Radiation Dose and Radiation Risk

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OBJECTIVE

Explain Radiation dose parameters (for CT) and associated risk of radiation exposure:

- **CT specific**: CTDIvol: milligray (mGy)
  - DoseLength product (mGy*cm)
- **general**: whole body dose (mSv)
  - (relates to risk)

Risk of Radiation Exposure

International commission on radiological protection – IRCP estimates

- **Deterministic** (high dose range)
  - 250 – 500 mSv blood changes
  - >4000 mSv 50% probability of death
- **Stochastic** (low dose range)
  - Risk of fatal cancer (~5% per 1000mSv)
  - Risk of non-fatal cancer (1.2% per 1000mSv)

~ 0.01 % /mSv Cancer risk (incl. non-fatal)
~ 0.005 % /mSv fatal Cancer risk

Deterministic effects of high radiation dose...

California Bill SB 1237
(signed Sept 2010)
Risk of Radiation Exposure
International Commission on Radiological Protection – ICPR estimates

- **Deterministic** (high dose range)
  - 250 – 500 mSv blood changes
  - >4000 mSv 50% probability of death

- **Stochastic** (low dose range)
  - <100 mSv: definition of 'low exposure'
  - Risk of non-fatal cancer
  - Risk of fatal cancer

  not well known, linear, no threshold dose-effect relationship?

Estimated number of cancers from 100mSv exposure for 100,000 persons
Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VI report

<table>
<thead>
<tr>
<th></th>
<th>All solid cancer</th>
<th>Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>males</td>
<td>females</td>
</tr>
<tr>
<td>Excess cases (including non-fatal)</td>
<td>800</td>
<td>1300</td>
</tr>
<tr>
<td>cases in the absence of exposure</td>
<td>45,500</td>
<td>36,900</td>
</tr>
</tbody>
</table>

~ 0.01% / mSv Cancer risk (incl. non fatal)
~ 0.005% / mSv fatal Cancer

MDCT Radiation Dose
Typical effective dose values
C. McCollough, MDCT Course 2003 San Francisco

- Head CT 1-2 mSv
- Chest CT 5-8 mSv
- Abdomen CT 5-10 mSv
- Pelvis CT 3-4 mSv
- Abd-Pelv CT 8-15 mSv
- Chest x-ray 0.02 mSv
- Abdomen x-ray 0.07 mSv

Average U.S. background radiation ~ 3.6 mSv
~ 0.01% / mSv Cancer risk (incl. non fatal)
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Computed Tomography (CT) in the United States in 2007
- approx. 70 million scans / year (threefold increase of CT since 1993)

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Overall, we estimated that approx. 29,000 (95% UL: 15,000-45,000) future cancers could be related to CT scans performed in 07 in US.

The largest contributions were from scans of:
- abdomen and pelvis (n = 14,000)
- chest (n=6,000)
- head (n=4,000)
- chest CT angiography (n=2,000).

(2% of ~1.4 m cancers diagnosed annually in US)
Number of CT Scans Performed in the U.S. in 2007

<table>
<thead>
<tr>
<th>Scan Type</th>
<th>Scans (mio)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>21.5</td>
<td>30</td>
</tr>
<tr>
<td>Chest</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>2.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Abdomen/pelvis</td>
<td>24.2</td>
<td>34</td>
</tr>
<tr>
<td>CTA chest</td>
<td>2.6</td>
<td>3.6</td>
</tr>
<tr>
<td>CTA abdomen</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>CTA pelvis</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>CTA head</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Other cardiac</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Whole body</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Colonography</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Calcium scoring</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>5.6</td>
</tr>
<tr>
<td>Total</td>
<td>71.7</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**MDCT Radiation Dose**

Typical effective dose values

- **Head CT**: 1-2 mSv
- **Chest CT**: 5-8 mSv
- **Abdomen CT**: 5-10 mSv
- **Pelvis CT**: 3-4 mSv
- **Abd-Pelv CT**: 8-15 mSv
- **Chest x-ray**: 0.02 mSv
- **Abdomen x-ray**: 0.07 mSv

**Average U.S. background radiation**: ~ 3.6 mSv

**Calculated radiation-induced Risk of dying from cancer per mSv.**

- **Child (0-10y)**: 14 / 100,000
- **Adolescent (10-20y)**: 10 / 100,000
- **Adult (20-30y)**: 7.5 / 100,000
- **Adult (30-40y)**: 3.5 / 100,000
- **Adult (60)**: 2.0 / 100,000
- **Adult (80)**: 1.0 / 100,000

**Average**: 5.0 / 100,000

**Natural risk**: 30,000.0 / 100,000

~ 0.01% / mSv (Cancer risk incl. non-fatal)

**Estimates, extrapolated from accidental or occupational whole-body exposure to high doses and dose-rates. Risk cannot yet be statistically proven for an effective dose below 20 mSv.**

The Lancet, June 2012

Interpretation

- Cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer.
- Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10,000 head CT scans is estimated to occur.
Interpretation.. cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur.

The Lancet, June 2012

MDCT Radiation Dose
Calculated radiation-induced Risk of dying from cancer per mSv.

