Radiation Dose Considerations in CT Guided Interventional Procedures

Shuai Leng, PhD, FAAPM
Professor of Medical Physics
Department of Radiology
Mayo Clinic, Rochester, MN
Disclosure

• Nothing to disclose
Outline

- CT dosimetry
- Dose levels in CT-guided interventional procedures
- Dose monitoring
  - Real time monitoring
  - Dose notification and dose alert
- Dose reduction techniques
- Dose to operator and staff
CT-guided interventional procedures

- Scan mode: CT Fluoro, Biopsy (intermittent), Helical
- Scan coverage: short for CTF and Biopsy
- Number of scans: many more than diagnostic CT
- Dose perspective:
  - Usually higher dose
  - Higher variation among the same procedure
CT Dosimetry

- CTDI, CTDIw, CTDIvol
- Dose length product (DLP)
- Size specific dose estimate (SSDE)
- Organ dose (e.g. skin dose)
- Effective dose
CT Dose Index (CTDI)

- Acrylic CTDI phantoms
  - 32 cm diameter (body)
  - 16 cm diameter (head)
- 100 mm ion chamber

- Multi scan average dose
  - Single measurement
CT Dose Index (CTDI)

X-ray source

collimator

phantom

Dose profile

table

Total Dose

Location:

CTDI_{vol}

Courtesy Dr. Chris Favazza
**CTDI\textsubscript{w} and CTDI\textsubscript{vol}**

- **CTDI\textsubscript{w}**
  - Weighted average of center and periphery doses
  \[
  \text{CTDI}_w = \frac{2}{3} \text{CTDI}_{100}(\text{edge}) + \frac{1}{3} \text{CTDI}_{100}(\text{center})
  \]

- **CTDI\textsubscript{vol}**
  - Takes into account scan overlap or gaps
  \[
  \text{CTDI}_{\text{vol}} = \frac{\text{CTDI}_w}{\text{Pitch}}
  \]
Dose length product (DLP)

- $\text{CTD}_{\text{vol}}$ doesn’t count for scan length
  - E.g. partial abdominal scan and a abdomen and pelvis scan may have the same $\text{CTD}_{\text{vol}}$

- $\text{DLP} = \text{CTD}_{\text{vol}} \times \text{Scan Length}$

- DLP in interventional procedures
  - Biopsy mode: Short scan length, low DLP
  - Helical scan: Long scan length, high DLP

- $\text{CTD}_{\text{vol}} = 10 \text{ mGy}$
  - Scan length = 5 cm
  - DLP = 50 mGy*cm

- $\text{CTD}_{\text{vol}} = 10 \text{ mGy}$
  - Scan length = 30 cm
  - DLP = 300 mGy*cm
CTDIvol is NOT patient dose

- CTDI quantifies scanner radiation output
- Patient size must be considered to estimate patient dose

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

In 1981, Shope et al. (1) published “A Method for Describing the Doses Delivered by Transmission X-ray Computed Tomography.” In that article, they introduced the computed tomography (CT) dose index (CTDI) as a metric identifying the radiation output of a CT scanner in a consistent and reproducibly measured fashion. This is because the primary beam emitted from the scanner (originally a relatively thin fan beam, which with current technology has expanded) is attenuated by the patient, thereby producing a larger dose to the patient. Thus, CTDIvol should not be used as an indicator of patient dose. This is why CTDIvol is NOT patient dose.
DIFFERENT doses for different size patients
Size Specific Dose Estimation (SSDE)

- Estimate mean dose at center of scan range from CTDI_{vol}, using a size dependent conversion factor

\[ SSDE = f_{size} \times CTDI_{vol} \]
SSDE for Helical and Biopsy Mode

- Average dose in biopsy mode

![Graph showing normalized dose vs. A/P+Lateral (cm) for Helical and Biopsy modes.]

- Helical mode:
  \[ y = 3.1597e^{-0.0155x} \]
  \[ R^2 = 0.9942 \]

- Biopsy mode:
  \[ y = 2.4497e^{-0.0208x} \]
  \[ R^2 = 0.9878 \]
Skin Dose Estimation

Skin dose can be respectively estimated from CTDI\textsubscript{vol} for helical mode and biopsy

\[
\text{skin dose} = \begin{cases} 
1.2 \times CTDI_{vol} & \text{helical mode} \\
0.6 \times CTDI_{vol} & \text{biopsy mode}
\end{cases}
\]

Bauhs et al, CT dosimetry: Comparison of measurement techniques and devices. Radiographics, 2008
Leng et al, Radiation Dose Levels for Interventional CT Procedures. AJR. 2011
Skin dose: patient size and collimation

\[ y = 2.92e^{-0.0121x} \quad R^2 = 0.99 \]

\[ y = 2.31e^{-0.0159x} \quad R^2 = 0.98 \]

Effective Dose

- A calculated quantity that reflects the radiation detriment of a non-uniform exposure in terms of an equivalent whole-body exposure.

