SSDE: Coming Soon to a Scanner Near You! Updates on Head Coefficients (AAPM Report 293) and IEC Codification

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OUTLINE

BACKGROUND
- Size-specific dose estimate (SSDE)
- SSDE for pediatric and body CT examinations (AAPM Report 204)

SSDE for head CT (AAPM Report 293)
- Monte Carlo simulations and phantom imaging
- $\text{CTDI}_{\text{vol}}$-to-SSDE conversion factors

International Electrotechnical Corporation (IEC) codification of SSDE
- Definitions
- Requirements and Limitations

Conclusions
DISCLOSURES

- Research funding from Canon Medical Systems
- Contractor for Izotropic Corporation of Canada
CTDI$_{\text{vol}}$ limitations

- CTDI$_{\text{vol}}$ provides a standardized method for comparisons of CT scanner output for a standardized cylindrical phantom.

- CTDI$_{\text{vol}}$ does not account for patient habitus and is not an estimate of actual patient dose.
"Absorbed dose to the center section along the z-axis of a typical clinical CT scan"
- AAPM Reports 204 and 293

Size-specific dose estimate (SSDE)

Voxelized head figure adopted from:
Hardy A.J., Bostani M., Hernandez A.M., Zankl M., McCollough C., Cagnon C., Boone J.M. McNitt-Gray M. Medical Physics 46(2); 2019
**Purpose**: to provide a single set of conversion factors that can be used to convert \( \text{CTDIcon} \) to SSDE for pediatric and body CT examinations within 20% error.

SSDE is especially important for the pediatric population because \( \text{CTDIcon} \) tends to underestimate the absorbed dose.
**Purpose:** to provide a single set of conversion factors that can be used to convert \( CTDI_{vol} \) to SSDE for pediatric and body CT examinations within 20% error.

\[
SSDE [mGy] = f^{B32} \times CTDI_{vol,32}
\]

\[
f^{B32} = \alpha e^{-\beta D_w}
\]

\[
\alpha = 3.7044 \\
\beta = 0.0367
\]

\[
SSDE [mGy] = f^{B16} \times CTDI_{vol,16}
\]

\[
f^{B16} = \alpha e^{-\beta D_w}
\]

\[
\alpha = 1.8748 \\
\beta = 0.0387
\]
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SSDE for head CT examinations

AAPM REPORT NO. 293

Size-Specific Dose Estimate (SSDE) for Head CT

The Report of AAPM Task Group 293
July 2019

Boone J.M. (Chair), Strauss K.J. (Vice-Chair), Hernandez A.M., Hardy A., Applegate K.E., Artz N.S., Brady S.L., Cody D.D., Kasraie N., McCollough C.H., McNitt-Gray M.
### Age-specific, tissue-equivalent CIRS head phantoms

<table>
<thead>
<tr>
<th></th>
<th>PA diameter (cm)</th>
<th>LR diameter (cm)</th>
<th>Cranium thickness (mm)</th>
<th>Cranium density (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>newborn</td>
<td>12</td>
<td>9.5</td>
<td>2.5</td>
<td>1.41</td>
</tr>
<tr>
<td>1 year old</td>
<td>16</td>
<td>12.0</td>
<td>3.0</td>
<td>1.45</td>
</tr>
<tr>
<td>5 year old</td>
<td>17</td>
<td>13.5</td>
<td>3.5</td>
<td>1.52</td>
</tr>
<tr>
<td>adult</td>
<td>19</td>
<td>14.5</td>
<td>5.0</td>
<td>1.60</td>
</tr>
</tbody>
</table>
Physical measurements in CIRS head phantoms

Scanner | SIEMENS Force
---|---

kV: | 70 – 150 kV (10 kV intervals)

Mode: | Helical (pitch =1)

Nominal collimation (mm): | 115.2 mm

\[
K_w = \frac{1}{3} K_{\text{center}} + \frac{2}{3} \text{avg}\{K_{12\text{o’clock}}, K_3\}
\]

\[
D_{\text{brain}} = 1.08 \times K_w
\]

\[
f^{H16} = \frac{D_{\text{brain}}}{\text{CTDI}_{\text{vol,16}}}
\]
MC simulations in virtual CIRS head phantoms

Dose to a 0.5 cm thick slab of solid water (brain tissue-mimicking) was estimated at the center (along z) of the scan volume.

