CT Dose Measures

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Disclosure of Commercial Interest

I have a financial relationship with a commercial organization that may have a direct or indirect interest in the content as follows:

• Siemens Medical Solutions: consultant, speakers bureau
Objectives

• Review radiation dose measures
  – General measures
  – CT specific measures
• Describe doses in common CT studies
General Dosimetry Measures

- Absorbed dose
- Effective dose
Absorbed Dose

- Measure of the amount of energy absorbed by a material per unit kilogram of mass
- Unit is the gray (Gy)
- Does not take into account where the radiation dose is absorbed or the relative radiosensitivity of the tissue being irradiated
Effective Dose (ED)

- Effective dose takes into account where the radiation dose is being absorbed and radiosensitivity of the tissue irradiated.
- Estimates the equivalent whole-body dose from the absorbed dose.
- ED allows estimate of stochastic risks (cancer induction) (BIER report).
- Unit is the Sievert (Sv).
Effective Dose

• Effective dose (E) is given by the following

\[ E = \sum_T \left( w_T \times D_{T,R} \right) \]

where, \( w_T \) is the tissue weighting factor for tissue \( T \) and \( D_T \) is the absorbed dose of tissue \( T \)
## Tissue Weighting Factors

<table>
<thead>
<tr>
<th>Tissue or organ</th>
<th>Tissue weighting factor, $w_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.20</td>
</tr>
<tr>
<td>Red bone marrow</td>
<td>0.12</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.05</td>
</tr>
<tr>
<td>Breast</td>
<td>0.05</td>
</tr>
<tr>
<td>Liver</td>
<td>0.05</td>
</tr>
<tr>
<td>Oesophagus</td>
<td>0.05</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.05</td>
</tr>
<tr>
<td>Skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Bone surface</td>
<td>0.01</td>
</tr>
<tr>
<td>Remainder</td>
<td>0.05</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Review: General Dosimetry Measures

• Absorbed Dose – refers to the amount of energy deposited per unit mass—unit is the gray

• Effective Dose – is a measure of the risk posed by the radiation exposure—unit is the Sievert
CT specific radiation dose measures
CT Specific Dose Measurements

- CT dose index (CTDI)
  - $\text{CTDI}_\text{w}$
  - $\text{CTDI}_\text{vol}$
- Dose Length Product (DLP)
- $\text{CTDI}_\text{vol}$ and DLP are patient doses
- $\text{CTDI}_\text{w}$ measured in with a 100-mm-long ionization chamber placed in an acrylic phantom (reported by manufacturer)
Dose in Phantoms - $\text{CTDI}_w$

**Pencil-shaped ionization chamber**

Measures dose in axial plane

32 cm phantom for body work
CTDI\textsubscript{w}

\begin{itemize}
  \item \(\text{CTDI}_{w} = \frac{1}{3} \text{CTDI (center)} + \frac{2}{3} \text{CTDI (surface)}\)
\end{itemize}

Fig from impactscan.org
CTDI$_{vol}$ and DLP = Patient Doses

<table>
<thead>
<tr>
<th>Scan</th>
<th>KV</th>
<th>mAs</th>
<th>CTDI$_{vol}$</th>
<th>DLP</th>
<th>Ti</th>
<th>cSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topogram</td>
<td>1</td>
<td>120</td>
<td>7.25</td>
<td>251</td>
<td>5.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Chest Routine</td>
<td>2</td>
<td>120</td>
<td>93</td>
<td></td>
<td>0.42</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- THESE MEASURES ARE ON PATIENT INFORMATION SHEET
- These are available at scanner-easily accessible
CTD\textsubscript{vol} is a measure of amount of energy deposited per unit mass. Proportional to absorbed dose. Unit is the gray (Gy). This is the metric used by the ACR for CT practice accreditation.

Dose Length Product (DLP)

- DLP takes into account scan length
- It is the product of the CTDI$_\text{vol}$ x scan length (in centimeters)
- Unit is the mGy.cm
- DLP is used to obtain effective dose
Effective Dose

- Effective dose (E) in CT given by the following

\[ E = DLP \times k \]

where, \( k \) is the tissue weighting factor based on region of body scanned
Estimating Effective Dose: K values

- Effective dose = DLP x $k$ ( $k$ is weighting factor)
- Representative adult values for $k$ are:
  - Head/Neck 0.0031
  - Head 0.0021
  - Neck 0.0059
  - Chest 0.014
  - Abdomen 0.015
  - Trunk 0.015

2007 recommendations of the ICRP. Publication 103 Ann ICRP 2007; 37:1-332
Conversion ($k$) Factors for adults and children of various ages