Effective Dose

- **Method 1**
  - Based on organ dose estimates (e.g. MC) and tissue weighting factors

- **Method 2**
  - Convenient “shortcut” based on DLP: \( E = k \times DLP \)
  - 5 generic \( k \) values, based on body region

### Anatomical Region

<table>
<thead>
<tr>
<th>Anatomical Region</th>
<th>( k ) value mSv/ (mGy-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head &amp; Neck</td>
<td>0.0031</td>
</tr>
<tr>
<td>Head</td>
<td>0.0021</td>
</tr>
<tr>
<td>Neck</td>
<td>0.0059</td>
</tr>
<tr>
<td>Chest</td>
<td>0.014</td>
</tr>
<tr>
<td>Abdomen &amp; Pelvis</td>
<td>0.015</td>
</tr>
</tbody>
</table>

### Calculation

<table>
<thead>
<tr>
<th>Organ</th>
<th>( x ) wt</th>
<th>( k ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyroid</td>
<td>x 0.05</td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>x 0.05</td>
<td></td>
</tr>
<tr>
<td>Lung</td>
<td>x 0.12</td>
<td></td>
</tr>
<tr>
<td>Breast</td>
<td>x 0.05</td>
<td></td>
</tr>
<tr>
<td>Colon</td>
<td>x 0.12</td>
<td>1.04</td>
</tr>
<tr>
<td>Skin</td>
<td>x 0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>Weighted ( \sum )</td>
<td></td>
<td>8.3</td>
</tr>
</tbody>
</table>
Dose Survey

- 561 patients in total

- Cryoablation (42)
- Aspiration (50)
- Biopsy (329)
- Drain (103)
- Injection (47)

Scan mode

- Helical mode
  - CTDIvol
  - DLP
  - Skin dose
  - Effective dose

- Biopsy mode
  - CTDIvol
  - DLP
  - Skin dose
  - Effective dose

Leng et al, Radiation Dose Levels for Interventional CT Procedures. AJR. 2011
Effective Dose Estimation

- $E = k \times DLP$.
- For helical mode, $k = 0.015$ for the torso.
- For Biopsy mode $k$ factor for.

1 Jessen et al., 1999; 50: 165-172.
4 Shrimpton, et al., *Br J Radiol*. Dec 2006;

http://www.impactscan.org
Average CTDI\textsubscript{vol}

- Generally higher CTDI\textsubscript{vol} than diagnostic exams
- Significant difference among procedures
- Large variation among the same procedure

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Intermittent Mode</th>
<th>Helical Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryoablation (n = 42)</td>
<td>183 ± 338</td>
<td>515 ± 217</td>
</tr>
<tr>
<td>Aspiration (n = 50)</td>
<td>89 ± 141</td>
<td>65 ± 41</td>
</tr>
<tr>
<td>Biopsy (n = 329)</td>
<td>102 ± 105</td>
<td>56 ± 36</td>
</tr>
<tr>
<td>Drain (n = 103)</td>
<td>95 ± 124</td>
<td>79 ± 45</td>
</tr>
<tr>
<td>Injection (n = 47)</td>
<td>273 ± 222</td>
<td>26 ± 23</td>
</tr>
</tbody>
</table>

Note—Data are mean ± SD.
Dose Length Product (DLP)

- Most DLP comes from helical mode
- Biopsy mode contributes little to DLP due to the short scan range

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cryoablation</th>
<th>Aspiration</th>
<th>Biopsy</th>
<th>Drain</th>
<th>Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermittent mode</td>
<td>132 ± 244</td>
<td>97 ± 135</td>
<td>110 ± 111</td>
<td>108 ± 125</td>
<td>198 ± 158</td>
</tr>
<tr>
<td>Helical mode</td>
<td>7814 ± 3360</td>
<td>1221 ± 696</td>
<td>792 ± 582</td>
<td>1554 ± 984</td>
<td>367 ± 283</td>
</tr>
<tr>
<td>Total</td>
<td>7946 ± 3351</td>
<td>1318 ± 724</td>
<td>902 ± 606</td>
<td>1662 ± 1019</td>
<td>565 ± 348</td>
</tr>
<tr>
<td>Intermittent/total (%)</td>
<td>2</td>
<td>7</td>
<td>12</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Helical/total (%)</td>
<td>98</td>
<td>93</td>
<td>88</td>
<td>93</td>
<td>65</td>
</tr>
</tbody>
</table>

Note—Except where noted, data are mean ± SD.
Skin dose

- The max skin dose observed was 1950 mGy
- 553 (out of 561) patients with skin dose < 1000 mGy (96%)
- Both biopsy mode and helical mode contribute substantially to skin dose.
Mean effective doses were 119.7 ± 50.3, 20.1 ± 11.0, 13.8 ± 9.2, 25.3 ± 15.4, and 9.1 ± 5.5 mSv for the 5 types of procedures.

