Outline

- CT dosimetry and metrics
- 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

Disclosure

- Nothing to disclose
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 than diagnostic CT
  - High variation among different procedures, and cases of 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
- CTDI ion chamber (100 mm long)
CTDI<sub>w</sub> and CTDI<sub>vol</sub>

- **CTDI<sub>w</sub>**
  - 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<sub>vol</sub>**
  - Takes into account scan overlap or gaps
  
  \[
  \text{CTDI}_{vol} = \frac{\text{CTDI}_w}{\text{Pitch}}
  \]

Dose length product (DLP)

- CTDI<sub>vol</sub> doesn’t count for scan length
  - E.g. partial abdominal scan and a abdomen and pelvis scan may have the same CTDI<sub>vol</sub>

- DLP = CTDI<sub>vol</sub> x Scan Length

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

CTDI<sub>vol</sub> = 10 mGy
Scan length = 5 cm
DLP = 50 mGy*cm

CTDI<sub>vol</sub> = 10 mGy
Scan length = 30 cm
DLP = 300 mGy*cm

CTDI<sub>vol</sub> is NOT patient dose

- CTDI quantifies scanner radiation output
- Patient size must be considered to estimate patient dose
DIFFERENT doses for different size patients  

SAME CTDIvol  

Relative dose vs Diameter  

SSDE for Helical and Biopsy Mode  

Size Specific Dose Estimates (SSDE)  

- Estimate mean dose at center of scan range from CTDIvol, using a size dependent conversion factor  

\[ SSDE = f_{size} \times CTDI_{vol} \]  

AAPM Report 204  

SSDE for Helical and Biopsy Mode  

- Average dose in biopsy mode  

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

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

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

\[ y = 2.4497e^{-0.0208x}, R^2 = 0.9878 \]  

Normalized Dose vs A/P+Lateral (cm)
Skin Dose Estimation

- Skin dose can be respectively estimated from CTDIvol for helical mode and biopsy

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

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 Estimation

- Dependence on patient size and beam collimation


Effective Dose

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

Abdomen/Pelvis CT

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

### 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

### Dose Levels in CTGI

**Dose Survey**

- 561 patients in total

**Scan mode**

- Helical mode
- Biopsy mode

- Cryoablation
- Aspiration
- Biopsy
- Drain
- Injection

**Effective Dose Estimation**

- \( E = k \times DLP \)
- For helical mode, published \( k \) factor of 0.015 for the torso was used
- For Biopsy mode: \( k \) factor was determined using ImPACT: \( k = E / DLP \), average \( k \) in typical body regions

1. Lassen et al. 1999. 5b: 156-172.

**Average CTDIvol**

- Generally higher CTDIvol than diagnostic exams
- Significant difference among procedures
- Large variation among the same procedure
Dose Length Product (DLP)

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

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.

Effective 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.
Personnel dose surveys

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

![Graph showing personnel dose surveys](image)


Dose Monitoring

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

![Dose Monitoring graphic](image)

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 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)

**Dose Reduction**

- Limit scan range
- Set the right image quality
- Limit number of scans
- Use automatic exposure control
- Select appropriate KV
- Use iterative reconstruction

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**Radiation dose reduction techniques**

- Reduce kV and mA

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

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**Not always need same quality as diagnostic CT scans.**
- Simulated low dose scans, image quality reviewed to determine the lowest dose with sufficient IQ
- 50% dose reduction

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**Pre-change**

**Post-change**
**Radiation dose reduction techniques**

- **Reduce number of monitoring scans**
  - Reduced number of monitoring scans from every 3 mins to physician's discretion and lower technique

<table>
<thead>
<tr>
<th>Procedure Phase</th>
<th>Median Standard DLP (mGy·cm)</th>
<th>Median Dose Reduction DLP (mGy·cm)</th>
<th>P</th>
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<tbody>
<tr>
<td>Total</td>
<td>4833.5</td>
<td>2648</td>
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<tr>
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<tr>
<td>Monitoring</td>
<td>1733</td>
<td>866</td>
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</tr>
</tbody>
</table>


- **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.
Radiation dose reduction techniques

- Use of angular beam modulation
  - Significant reduction in patient dose:
    - Effective dose
    - Breast dose
    - Skin dose
    - Reduction: 25% 43% 75%
  - Significant reduction in personnel dose:
    - In beam
    - 10 cm from beam
    - Reduction: 75% 35%


Radiation protection for the operator and staff

- In most scenarios, reduction of patient dose also results in reduction of operator dose
- 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 Practice Guidelines for CT-Guided Interventional Procedures. JVIR. 2017

Summary

- CT scans performed during interventional procedures are different than those in diagnostic:
  - 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
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Thank You!