CT for PET/CT and SPECT/CT
Principles of Dose Reduction

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Lifetime Attributable Risk
10 mGy in 100,000 exposed persons
(BEIR VII 2006)

<table>
<thead>
<tr>
<th></th>
<th>All Solid Tumors</th>
<th>Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Excess Cases</td>
<td>80</td>
<td>130</td>
</tr>
<tr>
<td>Excess Deaths</td>
<td>41</td>
<td>61</td>
</tr>
</tbody>
</table>

Note: About 45% will contract cancer and 22% will die.
Excess Attributable Risk (Deaths) from All Solid Tumors per 10,000 Person-Year-Sv by 60Y (BEIR VII 2006)

<table>
<thead>
<tr>
<th>Age at Exposure (Y)</th>
<th>EAR (Mortality)</th>
<th>Relative to &gt;30Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35.1</td>
<td>2.92</td>
</tr>
<tr>
<td>5</td>
<td>30.3</td>
<td>2.52</td>
</tr>
<tr>
<td>10</td>
<td>25.2</td>
<td>2.10</td>
</tr>
<tr>
<td>20</td>
<td>17.4</td>
<td>1.45</td>
</tr>
<tr>
<td>&gt;30</td>
<td>12.0</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Thus, if 1,000,000 10 YO receive 10 mSv, will die from solid tumors by age 60 due to this exposure.
Factors Affecting Radiation Dose in Multi-Detector CT

- Tube current or time (mAs)
- Reduce tube voltage (kVp²)
- Beam collimation
- Pitch (table speed)
- Patient size
- Region of patient imaged
CIRS Tissue Equivalent Phantoms

- Dosimetric CT phantoms
- Simulated spine
- Five 1.3 cm holes
- Five different sizes

<table>
<thead>
<tr>
<th>Phantom</th>
<th>AP x Lat (cm)</th>
<th>Circum (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>9 x 10.5</td>
<td>32</td>
</tr>
<tr>
<td>1 Year Old</td>
<td>11.5 x 14</td>
<td>42</td>
</tr>
<tr>
<td>5 Year Old</td>
<td>14 x 18</td>
<td>53</td>
</tr>
<tr>
<td>10 Year Old</td>
<td>16 x 20.5</td>
<td>61</td>
</tr>
<tr>
<td>Med Adult</td>
<td>25 x 32.5</td>
<td>96</td>
</tr>
</tbody>
</table>


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Dosimetry of PET-CT and SPECT-CT

- **PET/CT**
  - GE Discovery LS

- **SPECT/CT**
  - Philips Precedent
Dose from CT of PET-CT
GE Discovery LS (4-slice)

CTD\text{vol} (160 \text{ mA}, 0.8 \text{ s}, 1.5:1 \text{ pitch})

<table>
<thead>
<tr>
<th>Tube Voltage (kVp)</th>
<th>CTAD\text{vol} (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.00</td>
</tr>
<tr>
<td>90</td>
<td>5.00</td>
</tr>
<tr>
<td>110</td>
<td>10.00</td>
</tr>
<tr>
<td>130</td>
<td>15.00</td>
</tr>
<tr>
<td>150</td>
<td>20.00</td>
</tr>
</tbody>
</table>

ED from 10 mCi of FDG
9 mSv

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Dose from CT of PET-CT
GE Discovery LS (4-slice)

CTD\text{vol} (10 \text{ year old}, 0.8 \text{ s}, 1.5:1 \text{ pitch})

\begin{figure}
\centering
\includegraphics[width=\textwidth]{CTDvol_10_year_old_0.8_s_1.5_1_pitch.png}
\end{figure}

- 80 kVp
- 100 kVp
- 120 kVp
- 140 kVp

0.3 mGy

Tube Current (mA)

0 50 100 150 200

21 mGy

CTD\text{vol} (l) (mGy)

80 kVp

100 kVp

120 kVp

140 kVp

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Dose from CT of SPECT-CT Philips Precedence 6-slice

CTADlw for 10 YO, pitch =1:1

CTADlw (mGy)

mAs

0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00

0 50 100 150 200

- 90 kVp
- 120 kVp
- 140 kVp

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Dose from CT of SPECT-CT Philips Precedence 6-slice

CTADlw for 140 kVp, Pitch = 1:1

- Infant Body
- 1 YO Body
- 5 YO Body
- 10 YO Body
- Med Adult Body

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Typical Effective Dose Values

- Low Dose Chest CT: 0.7 mSv (70 mrem)
- Head CT: 1 - 2 mSv (100 - 200 mrem)
- Chest CT: 5 - 7 mSv (500 - 700 mrem)
- Abdomen CT: 5 - 7 mSv (500 - 700 mrem)
- Pelvis CT: 3 - 4 mSv (300 - 400 mrem)
- Abd & pelvis CT: 8 - 11 mSv (800 - 1100 mrem)

Average U.S. background radiation

≈ 3 mSv (300 mrem)
Organ and effective doses in pediatric patients undergoing helical multislice computed tomography examination

Lee et al. Med Phys 2007;34:1858-1873

Estimated organ and effective doses from helical CT for 5 phantoms and the MCNPX Monte Carlo photon transport code

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UF CT Phantoms (Bolch et al.)