Mean effective dose across all procedures was 24.1, with 2.3 mSv (9%) from intermittent mode and 21.8 mSv (91%) from helical mode.
Dose Fraction: Biopsy Mode and Helical Mode

Ablation

Aspiration

Biopsy

Drain

Injection

Biopsy mode
Helical mode

(Skin dose)

(Effective dose)
Dose Levels in CTGI

Dose Survey

- Different scopes and number of patients
- Imaging mode varies from practice to practice
- Dose metrics varies: CTDIvol, DLP, Skin dose, Effective dose etc.

- Common threads among disparate surveys:
  - Radiation dose widely varies: ~1-120 mSv effective dose &~100-2000 mGy peak skin dose
  - Helical scans are the primary contributor to effective dose

- These data can serve as benchmarks within the institution or for other radiology practices
Personnel dose surveys

- Personnel dose is relatively low and varies with complexity, experience, & procedure\(^1\)

Dose Monitoring

- Live tracking on the scanner
- Displays both a countdown of scan time remaining and the accumulation of CTDIvol during such procedures
Dose Notification and Dose Alert

- XR-25 defined the dose notification and dose alert
- Dose Notification: protocol level
- Dose Alert: global setting
Dose Alert

- Pop-up window once threshold reached.
- Username, diagnostic reason and password may be needed before continuing the procedure.
Potential Problems with Dose Alert in CTGI

- Common to exceed dose alert, even at 2000 mGy
- Interrupt workflow, may substantial delay urgent procedures
  - Occur the first time threshold is reached
  - Some sw may occur frequently
- Password may be needed
- Potential solutions:
  - Disable password
  - Disable dose alert (Caution: global setting, this will disable dose alert for all protocols)

McCollough and Favazza, Potential Clinical Ramifications of Dose Alert on CT-Guided Interventional Procedures. JACR. 2016
Dose Reduction

- Limit scan range
- Limit number of scans
- Set the right image quality
- Use automatic exposure control
- Select appropriate KV
- Use iterative reconstruction
• Simulated low dose scans.
• Image quality reviewed by 3 radiologists to determine the lowest dose with sufficient image quality
• 50% dose reduction

Leng et al, Radiation Dose Reduction for CT-Guided Renal Tumor Cryoablation. AJR, 2011
Radiation dose reduction techniques

▸ Reduce kV and mA

Radiation dose reduction techniques

- Reduce number of monitoring scans\(^1\)

Reduced number of monitoring scans from every 3 mins to physicians discretion and lower technique

<table>
<thead>
<tr>
<th>Procedure phase</th>
<th>Median standard protocol DLP</th>
<th>Median dose reduction protocol DLP</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4833.5 mGy*cm</td>
<td>2648 mGy*cm</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Targeting</td>
<td>2087 mGy*cm</td>
<td>1092 mGy*cm</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Monitoring</td>
<td>1733 mGy*cm</td>
<td>866 mGy*cm</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Radiation dose reduction techniques

▶ Use of iterative reconstruction

Metal Artifact Reduction

- Metal artifacts are commonly seen in CTGI

- Techniques used to overcome metal artifacts, e.g. high kV, high mA, may increase radiation dose

- Metal artifact reduction (MAR) can help improve image quality and reduce radiation dose.

1Sheedy, EN et al. Can Metal Artifact Reduction Improve the Conspicuity of Interventional Needle Placement? RSNA 2018 VI147-ED-X:
Radiation dose reduction techniques

▶ Use of angular beam modulation

**Significant reduction in patient dose:**

<table>
<thead>
<tr>
<th>Effective dose</th>
<th>Breast dose</th>
<th>12 o’clock skin dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction</td>
<td>35%</td>
<td>47%</td>
</tr>
</tbody>
</table>

**Significant reduction in personnel dose:**

<table>
<thead>
<tr>
<th>In beam</th>
<th>Reduction</th>
<th>10 cm from beam</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>72%</td>
<td>27%</td>
<td></td>
</tr>
</tbody>
</table>

Radiation protection for the operator and staff

- Patient dose and operator dose are correlated
- Select low dose imaging mode, if possible
- Time, distance, and shielding
  - Outside scan room if possible
  - Stay at low dose areas: use gantry as a shield
  - Shielding devices: lead apron, thyroid, hand, eye
- Monitoring occupational dose

Jones et al, Best Practices Guidelines for CT-Guided Interventional Procedures. JVIR. 2017
CT scans performed during interventional procedures are different than those in diagnosis:
- More scans are commonly performed
- Scan mode different

Dose in CT-guided interventional procedures:
- Higher than routine diagnostic scans
- Significant dose variation for different procedures, for the same procedures, among different institutes
- Helical scans contribute majority of the effective dose

Various dose reduction techniques can be used to reduce radiation dose without sacrificing outcome of CT guided interventional procedures
Acknowledgement

- Chris Favazza, PhD
- Cynthia McCollough, PhD
- Tom Atwell, MD
- Jodie Christner, PhD
- Stephanie Carlson, MD
- Lifeng Yu, PhD
- Tom Vrieze
- Kai Yang, PhD

Thank You!