New ICRU* Report on CT Dosimetry

*International Commission on Radiation Units
(and Measurement)

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Disclosures

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\[ CTDI_{100} = \frac{1}{nT} \int_{-50\text{mm}}^{+50\text{mm}} D(z) \, dz \]
CTDI - based Dose Metrics

The Tools

The Methods

CTDI_{100} (center & peripheral)

CTDI_w

CTDI_{vol}

DLP
CTDI is a good measure of CT dose to a large plastic phantom, but is not a stand-alone metric for patient dose.

A new look at CT dose measurement: Beyond CTDI

Robert L. Dixon

Med Phys 2003

The trouble with CTDI_{100}

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Restructuring CT dosimetry—A realistic strategy for the future

Requiem for the pencil chamber

Robert L. Dixon


CT Dose Index and Patient Dose: They Are Not the Same Thing

Experimental validation of a versatile system of CT dosimetry using a conventional ion chamber: Beyond CTDI100

Robert L. Dixon and Adam C. Ballard

ICRU Report on CT Dosimetry

Introduction & Historical CT Dose Metrics

Dose dependency on patient size

Dose and CT scan length

Phantoms and radiation meters

ICRU extension to AAPM Report 111

Summary
Dose Dependency on patient size

32 cm PMMA phantom
1138 cm²

average patient
615 cm²

85% bigger by mass

ρ = 1.19

ρ = 1.0
practical methods to correct dosimetry estimates for patient size
AAPM Report No. 204

Size Specific Dose Estimates (SSDE) in Pediatric and Adult CT Examinations
CT Dose Summit:
Scan Parameter Optimization
April 29-30, 2010
The Renaissance Concourse Atlanta Airport Hotel
Atlanta, GA

100% Dose, 120 kV

75% Dose, 100 kV
Lower Dose & Brighter Iodine

Default Protocol
Improved Protocol
Size Specific Dose Estimates (SSDE) in Pediatric and Adult CT Examinations
TG-204 Approach

- Four Independent Research Groups
- Studied Size-dependent CT Dose
Family of physical phantoms
Cynthia McCollough, Mayo Clinic
standard phantoms
Tom Toth & Keith Strauss
Anthropomorphic Monte Carlo phantoms
Mike McNitt-Gray, UCLA
Monte Carlo evaluation of CTDI$_\infty$ in infinitely long cylinders of water, polyethylene and PMMA with diameters from 10 mm to 500 mm

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Monte Carlo phantoms (1 – 50 cm)  
John M. Boone, UC Davis
Figure 2

circle of equal area

effective diameter

AP

lateral
normalization point

32 cm PMMA

CTDI_{vol}
After normalization, the correction factor decreases with increasing patient size. For a patient size of 32 cm, the correction factor is approximately 1.0.
32 cm 120 kV

Conversion Factor

water-equivalent diameter (cm)

Conversion Factor

age in years

0 1 5 10 15

- Mc-GE-120 kV
- Mc-Si-120 kV
- MG-Si-120 kV
- MG-Ph-120 kV
- MG-GE-120 kV
- MG-To-120 kV
- TS-Mx-120 kV
- ZB-GE-120 kV

Conversion Factor

water-equivalent diameter (cm)
16 cm 120 kV

Conversion Factor

age in years

Effective Diameter (cm)
CTDI$_{vol}$ is indicated on most scanners....

CTDI$_{vol}$ 5.11 mGy

CTDI$_{vol}$ 13.2 mGy
Exam Description: CT CHEST WITH CONTRAST

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>Scan Range (mm)</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy·cm)</th>
<th>Phantom cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scout</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Helical</td>
<td>1510.250–1700.250</td>
<td>15.55</td>
<td>349.79</td>
<td>Body 32</td>
</tr>
<tr>
<td>4</td>
<td>Helical</td>
<td>150.000–1395.000</td>
<td>17.48</td>
<td>661.77</td>
<td>Body 32</td>
</tr>
<tr>
<td>4</td>
<td>Helical</td>
<td>1230.750–1715.750</td>
<td>16.09</td>
<td>834.64</td>
<td>Body 32</td>
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<tr>
<td>4</td>
<td>Helical</td>
<td>1230.750–1725.750</td>
<td>7.98</td>
<td>421.68</td>
<td>Body 32</td>
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</tbody>
</table>

Total Exam DLP: 2267.88
determine patient size
determine patient size

\[ D_w \]
Size-Specific Dose Estimate (SSDE)

SSDE conversion factor

\[ \text{CTDI}_{\text{vol}} (\text{mGy}) \times f = \text{SSDE (mGy)} \]

SSDE conversion factor

air kerma

absorbed dose

Graph: Normalized Dose Coefficient vs. Effective Diameter (cm)
Example of SSDE calculation from localizer view