15 Year Old – Male (A) and Female (B)

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CAP CT exam, 120 kVp, 100 mAs
12 mm beam thickness, 1:1 Pitch
(Dose in mGy)

<table>
<thead>
<tr>
<th>Organ</th>
<th>9 MO (M)</th>
<th>4 YO (F)</th>
<th>11 YO (M)</th>
<th>14 YO (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone marrow</td>
<td>6.02</td>
<td>6.64</td>
<td>7.33</td>
<td>7.62</td>
</tr>
<tr>
<td>Lungs</td>
<td>15.95</td>
<td>14.75</td>
<td>12.74</td>
<td>13.04</td>
</tr>
<tr>
<td>Stomach</td>
<td>15.62</td>
<td>14.13</td>
<td>12.71</td>
<td>10.73</td>
</tr>
<tr>
<td>Muscle</td>
<td>8.20</td>
<td>7.68</td>
<td>5.93</td>
<td>5.40</td>
</tr>
<tr>
<td>Breast</td>
<td></td>
<td>10.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>12.66</td>
<td>14.39</td>
<td>8.15</td>
<td>7.83</td>
</tr>
</tbody>
</table>

Lee et al. Med Phys 2007;34:1858-1873
CAP CT exam, 120 kVp, 100 mAs
12 mm beam thickness, 1:1 Pitch

<table>
<thead>
<tr>
<th>*UF Age</th>
<th>9 MO (M)</th>
<th>4 YO (F)</th>
<th>11 YO (M)</th>
<th>14 YO (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eff Dose (mSv)</td>
<td>12.41</td>
<td>12.80</td>
<td>9.88</td>
<td>9.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>**CTADI Age</th>
<th>12 MO</th>
<th>5 YO</th>
<th>10 YO</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTADI (mGy)</td>
<td>11.11</td>
<td>10.2</td>
<td>9.19</td>
</tr>
</tbody>
</table>

*Lee et al. Med Phys 2007;34:1858-1873
**Fahey et al. Radiology 2007;243:96-104
Radiation Risk for CT

For 10 & 1 YO, ~ 4X & 7X higher lifetime risk per CT scan, respectively

Brenner, Hall, NEJM, 2007;357:2277-2282

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Estimated Cumulative Radiation Dose from PET/CT in Pediatric Patients with Malignancies
A 5 Year Retrospective Review
Soni C. Chawla, MD, UCLA

- 248 PET-CT studies on 78 patients
  - 50 males, 28 females, 1.3-18 YO
- CT effective dose estimated by ImPACT - 20.3 mSv/scan
- PET effective dose estimated by OLINDA - 4.6 mSv/scan
- PET-CT effective dose - 24.8 mSv/scan
- Average number of scans/patient - 3.2 (range 1-14)

- Cumulative effective dose per patient – 78.9 mSv (range 6.2 – 399)
- 27% of patients received > 100 mSv
PET-CT Attenuation Correction

![Graph showing the relationship between CT value (HU) and attenuation coefficient (cm⁻¹).](image-url)
PET-CT Attenuation Correction

- Acquire CT Scan and reconstruct
- Apply energy transformation
- Reproject to generate correction matrix
- Smooth to resolution of PET
- Apply during reconstruction
Applications for very low-dose CT for anatomical correlation

- Pediatrics
- MR is correlative imagine modality of choice (e.g. brain imaging)
- Multiple acquisitions in single imaging session (stress-rest $^{82}$Rb cardiac imaging)
Quality of CTAC

80 kVp
10 mA
0.5 s/rot
1.5:1

140 kVp
160 mA
0.8 s/rot
1.5:1

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Quality of CTAC

- 80 kVp
- 10 mA
- 0.5 s/rot
- 1.5:1

- 140 kVp
- 160 mA
- 0.8 s/rot
- 1.5:1
Effect of Patient Size
80 kVp, 10 mA, 0.5 s/rotation

Accuracy of Attenuation Correction with Patient Size

<table>
<thead>
<tr>
<th>Patient Size</th>
<th>Linear Attenuation Coefficient (cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New born</td>
<td>0.0900</td>
</tr>
<tr>
<td>1 YO</td>
<td>0.0900</td>
</tr>
<tr>
<td>5 YO</td>
<td>0.0900</td>
</tr>
<tr>
<td>10 YO</td>
<td>0.0900</td>
</tr>
<tr>
<td>15 YO</td>
<td>0.0900</td>
</tr>
<tr>
<td>Small Adult</td>
<td>0.0900</td>
</tr>
<tr>
<td>Med Adult</td>
<td>0.0900</td>
</tr>
<tr>
<td>Large Adult</td>
<td>0.0900</td>
</tr>
</tbody>
</table>

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SPECT-CT CTAC

- CT image reoriented into SPECT coordinates
- CT image resampled to match SPECT pixel size
- CT image smoothed to SPECT resolution
- Conversion from HU to linear attenuation coefficient (piecewise linear)

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SPECT-CT CTAC

90 kVp/22 mAs

140 kVp/225 mAs

Jaszczak

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CT-Based Attenuation Correction

• For PET/CT, adequate attenuation correction can be obtained for pediatric patients with acquisition parameters as low as 80 kVp, 10 mA and 0.5 s per rotation. In adults, 120 kVp, 10 mA, 0.8 s. For pediatric patients, if one is only using the CT for attenuation correction, the CT radiation dose can be substantially reduced, by on the order of a factor of 50.

• For SPECT/CT, adequate attenuation correction can be obtained with parameters as low as 90 kVp, 15 mAs for pediatric and adult patients.
Summary

• The cancer risk due to radiation exposure is higher for children than in adults.
• There are a number of factors that can affect the radiation dose from CT including kVp, mAs, pitch and area imaged.
• The effective dose from CT in PET/CT and SPECT/CT is on the order of 10-20 mSv depending on the factors above.
• Dose reduction for CTAC as above.