Patient Dose Calculations: Computed Tomography

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Disclosures

• None

Objectives

1. Describe the limitations of displayed dose metrics for estimating patient dose
2. Review methods to estimate effective dose for a generic patient
3. Discuss how patient specific risk estimates may be performed
The patient:

- 58 yo female
- Weight 85 kg
- History of adrenal mass

Protocol:

What dose information do we have?

- Dose metrics displayed on the CT scanner:
  - CTDI<sub>VOL</sub> & DLP
    - Projected value displayed prior to scan
    - Average value displayed post scan
  - Based on:
    - Technique parameters
    - Planned scan range
    - Phantom size
Displayed CTDI_{VOL}

- Useful for comparing output across scanners, protocols, facilities
- E.g. Comparison of reported values from patient scans

Median CTDI_{VOL} - Routine Abdomen/Pelvis scans

Displayed CTDI_{VOL}

- Useful for benchmarking
- E.g. ACR Dose Index Registry

Displayed CTDI_{VOL}

- Limitations:
  - Length of 100 mm pencil chamber is not sufficient to capture all of the scatter produced
  - Based on average mA used with dose modulation
  - Air kerma, not dose to tissue
  - Typical patient scan length doesn’t correspond to the length of phantom
  - Diameter of the patient is often different than the diameter of the phantom

- Does not represent patient dose
Limitations of Displayed CTDI$_{vol}$

CTDI is a measure of scanner output (air kerma) as measured using one of two sized phantoms:

- Overestimates dose for patients larger than the phantom
- Underestimates dose for patients smaller than the phantom

$$\text{Displayed CTDI}_{vol} = 15 \text{ mGy}$$

$100 \text{ mAs}$

$100 \text{ mAs}$

**Calculation of SSDE**

Patient AP diameter = 292.2 mm
Patient lat diameter = 331.5 mm
Sum = 623.7 mm
Effective diameter = 311.2 mm
Calculation of SSDE

\[ SSDE = f_{\text{eff}} \times CDM_{\text{eq}} \]

Patient AP diameter = 292.2 mm
Patient lat diameter = 331.5 mm
Sum = 623.7 mm
Effective diameter = 311.2 mm

\[ SSDE = 1.19 \times 12.16 \text{ mGy} = 14.5 \text{ mGy} \]

A more robust estimate...

- Method for estimating patient size that accounts for attenuation properties of tissues.
- Intended for use by scanner manufacturer's and other software vendors

**Manual calculation:**
- Effective diameter = 31 cm
- SSDE = 14.5 mGy

**Dose Monitoring Software calculation:**
- Effective diameter = 32.2 cm
- Water equivalent diameter: 30.9 cm
- SSDE = 14.9 mGy
Estimating Patient Dose

- SSDE provides an estimate of patient absorbed dose
- Dose not provide information about the risk of the procedure or risk to the patient
- Determination of effective dose:

\[
\text{Effective Dose (mSv)} = \sum w_T H_T
\]

Effective Dose Estimates – Monte Carlo Simulations

Effective dose estimates – DLP Method

- Dose Length Product (mGycm)
- Multiply CTDI\text{vol} by the scan length
- Total energy imparted during the scan
- \( E \text{ (mSv)} = k \times \text{DLP} \)

<table>
<thead>
<tr>
<th>Region</th>
<th>0 yrs</th>
<th>1 yr</th>
<th>5 yr</th>
<th>10 yr</th>
<th>Adult</th>
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<tbody>
<tr>
<td>Head</td>
<td>0.011</td>
<td>0.007</td>
<td>0.004</td>
<td>0.002</td>
<td>0.002</td>
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<tr>
<td>Neck</td>
<td>0.017</td>
<td>0.012</td>
<td>0.013</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Chest</td>
<td>0.039</td>
<td>0.024</td>
<td>0.018</td>
<td>0.013</td>
<td>0.014</td>
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<tr>
<td>Abdominal</td>
<td>0.049</td>
<td>0.030</td>
<td>0.020</td>
<td>0.015</td>
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</tbody>
</table>

AAPM Report 96: Measurement, reporting, and management of dose in CT
Effective dose estimates – DLP Method

\[ E \text{ (mSv)} = k \times \text{DLP} \]

<table>
<thead>
<tr>
<th>Region</th>
<th>Adult</th>
<th>Child</th>
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<tbody>
<tr>
<td>Head</td>
<td>0.0021</td>
<td>0.0021</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0010</td>
<td>0.0010</td>
</tr>
<tr>
<td>Chest</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td>Abd/pelvis</td>
<td>0.015</td>
<td>0.015</td>
</tr>
</tbody>
</table>

\[ E = 0.015 \times 388 \text{ mGy/cm} = 5.82 \text{ mSv} \]

Limitations of the DLP Method

• DLP is calculated from CTDI\text{ VOL}
• k-factors were determined
• Derived using a pitch of 1 only
• k-factors were not based of ICRP 103 weighting factors
• Updated in 2011

\[ E = 0.015 \times 0.92 \times 388 \text{ mGy/cm} = 5.35 \text{ mSv} \]


Protocol:
Effective Dose Estimates

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<table>
<thead>
<tr>
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<th>Values</th>
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<tbody>
<tr>
<td>Process 1</td>
<td>Setting X</td>
<td>Value 1</td>
</tr>
<tr>
<td>Process 2</td>
<td>Setting Y</td>
<td>Value 2</td>
</tr>
<tr>
<td>Process 3</td>
<td>Setting Z</td>
<td>Value 3</td>
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<td>Value 3</td>
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Total Effective Dose – 18.2 mSv

Dose Calculations

Common requests / requirements for dose estimates:
• Equipment performance testing
• Regulatory / Accreditation reporting & standards
• Protocol optimization
• QA / Benchmarking
• IRB Risk Estimates
• Patient / physician request

Patient Risk

BEIR VII:

“This chapter presents models that allow one to estimate the lifetime risk of cancer resulting from any specified dose of ionizing radiation and applies these models to example exposure scenarios for the U.S. population.”
Patient Risk

• Lifetime attributable risk of cancer mortality from liver cancer

\[
\frac{0.032 \text{ Gy}}{0.1 \text{ Gy}} \times 31 = 9.92 \text{ per 100,00 exposed}
\]

\[
= 0.0000992 = \frac{1}{10,000}
\]

Compute for each organ and sum \[= \frac{1}{2,700}\]

Patient Risk

BEIR VII:

“Risk estimates are subject to several sources of uncertainty due to inherent limitations in epidemiologic data and in our understanding of exactly how radiation exposure increases the risk of cancer. In addition...”

Does not provide a patient specific risk estimate!
References

• AAPM Report 204, Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations, 2011.
• AAPM Report 220, Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT, September 2014.
• McCollough et al. CT dose index and patient dose: they are not the same thing. Radiology 2011;259(2):311-316.

References

• Brady, et al. How to appropriately calculate effective dose for CT using either size-specific dose estimates or dose-length product. AJR 2015;204:953-958.
• Health risks from exposure to low levels of ionizing radiation : BEIR VII, Phase 2 / Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects, Research Division on Earth and Life Studies, National Research Council of the National Academies, 2006.