<table>
<thead>
<tr>
<th>Conversion factor from DLP to Effective Dose in [mSv/(mGy·cm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region of the Body</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Head and neck</td>
</tr>
<tr>
<td>Head</td>
</tr>
<tr>
<td>Neck</td>
</tr>
<tr>
<td>Chest</td>
</tr>
<tr>
<td>Abdomen and pelvis</td>
</tr>
<tr>
<td>Trunk</td>
</tr>
</tbody>
</table>

2007 recommendations of the ICRP. Publication 103 Ann ICRP 2007; 37:1-332
Effective Dose Estimate
example: chest CT

- DLP = 251 mGy-cm
- Effective dose = DLP x 0.014 (k) = 3.5 mSv

• MEASURES AVAILABLE ON SCANNER
Review

- $\text{CTD}\text{I}_{\text{vol}}$ is an estimate of the absorbed dose
- DLP – can be converted into ED which reflects the total dose and stochastic risks of radiation
- Both data can be used in clinical practice to compare CT dose against national references
- ED also permits direct comparisons of CT doses with other types of imaging studies and natural background
What are the effective doses in CT in Common Examinations?

Mettler FA. Radiology 2008; 248:254-263
Typical Radiation Doses per year (mSv)

- Natural background 3.2*
- Medical population 0.3-0.6

*From natural radiation in soil & rocks, radon gas which seeps into homes & other buildings, plus radiation from space
<table>
<thead>
<tr>
<th>Exam</th>
<th>Mean Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest PA/Lat</td>
<td>0.1-0.01</td>
</tr>
<tr>
<td>Skull x-ray</td>
<td>0.1</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>0.2</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.6</td>
</tr>
<tr>
<td>Upper GI series (fluoro)</td>
<td>6</td>
</tr>
<tr>
<td>Small bowel series</td>
<td>5</td>
</tr>
<tr>
<td>Barium enema</td>
<td>8</td>
</tr>
</tbody>
</table>

Source:
- www.cancer.gov/cancertopics (NCI)
- Mettler Radiology 2008; 248:254-263
- Hollingsworth AFR 2007; 189:12-18
Estimated Effective Doses (mSv) from Typical CT Scans

- Head 2
- Chest CT 7
- Abdomen 8
- Pelvis 6

Hollingsworth AFR 2007; 189:12-18
Effective Doses for Cardiac CT (mean mSv)

- Chest PA/Lat 0.1
- Coronary calcium scoring 3
- Coronary CTA (64)
  - without current modulation 16
  - with current modulation 9
- Prospectively triggered coronary CTA 3
- Invasive coronary angiogram 7

Effective Doses for Myocardial Perfusion (mSv) & ranges

- Sestamibi stress test  9
- Thallium stress test  41
- F-18 FDG            14
- Rubidium 82         5

Pregnancy & CT Doses

Information abstracted from ICRP *Publication 84* (2000)
Available at [www.icrp.org](http://www.icrp.org)
Radiation Effects

- Radiation-related risks to fetus are related to stage of pregnancy and dose
- Threshold is 50 mGy
- Fetal dose < 50 mGy not likely to have adverse effect
- Fetal dose > 50 mGy has a small risk (<1%) of cancer and may reduce IQ

McCullough et al Radiographics 2007; 27: 909-917-NCRP recommendation
## Mean Fetal Doses from Standard CT

<table>
<thead>
<tr>
<th>CT Examination</th>
<th>Dose (mGy)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>&lt;0.005</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Abdomen</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

- Dose from abdominal & pelvic CT may be significant
- Dose from brain or chest CT is minimal
Fetal / Maternal Doses in PE Imaging
Meta-analysis (1990-2010)

- Fetal doses same for CT and V/Q
- Maternal doses higher with CT

<table>
<thead>
<tr>
<th>Imaging Test</th>
<th>Fetal Dose (mGy)</th>
<th>Maternal Dose (ED, mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V/Q</td>
<td>0.32 – 0.74</td>
<td>1–2.5</td>
</tr>
<tr>
<td>CTA</td>
<td>0.03 – 0.66</td>
<td>4–18</td>
</tr>
</tbody>
</table>

Breast exposure: CTA-20-50 mGy vs. V/Q-1.0 mGy

Diagnostic algorithm for suspected PE in pregnancy

- Normal chest: perform VQ
  - Negative: STOP
  - Positive: Treat

- Abnormal Chest: perform CT
  - Negative: STOP
  - Positive: Treat

Take Home Points

- Benefit of CT needs to outweigh the risk
- Dose must be “As Low As Reasonably Achievable” (ALARA) while maintaining image quality
- To achieve a low dose, dose measurements need to be understood and used