Scanning and Radiation Dose Parameters in CT

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Computed Tomography (CT) in the United States in 2007
- approx. 70 million scans / year (threefold increase of CT since 1993)

Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007
Lucas Learning Center, NOV 18, 2010
Berrington de Gonzalez et al., Arch Intern Med. 2009

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>All solid cancer</th>
<th>Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess cases (including non-fatal)</td>
<td></td>
</tr>
<tr>
<td>males</td>
<td>females</td>
</tr>
<tr>
<td>800</td>
<td>1300</td>
</tr>
<tr>
<td>(400-1600)</td>
<td>(600-2500)</td>
</tr>
<tr>
<td>cases in the absence of exposure</td>
<td></td>
</tr>
<tr>
<td>males</td>
<td>females</td>
</tr>
<tr>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>(30-300)</td>
<td>(20-250)</td>
</tr>
<tr>
<td>Excess deaths from exposure to 100 mSv</td>
<td></td>
</tr>
<tr>
<td>males</td>
<td>females</td>
</tr>
<tr>
<td>410</td>
<td>70</td>
</tr>
<tr>
<td>(200-830)</td>
<td>(20-220)</td>
</tr>
<tr>
<td>Deaths in the absence of exposure</td>
<td></td>
</tr>
<tr>
<td>males</td>
<td>females</td>
</tr>
<tr>
<td>22,100</td>
<td>710</td>
</tr>
<tr>
<td>(14,800-30,300)</td>
<td>(10-190)</td>
</tr>
</tbody>
</table>

~ 0.01% / mSv Cancer risk

Estimated Radiation Dose Associated with Cardiac CT Angiography
n=1965 patients, at 50 study sites
Hausleitner et al. JAMA. 2009;301:500-507

Range of medians: 329-2147 mGy*cm
4.6 - 30.1 mSv

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4.6 - 30.1 mSv

Hausleitner et al., JAMA. 2009;301:500-507
California Bill
SB 1237
(signed Sept 2010)

Radiation Dose in Computed Tomography

OBJECTIVE

Explain risk of radiation exposure and Radiation dose parameters:

- General
  - [milliSv] [mSv]
- Whole body

 jenisified

CT specific
- CTDIvol: milligray (mGy)
- DoseLength product (mGy*cm)

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
- CT P: 3-4 mSv
- Head Neck CTA: 4-5 mSv
- Coronary CT: 5-30 mSv

- Average U.S background radiation ~ 3.6 mSv

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- Abdomen CT: 5-10 mSv
- Pelvis CT: 3-4 mSv
- Abd-Pelv CT: 8-15 mSv
- Chest: 5-8 mSv (12-18 mGy)
  - Low-dose Chest: 2-5 mSv (5-12 mGy)
  - HR-CT: 1.2-2.5 mSv (3-5 mGy)

- Average U.S background radiation ~ 3.6 mSv

Beren de Gonzalez et al., Arch Intern Med. 2009

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>

Estimated using IMV, Medicare and non-commercial insurance databases.

C. McCollough, MDCT Course 2003 San Francisco
MDCT Radiation Dose

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

- Child (0-10y) 14 / 100,000
- Adolescent (10-20y) 20 / 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)

Estimated, 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.

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

Estimated Risks of Fatal Malignancy of Death from Radiation Exposure and Lifetime Odds of Dying as a Result of Selected Activities of Everyday Life

(1 mSv (calcium score) 0.005
10 mSv (coronary CT, cath, ..) 0.05
50 mSv (yr radiation worker allowance) 0.25
100 mSv (definition of "low exposure") 0.5
NATURAL fatal cancer 21.2
passive smoking 0.4-1.0
radon in home (US average) 0.3
Motor vehicle accident 1.9

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Radiation Dose in Computed Tomography

OBJECTIVE

Explain risk of radiation exposure and Radiation dose parameters:

- General (whole body)
  - mSv
  - mSv
- CT specific
  - CTDI
  - milligray (mGy)
  - Dose-Length product (mGy*cm)

Scan Protocol / Dose Optimization?