<table>
<thead>
<tr>
<th>Scanner:</th>
<th>GE VCT</th>
<th>GE Revolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV:</td>
<td>80, 100, 120, 140</td>
<td></td>
</tr>
<tr>
<td>Mode:</td>
<td>Helical (pitch = 0.516)</td>
<td>Axial</td>
</tr>
<tr>
<td>Nominal collimation (mm):</td>
<td>20</td>
<td>120-160 mm Depending on phantom size</td>
</tr>
</tbody>
</table>

\[ f^{H16} = \frac{D_{\text{brain}}}{CTD_{\text{vol},16}} \]

Simulations performed at UC Davis (Andrew M. Hernandez and John M. Boone)
MC validation against physical measurements

Physical measurements performed at St. Jude Children’s Hospital (Keith J. Strauss, Samuel L. Brady, Nathan S. Artz)
MC simulations in mathematical head phantoms

Red Marrow in the cranium expressed as % of active marrow in the body

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Cranium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27.0</td>
</tr>
<tr>
<td>1</td>
<td>25.1</td>
</tr>
<tr>
<td>5</td>
<td>15.9</td>
</tr>
<tr>
<td>15</td>
<td>19.2</td>
</tr>
<tr>
<td>40</td>
<td>7.6</td>
</tr>
</tbody>
</table>

ICRP Report 70

MC simulations in mathematical head phantoms

Mathematical phantoms, derived from ICRP 70, 46, 89 and other published data [Kleinman 2010], were simulated for estimation of absorbed dose to the brain parenchyma, shallow marrow (SM), and red bone marrow (RBM).

\[ f_{H16} = \frac{D_{\text{head}}}{CTDI_{\text{vol,16}}} \]

\[ D_{\text{head}} = \frac{D_{\text{brain}}M_{\text{brain}} + D_{\text{SM}}M_{\text{SM}} + D_{\text{RBM}}M_{\text{RBM}}}{M_{\text{brain}} + M_{\text{SM}} + M_{\text{RBM}}} \approx D_{\text{brain}} \]

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>PA</th>
<th>Lateral</th>
<th>( D_w ) (CV)</th>
<th>Cranium Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.6</td>
<td>9.6</td>
<td>11.6 (1.1%)</td>
<td>0.34</td>
</tr>
<tr>
<td>1</td>
<td>16.4</td>
<td>13.2</td>
<td>15.8 (0.9%)</td>
<td>0.41</td>
</tr>
<tr>
<td>5</td>
<td>18.4</td>
<td>14.6</td>
<td>17.7 (1.0%)</td>
<td>0.52</td>
</tr>
<tr>
<td>21</td>
<td>20.6</td>
<td>16.2</td>
<td>20.0 (1.2%)</td>
<td>0.69</td>
</tr>
</tbody>
</table>


Simulations performed at UC Davis (Andrew M. Hernandez and John M. Boone)
MC simulations in voxelized head models

Absorbed dose to brain ($D_{\text{brain}}$) tallied in MCNP within a slab in the center of the scan volume

- 8 from GSF family of patient models
- Two reference ICRP patient models
- 5 voxelized patient models from routine pediatric head CT exams

- Simulations performed at UCLA (Anthony Hardy and Michael McNitt-Gray)

Hardy A.J., Bostani M., Hernandez A.M., Zankl M., McCollough C., Cagnon C., Boone J.M. McNitt-Gray M. Medical Physics 46(2); 2019
Absorbed dose to brain ($D_{brain}$) tallied in MCNP within a slab in the center of the scan volume

- Simulations performed at UCLA (Anthony Hardy and Michael McNitt-Gray)
- Hardy A.J., Bostani M., Hernandez A.M., Zankl M., McCollough C., Cagnon C., Boone J.M. McNitt-Gray M. Medical Physics 46(2); 2019
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Results: CTDI\textsubscript{vol}-to-SSDE conversion factors

\[ f_{H16} = 1.9852 \exp(-0.0486 D_w) \]

\[ R^2 = 0.8421 \]

Newborn  1 y.o.  5 y.o.  Adult
Results: CTDI$_{vol}$-to-SSDE conversion factors

- **80 kV**
  \[ f_{H16} = 2.2572 \exp(-0.0624 D_w) \]
  \[ R^2 = 0.9396 \]

- **100 kV**
  \[ f_{H16} = 2.0536 \exp(-0.0521 D_w) \]
  \[ R^2 = 0.9432 \]

- **120 kV**
  \[ f_{H16} = 1.8873 \exp(-0.0439 D_w) \]
  \[ R^2 = 0.9198 \]

- **140 kV**
  \[ f_{H16} = 1.8924 \exp(-0.0419 D_w) \]
  \[ R^2 = 0.9551 \]
Results: CTDI$_{vol}$-to-SSDE conversion factors

\[ f_{H16} = 1.9852 \exp(-0.0486 \, D_w) \]
Results: $\text{CTDI}_{\text{vol}}$-to-SSDE conversion factors

The conversion factors for head CT examinations (Report 293) are consistently lower than for body CT (Report 204) because of attenuation of the skull.
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Methods for calculating size specific dose estimates (SSDE) for computed tomography

Méthodes de calcul de l’estimateur de dose morphologique (SSDE) en tomodensitométrie

Note: the following slides describing IEC 62985 are in some cases abbreviated for the purpose of dissemination and understanding in this talk. Please refer to the IEC document for exact definitions and detailed explanations.
IEC 62985: CTDI\textsubscript{vol}(z) and D\textsubscript{w}(z)

3.1 CTDI\textsubscript{vol} at Longitudinal Position z
CTDI\textsubscript{vol}(z)
value quantifying the RADIATION output at position z for the selected CT CONDITIONS OF OPERATION.

