM, FSBI, FACR
- Size Specific Dose Estimates

AAPM Report No. 204

Size Specific Dose Estimates (SSDE) in Pediatric and Adult CT Examinations
16 cm 120 kVp

Conversion Factor

Effective Diameter (cm)
circle of equal area

lateral
effective diameter
ICRU 74
Strauss
Boone
Fit to All

- Effective Diameter (cm)
- AP+LAT Dimension (cm)

Equation: $y = 4.958912E-01 x - 2.031284E-01$

$R^2 = 9.995025E-01$
Real-Life Example

- Email from pediatric radiologist (July)


- Dose ranges for pediatric CT exams

- How does the dose delivered in this particular case (5 year old abdomen/pelvis CT) compare to published range???
<table>
<thead>
<tr>
<th>BW Group</th>
<th>No. of Scans</th>
<th>Mean</th>
<th>Standard Error</th>
<th>Lower DRR, 25th Percentile</th>
<th>Median, 50th Percentile</th>
<th>Upper DRR, 75th Percentile</th>
<th>SSDE/SSDE$_{adult}$ Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15 cm</td>
<td>21</td>
<td>8.6</td>
<td>0.9</td>
<td>5.8</td>
<td>8.0</td>
<td>12.0</td>
<td>0.52</td>
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<td>15–19 cm</td>
<td>153</td>
<td>10.0</td>
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<td>11.4</td>
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<td>16.5</td>
<td>0.4</td>
<td>13.1</td>
<td>15.6</td>
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### Table 3: Distribution of SSDE

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11.4 mGy average
7.6 to 13.4 mGy range
25\textsuperscript{th} - 75\textsuperscript{th} percentiles
<table>
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<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy·cm)</th>
<th>Phantom cm</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>14.500–1334.500</td>
<td>2.82</td>
<td>2.91</td>
<td>Head 16</td>
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<td>2</td>
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Total Exam DLP: 111.98
Report 204 – table for 16cm CTDI & Lateral dimension

SSDE = CTDI_{vol} \times x \text{ conversion factor}

SSDE = 2.82 \text{ mGy} \times 0.94

SSDE = 2.65 \text{ mGy}, or 2.7 \text{ mGy}
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11.4 mGy average
7.6 to 13.4 mGy range
25th - 75th percentile

Our case \( \text{SSDE} = 2.7 \text{ mGy} \) ...

CLEARLY LOW COMPARED TO THIS RANGE
Reaction?

- Rationale to slowly systematically increase technique on our pediatric exam protocols
- Currently planning to increase CTDI$_{vol}$ in 25% steps
Take home message?

- SSDE can be hugely helpful in real clinical cases
- Individual patients can have very unique aspects
- Be wary of one-size-fits-all approach
- Think big-picture with dose data base analysis
- Think customized medicine for individual patient analysis
What does new metric mean?

SSDE

- Size corrected CTDIvol
- DO NOT apply standard k-factors to this value
  - k-factors are based on standard man size
  - Will require some effort to sort out
- May be similar to average dose in cross-section
  - Organ dose???
In Vivo dose comparison to SSDE

- TLDs attached to enema tip
- Virtual Colonoscopy CT Exam (no TCM)
- N=10 patients
- IRB approved
TLD vs SSDE

w/in 10% for 8 of 10 cases
Future???

- CT Vendors –
  - Use information in localizer scan
    - Provide Water Equivalent Diameter (or surrogate)
  - With CTDI\textsubscript{vol}, provide \textit{SSDE} automatically
  - For exams using tube current modulation (TCM):
    - Mean SSDE
    - Min & Max SSDE?
    - May need a method for scaling SSDE for specific organ locations (organ dose)
SSDE to Organ Dose?

- CTDIvol for average mA over scan extent
- Adjust for mA in section of interest
- Adjust for patient size (SSDE)
- Result – organ dose estimate for tissues in that section

- Potential for automated calculation of organ dose values
But...

- Just because we can, should we?
- Which patients would this benefit?
- Younger patients with chronic conditions or stable disease
- Small proportion of our patients?

- By the time organ data bases are ready, scanners may deliver tiny exposures
- Worth the effort and expense? Not sure...
- Over-zealous application of technology?
Summary

- Current metrics **not intended** for individual patients
- SSDE provides method for scaling $\text{CTDI}_\text{vol}$ for patient size
- SSDE **may** represent average dose at measured cross section
- May be useful in building organ dose databases
- Must be automatic and robust for routine clinical use