Attempt that scanning and exposure parameters best balance
- Image quality
- Other factors, e.g., total scan time

Adjustable parameters
- kV
- mAs
- Collimation / slice thickness
- Pitch / table feed per rotation

Dose Quantities in CT

CTDIvol (mGy)
- CT dose index \( \rightarrow \) local dose measured in head or body phantom

DLP (mGy cm)
- Dose Length product \( \rightarrow \) total scan dose

E (mSv)
- Effective dose \( \rightarrow \) biological risk

Instrumentation for measurement of radiation exposure in computed tomography

CTDI: local dose \( \rightarrow \) (mGy)
DLP: local dose \( \times \) length (mGy \( \times \) cm)
How to estimate Risk from Exposure
How to get E (mSv) from CTDI

For whole body exposure, 1mGy = 1mSv

For non-uniform and partial irradiation Monte Carlo simulations model dose distributions within the body of calculated x-ray spectra in mathematical phantom

Sum of the organ doses is the effective dose

Normalized values of effective dose per dose-length product (DLP) over various body regions

Region of Body | E / CTDI | Normalised effective dose, $E_{eff}$ (mSv/mGy/cm)
--- | --- | ---
Neck (20cm) | 20% | 0.0054
Chest (30cm) | 42% | 0.017
Liver (20cm) | 32% | 0.012
Abd.+Pelv. (40cm) | 73% | 0.015
Pelvis (20cm) | 41% | 0.019

Conversion Factors for Children (for CT abdomen/pelvis)

<table>
<thead>
<tr>
<th>Age</th>
<th>Conversion factor (mSv/mGy/cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>0.049</td>
</tr>
<tr>
<td>1 year</td>
<td>0.030</td>
</tr>
<tr>
<td>5 year</td>
<td>0.020</td>
</tr>
<tr>
<td>10 year</td>
<td>0.019</td>
</tr>
<tr>
<td>15 year</td>
<td>0.019</td>
</tr>
<tr>
<td>Adult</td>
<td>0.015 / 0.019</td>
</tr>
</tbody>
</table>

Practical Example:
CTA of the Abdominal Aorta

60 y o man with AAA
Using the preset protocol for routine abdom. CTA Siemens Sensation 16
- Topogram - Non-con series 3mm (16×1.5)
- Monitoring series (bolus) 4.5mm
- CTA 1.5mm (16×1.5mm)

Patient Protocol (single DICOM image)

Scan | KV | mAs | CTDIvol | DLP
--- | --- | --- | --- | ---
Topogram | 1 | 120 | 9.63 | 499
NON-CON | 2 | 120 | 138 | 2
PreMonitoring | 3 | 120 | 20 | 4.18
Monitoring | 4-11 | 120 | 20 | 33.28
ABD ANGIO | 12 | 120 | 135 | 10.55


d20 mGy cm (× 75%) ~ 15 mSv
d1040 mGy cm (× 0.015) ~ 15 mSv

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 (40-60y) 2.0 / 100 000
- Adult (60-80y) 1.0 / 100 000
- Average 5.0 / 100 000

- Natural risk 30 000.0 / 100 000
- Natural risk ~1.3
- Cancer risk (incl. non-fatal): 0.15%

IRCP publication

European guidelines on quality criteria for Computed Tomography - EUR 16262
.. Keep in Mind

- The amount of information in a CT exam is far greater than an equivalent x-ray, huge amount of diagnostic information available
  - Diagnostic image quality is overriding concern
    - Non-diagnostic exam is 100% wasted dose
  - Some dose savings can be achieved without loss of image quality
  - The remainder comes down to dose and image-quality optimization

Scan Protocol Optimization

- Start with
  - Review scanning protocols
  - Scanning range, patient positioning
  - Number of phases
  - Appropriate use of automated exposure control
  - New dose reduction techniques (e.g., ASIR)
  - Cardiac: gating technique, low heart rate