- Child (0-10y) 14 / 100 000
- Adolescent (10-20y) 10 / 100 000
- Adult (20-30y) 7.5 / 100 000
- Adult (30-40y) 3.5 / 100 000
- Adult (60) 2.0 / 100 000
- Adult (80) 1.0 / 100 000
- Average 5.0 / 100 000 0.005% / mSv
- Natural risk 30 000.0 / 100 000

~ 0.01% / mSv Cancer risk (incl. non-fatal)
~ 0.005% / mSv fatal Cancer

Radiation Risk: Summary
- very difficult estimate true effective dose (mSv) from CT exposure parameters (CTDI, DPL)
- Radiation has deterministic effects at high doses (>250mSv),
- CT doses are in the low dose range (<100mSv), typically 1–50 mSv, which has stochastic effects (i.e. cancer, on population basis), with wide error margins of estimates
  - ~ 0.01% / mSv Cancer risk (incl. non fatal)
  - ~ 0.005% / mSv fatal Cancer
- prudent to reduce dose ALARA (as low as reasonably achievable)

Radiation Dose in Computed Tomography

OBJECTIVE

Explain risk of radiation exposure and Radiation dose parameters:

- general: milli Sievert [mSv] (whole body)
- CT specific: CTDIvol: milligray (mGy)
  - DoseLength product (mGy*cm)

CTDI: CT Dose Index

CTDIw = (2*CTDIperiphery + CTDIcenter)/3
CTDIvol = CTDIw / pitch

Instrumentation for measurement of radiation exposure in computed tomography

CTDI (CT Dose Index)
Not so Intuitive Concept …
• Phantom size gives different CTDI for same scanning parameters: large phantom – less dose!

• Large patients shield themselves, slim patients more dose than CTDI suggests

Dose Quantities in CT
CTDIvol (mGy)
CT dose index → local dose measured in head or body phantom
STANDARDIZED on all scanners, and all models …
… most important parameter to optimize your scan protocols!

Dose Quantities in CT
CTDIvol (mGy)
CT dose index → local dose measured in head or body phantom
displayed on the scanner console

• mAs
• kVp
• gantry rotation time
• pitch
• filtration

summarized completely in CT Dose index (CTDI) in milli-Gray (mGy)

Scan Protocol Optimization
start with reviewing scanning protocols and optimizing
• patient positioning (centering)
• scanning range
• number of phases
• appropriate use of automated exposure control
• new dose reduction techniques (e.g. ASIR)
• cardiac: gating technique, low heart rate
• for each acquisition, look at the CTDI
• COMPARE TO REFERENCE VALUES

Table 3: Proposed reference dose values for routine CT examinations on the basis of absorbed dose to air

<table>
<thead>
<tr>
<th>Examination</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine head</td>
<td>60</td>
<td>1050</td>
</tr>
<tr>
<td>Face and sinuses</td>
<td>35</td>
<td>360</td>
</tr>
<tr>
<td>Vertebral trauma</td>
<td>70</td>
<td>460</td>
</tr>
<tr>
<td>Routine chest</td>
<td>30</td>
<td>650</td>
</tr>
<tr>
<td>HRCT of lung</td>
<td>35</td>
<td>280</td>
</tr>
<tr>
<td>Routine abdomen</td>
<td>35</td>
<td>780</td>
</tr>
<tr>
<td>Liver and spleen</td>
<td>35</td>
<td>900</td>
</tr>
<tr>
<td>Routine pelvis</td>
<td>35</td>
<td>570</td>
</tr>
<tr>
<td>Osseous pelvis</td>
<td>25</td>
<td>520</td>
</tr>
</tbody>
</table>

Notes: a. Data relate to head phantom (PMMA, 16 cm diameter)
b. Data relate to body phantom (PMMA, 32 cm diameter)

upper limits (ACR)
• Head    ~ 70 mGy
• Body    ~ 35 mGy
• Cardiac ~ 50 mGy
• head perfusion <500mGy

Notes: a. Data relate to head phantom (PMMA, 16 cm diameter)
b. Data relate to body phantom (PMMA, 32 cm diameter)
Stanford Hospital and Clinics Policy

CT Reference Exposure Values and Repeat Exposure

Stanford Reference CTDI values (per series)

<table>
<thead>
<tr>
<th>Description of Series</th>
<th>Phantom</th>
<th>CTDI Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Head</td>
<td>14 cm</td>
<td>27.5 mGy</td>
</tr>
<tr>
<td>Adult Head</td>
<td>12 cm</td>
<td>17.5 mGy</td>
</tr>
<tr>
<td>Adult Body</td>
<td>16 cm</td>
<td>9 mGy</td>
</tr>
<tr>
<td>Adult Body</td>
<td>12 cm</td>
<td>10 mGy</td>
</tr>
<tr>
<td>Adult Body</td>
<td>22 cm</td>
<td>17.5 mGy</td>
</tr>
<tr>
<td>Adult Body</td>
<td>22 cm</td>
<td>20 mGy</td>
</tr>
<tr>
<td>Adult Cardiac</td>
<td>25 cm</td>
<td>150 mGy</td>
</tr>
<tr>
<td>Cardiac (Mediclinic)</td>
<td>34 cm</td>
<td>90 mGy</td>
</tr>
<tr>
<td>Cardiac (MDCT)</td>
<td>34 cm</td>
<td>120 mGy</td>
</tr>
<tr>
<td>Pediatric</td>
<td>15 cm</td>
<td>25 mGy</td>
</tr>
<tr>
<td>Pediatric</td>
<td>16 cm</td>
<td>20 mGy</td>
</tr>
<tr>
<td>Pediatric</td>
<td>16 cm</td>
<td>25 mGy</td>
</tr>
</tbody>
</table>

based on ACR guidelines, and AAPM recommendations
(Jia Wang, PhD)