CT Radiograph

<table>
<thead>
<tr>
<th>Lateral Dim (cm)</th>
<th>Effective Dia (cm)</th>
<th>Correction Factor</th>
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<tbody>
<tr>
<td>8</td>
<td>9.2</td>
<td>2.65</td>
</tr>
<tr>
<td>9</td>
<td>9.7</td>
<td>2.60</td>
</tr>
<tr>
<td>10</td>
<td>10.2</td>
<td>2.55</td>
</tr>
<tr>
<td>11</td>
<td>10.7</td>
<td>2.50</td>
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<tr>
<td>12</td>
<td>11.3</td>
<td>2.45</td>
</tr>
<tr>
<td>13</td>
<td>11.8</td>
<td>2.40</td>
</tr>
<tr>
<td>14</td>
<td>12.4</td>
<td>2.35</td>
</tr>
<tr>
<td>15</td>
<td>13.1</td>
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<td>33.8</td>
<td>1.07</td>
</tr>
<tr>
<td>40</td>
<td>34.9</td>
<td>1.03</td>
</tr>
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</table>
Example of SSDE calculation from localizer view

5.40 mGy = CTDI_{vol}

SSDE = 5.4 mGy × 2.5

SSDE = 13.5 mGy
ICRU Report on CT Dosimetry

Introduction & Historical CT Dose Metrics

Dose dependency on patient size

Dose and CT scan length

Phantoms and radiation meters

ICRU extension to AAPM Report 111

Summary
Problems with CTDI$_{vol}$

15 cm phantom

32 cm diameter PMMA phantom

10 cm scan length
How long are the scatter tails in CT?

How long are the scatter tails in CT?

~130 mm

10%

140 kVp

80 kVp

80%
How long are the scatter tails in CT?

Dose profiles as a function of Scan Length
Equilibrium Dose as a function of Scan Length

$D_{eq} \text{ as a function of } L$

$D_o(L)$ vs. Scan Length (mm)
Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

A New Measurement Paradigm Based on a Unified Theory for Axial, Helical, Fan-Beam, and Cone-Beam Scanning With or Without Longitudinal Translation of the Patient Table
Integrating thimble chamber
TG-111 Method
TG-111 Method

![Diagram of TG-111 Method with a graph showing H(L) vs. Scan Length (cm)]
TG-111 Method

[Diagram of TG-111 Method]

[Graph showing H(L) vs. Scan Length (cm) with data points at 0, 5, 10, 15, 20 cm]
TG-111 Method
Cone beam CT dosimetry: A unified and self-consistent approach including all scan modalities—with or without phantom motion

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\[
\text{lsf}(z) = (1 - \varepsilon) \frac{1}{d} \exp(-2|z|/d) + \varepsilon \frac{1}{\delta d} \exp(-2|z|/\delta d),
\]

\[
H(a) = \frac{1}{1 + \eta} + \frac{\eta}{1 + \eta} \left[ (1 - \varepsilon)(1 - e^{-a/d}) + \varepsilon(1 - e^{-a/\delta d}) \right].
\]

\[\eta = \text{scatter / primary}\]
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Summary
Phantom is polyethylene 60 cm long by 30 cm in diameter

Each section is 20 cm long and weighs 13.7 kg (30 lbs)

compared to 32 cm diameter PMMA: 14.4 kg (5% lighter)

Total phantom 41.1 kg (90 lbs)
Integrating thimble chamber
real time probes
The thimble chamber with real time (>1000 Hz) readout rates

*active length
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Summary
real time thimble chamber
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Summary
CTDI-based methods need to be updated

**SSDE** is a method for adjusting for patient size

Scan length dose dependencies $\rightarrow h(L)$

Longer phantoms and faster radiation meters

Methods for automatic size detection

ICRU CT Report Available Q3 2013
Figures from CT Chapter
ICRU Report on CT Dosimetry

Introduction & Historical CT Dose Metrics

Dose dependency on patient size

Dose and CT scan length

Phantoms and radiation meters

ICRU extension to AAPM Report 111

Summary
Method for evaluating bow tie filter angle-dependent attenuation in CT: Theory and simulation results

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Computer simulation

(a) 120 kVp

(b) 140 kVp, 120 kVp, 100 kVp, 80 kVp
Physical Measurement

- Chart 1: Air Kerma Rate (mGy/s) vs. Time (s)
  - Black: Unfiltered beam
  - Gray: Filtered beam

- Chart 2: Relative Attenuation vs. Fan Angle (degrees)
  - 140 kVp
  - 120 kVp
  - 100 kVp
  - 80 kVp

- Chart 3: Filter Thickness (mm) vs. Fan Angle (degrees)
  - PMMA filter
  - AI Filter