Radiation Exposure Reduction in Cardiac CT

- Retrospective Gating
  - No EKG dose modulation: 100%
  - EKG mod. 20% mA: 30-70% RR ~ 70%
  - EKG mod. 4% mA: 30-70% RR ~ 50%
  - EKG mod. 4% mA: 70% RR ~ 25%

- Prospective Gating
  - Prospective std. padding ~ 25%

- 100kV
  - Dose proportional to square of kV; iodine signal incr.; noise increases too; subtract
  - 120 → 100kV: -30% dose (at same mA) - 30%

56 yo physician
5'6" (168cm)
133 lbs (60kg)
1.68 BSA
HR: 48 bpm
Scan Protocol Optimization

...start with

Review scanning protocols

• scanning range, patient positioning
• number of phases
• appropriate use of automated exposure control
• new dose reduction techniques (e.g. ASIR)
• cardiac: gating technique, low heart rate

• 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>Reference dose value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$CTD_{w}$ (mGy)</td>
</tr>
<tr>
<td>Routine head</td>
<td>60</td>
</tr>
<tr>
<td>Face and sinuses</td>
<td>35</td>
</tr>
<tr>
<td>Vertebral trauma</td>
<td>70</td>
</tr>
<tr>
<td>Routine chest</td>
<td>30</td>
</tr>
<tr>
<td>HRCT of lung</td>
<td>35</td>
</tr>
<tr>
<td>Routine abdomen</td>
<td>35</td>
</tr>
<tr>
<td>Liver and spleen</td>
<td>35</td>
</tr>
<tr>
<td>Routine pelvis</td>
<td>35</td>
</tr>
<tr>
<td>Osseous pelvis</td>
<td>25</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)

European guidelines on quality criteria for Computed Tomography – EUR 16262

Radiotherapy Dose in Computed Tomography

OBJECTIVE

Explain risk of radiation exposure and Radiation dose parameters:

- general: milli Sievert [mSv]
- whole body

- CT specific: CTD_{vol}: milligray (mGy)
- DoseLength product (mGy*cm)

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
- neuro perfusion <500 mGy

Thank you ...
QUIZ CASE

CTA of the Abdominal Aorta
60 y o man with AAA
- Topogram
- Non-con series 3mm (16×1.5)
- Monitoring series (bolus)
- CTA 1.5mm (16×1.5mm)

Estimate eff. radiation dose!

Patient Protocol (single DICOM image)

<table>
<thead>
<tr>
<th>Scan Type</th>
<th>kV</th>
<th>mAs</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topogram</td>
<td>1</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NON-CON</td>
<td>2</td>
<td>120</td>
<td>138</td>
<td>9.63</td>
</tr>
<tr>
<td>PreMonitor</td>
<td>3</td>
<td>120</td>
<td>20</td>
<td>4.16</td>
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<td>12</td>
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What is the effective Dose in mSv?

A. \( \text{_____ mGy cm} \times \text{_____ mSv} \)
B. \( \text{_____ mGy cm} \times \text{_____ mSv} \)

Normalized values of effective dose per dose-length product (DLP) over various body regions

<table>
<thead>
<tr>
<th>Region of Body</th>
<th>E / CTDI_{vol}</th>
<th>Normalised effective dose, ( E_{\text{DLP}} ) (mSv mGy^{-1} cm^{-1})</th>
</tr>
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<tr>
<td>Neck (20cm)</td>
<td>20%</td>
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<td>Liver (20cm)</td>
<td>32%</td>
<td>0.012</td>
</tr>
<tr>
<td>Abd.+Pelv. (40cm)</td>
<td>73%</td>
<td>0.015</td>
</tr>
<tr>
<td>Pelvis (20cm)</td>
<td>41%</td>
<td>0.019</td>
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Conversion Factors for Children (for CT abdomen/pelvis)

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European guidelines on quality criteria for Computed Tomography - EUR 18262