3.4 Water Equivalent Diameter at Longitudinal Position z
D\textsubscript{w}(z)
diameter in cm, of a cylinder of water having the same averaged ABSORBED DOSE as the material contained in an axial plane at longitudinal position z of the object scanned, calculable for a material of any composition, and quantifying the ATTENUATION of any material in terms of the ATTENUATION of water
**IEC 62985: CTDI\textsubscript{vol}-to-SSDE conversion factor**

\[ f(D_w(z)) = a \times e^{-bD_w(z)} \]

### Table A.1

<table>
<thead>
<tr>
<th>Description</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG 204: Body exam and CTDI\textsubscript{vol} measured with 32 cm CTDI phantom</td>
<td>3.7044</td>
<td>0.0367</td>
</tr>
<tr>
<td>TG 204: Body exam and CTDI\textsubscript{vol} measured with 32 cm CTDI phantom</td>
<td>1.8748</td>
<td>0.0387</td>
</tr>
<tr>
<td>TG 293: Head exam and CTDI\textsubscript{vol} measured with 16 cm CTDI phantom</td>
<td>1.9852</td>
<td>0.0486</td>
</tr>
</tbody>
</table>
3.9 SIZE SPECIFIC DOSE ESTIMATE AT LONGITUDINAL POSITION Z
SSDE(z)
estimate of the average ABSORBED DOSE to the material contained in an axial plane at
longitudinal position z within the RECONSTRUCTION LENGTH, expressed in units of mGy:

\[ SSDE(z) = f(D_W(z)) \cdot CTDI_{vol}(z) \]

3.10 SIZE SPECIFIC DOSE ESTIMATE
SSDE
arithmetic average of SSDE(z), calculated over the RECONSTRUCTION LENGTH at the same
z-positions as the corresponding D_W(z) values used to calculate D_W:

\[ SSDE = \frac{1}{n} \sum_{i=1}^{n} SSDE(z_i) \]

where

\( n \) is the number of z positions \( (z_i, i = 1,2,...,n) \) within the RECONSTRUCTION LENGTH
5.1: Calculation of SSDE and Dw for CT scanners

SSDE and Dw:
- determined over the reconstruction length containing patient-anatomy.
- not required to be calculated, displayed or recorded when a scanned projection radiograph does not exist for given protocol or reconstruction length.
5.2: Pre-scan display of SSDE for CT scanners

Except as identified in 5.1:
- SSDE (mGy units) shall be displayed on the control panel prior to initiation of scanning sequence on same screen and proximity to displayed CTDIvol.

5.3: Post-scan updating of SSDE and Dw for CT scanners

Following a sequence of scanning:
- Pre-scan SSDE and SSDE(z) shall be updated to account for changes between pre-scan CTDIvol and post-scan CTDIvol.
- Pre-scan Dw and Dw(z) shall be updated as well.
5.4: Pre and post-scan display of SSDE and Dw for CT scanners
For each protocol, the pre- and post-scan SSDE, and pre- and post-scan Dw shall be displayed on the control panel on same screen and in proximity to CTDI\textsubscript{vol}.

5.5: Post-scan recording of SSDE and Dw
IF DICOM radiation dose structured report (RDSR) .......

has necessary fields:
- Post-scan SSDE and Dw values (as well as SSDE(z) and Dw(z) at the interval used), shall be recorded in the DICOM RDSR.

does not have necessary fields for recording SSDE and Dw:
- Corresponding post-scan values shall be recorded as part of a dose report saved as an image.

does not have necessary fields for recording SSDE(z) and Dw(z) at interval used,
- Corresponding post-scan values do not need to be recorded.?
5.6: Limitations of calculation and display of SSDE and Dw

For **axial scanning with total table travel \(<\!\!\!< N \times T** OR patient **support is manually moved or remains stationary:**

- **CTD\(\text{Ivol}\) overestimates average absorbed dose** that would accrue in phantom’s central section. SSDE will propagate this error.

For **helical scanning when the product of a smaller number of rotation times the table travel per rotation \(<\!\!\!< N \times T:**

- **CTD\(\text{Ivol}\) overestimates average absorbed dose** that would accrue in phantom’s central section. SSDE will propagate this error.
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Conclusions: So what?

What is the utility of SSDE?

- Establish diagnostic reference levels across patient sizes
- CT patient dose monitoring and alerts that account for patient size
- More accurate reporting of patient dose for the ACR Dose Index Registry (for example), facilitating improved comparisons between regional and national values
- Improves risk predictions and therefore decision making in terms of potentially using other modalities such as MR and US
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Thank you!