X-ray Imaging Dose from IGRT

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Introduction
- Image-guided radiation therapy (IGRT) has dramatically improved the accuracy of radiotherapy.
- IGRT has emerged as the new paradigm in radiotherapy.
- X-ray imaging, such as cone-beam CT (CBCT), for patient setup can add radiation dose to patients.
- Additional imaging dose may entail biological risk.
- Knowledge of x-ray imaging dose is useful in managing additional exposure to radiosensitive organs.

Imaging modalities and the use in radiotherapy
- electronic portal imaging device (EPID)
- kilovoltage digital radiography (kV DR)
- megavoltage cone-beam CT (MV-CBCT)
- kilovoltage cone-beam CT (kV-CBCT)
- CT-on-rails

MV AP setup field (Head and Neck)
MV AP setup field (double exposure)

MVCT on Linac unit

MVCT images

MVCT images

MVCT on Tomotherapy unit

MVCT Tomotherapy unit
Images of MVCT Tomotherapy unit

CT-on-rail system

Fig. 3. The schematic geometry for a CT-on-rails system showing the two rotation axes of the couch. C1 being the conventional rotational axis with respect to the Linac isocenter and C2 being the axis to rotate the couch into alignment with the CT scanner, which moves on rails along the scan axis.

kV CBCT system

kV Lat setup field

kV CBCT application for SBRT- Lung
Information from 2D images

- 2D projected verification images:
  - Bony anatomy relative to treatment isocenter
  - Seeds position relative to treatment field
  - Two orthogonal project images for 3D positioning
  - Treatment field shaped by MLC

Information from images

- 3D images from cone-beam CT:
  - Can be viewed in axial, coronal, and sagittal reconstructions from the volumetric images
  - Organ shape and position relative to isocenter
  - Small lung tumor
  - Can be used for monitor treatment progress and adaptive radiotherapy (ART)
  - Potential treatment target margin reduction

Monitoring treatment progress and ART

- Can be viewed in axial, coronal, and sagittal reconstructions from the volumetric images
- Organ shape and position relative to isocenter
- Small lung tumor
- Can be used for monitor treatment progress and adaptive radiotherapy (ART)
- Potential treatment target margin reduction
Radiation doses

- Detailed list see AAPM TG-75

- 2D projected verification images:
  - MV beams EPID (1-2 MU ~ 1-2 cGy/field)
    - Setup fields: two orthogonal beams
    - Treatment portal field
      - can be acquired during treatment (no additional dose)
      - Before or after (can be added to total dose)
    - Double exposure (area larger than the treatment field)

Radiation doses cont...

- 2D projected verification images:
  - kV beams from OBI device (~mGy/field)
    - Setup fields: two orthogonal beams
    - mAs can be automatically adjusted (patient size ↑ → dose ↑)
  - Dose rapidly decreases as a function of depth in patient

Radiation doses cont...

- CBCT volumetric images:
  - scan area is larger than the treatment field (~cGy/scan)
  - Standard acquisition mode
  - Low-dose acquisition mode
  - For the same scan (patient size ↓ → dose ↑)

Dose dependency on depth

- 6 MV
- 120 kVp

Dose dependency on medium for MV beam

- 6 MV
- Bone slabs in water

Dose dependency on medium for kV beam

- 125 kVp
- Bone slabs in water
X-rays (125 kVp) were used for CBCT from a Varian Trilogy.

Isodose distributions: single AP X-ray (CBCT beam) no bow-tie

Isodose: single AP 6 MV beam

Dose profiles along the line A-B on chest CT: kV vs. MV


kV-CBCT scans

Figure 1 Illustration of (a) the source rotation range for full fan type scan in which the x-ray source starts from patient’s left side and ends at 20 degrees over patient’s right side, (b) half fan type scan in which the x-ray source starts from patient’s left side and ends at patient’s left side.
Radiation dose dependency on scan techniques: Head

(a) OBI 1.3 Head scan in which the kV x-ray source rotated 370 degrees
(b) OBI 1.4 Standard Head scan in which the x-ray source rotates 200 degrees below the patient
(c) OBI 1.4 Standard Head scan in which the x-ray source rotates 200 degrees above the patient

Radiation dose dependency on scanned length: Pelvis

Full length (17 cm) Reduced length (5 cm)

Head scan: x-ray source rotated 200 degrees below the patient

Head scan: x-ray source rotated 200 degrees above the patient

Radiation dose to organs: DVH analysis
Radiation dose dependency on scanned length

Dose profiles in axial direction

- Standard scan length (17 cm)
- Scan length set to 10 cm
- Scan length set to 5 cm

Radiation dose dependency on scan techniques and filters: Pelvis Spot Light

Half-fan Bow-tie
Full-fan Bow-tie

Radiation dose dependency on patient size and scan techniques

Pelvis
Thorax

Dose distributions resulting from MV-CBCT: pelvic scan

PET Dose Results Using the OLINDA Code: Effective Dose

<table>
<thead>
<tr>
<th>Phantom</th>
<th>ICRP-60 ED (mSv/MBq)</th>
<th>Admin. Activity (MBq)</th>
<th>ED (mSv)</th>
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<td>Adult Male</td>
<td>1.85 x 10^{-2}</td>
<td>555</td>
<td>10.3</td>
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<tr>
<td>Adult Female</td>
<td>2.41 x 10^{-2}</td>
<td>555</td>
<td>13.4</td>
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</tbody>
</table>

Courtesy of Parham Alaei

Dose Calculations-Eleka XVI

Courtesy of George Xu
Summary

Commonly used image-guided procedures

- MV imaging:
  - megavoltage electronic portal imaging (MV-EPI)
  - megavoltage cone-beam CT (MV-CBCT)
    - On Linac unit
    - On Tomotherapy unit
  - 
kV imaging:
  - kilovoltage digital radiography (kV DR)
  - kilovoltage cone-beam CT (kV-CBCT)
  - CT-on-rail

Doses from image-guided procedures

- MV imaging:
  - MV-EPID: ~ 1-2 cGy /setup field
  - megavoltage cone-beam CT (MV-CBCT)
    - Linac unit: ~ 1 – 20 cGy /acquisition
    - Tomotherapy unit: 2-12 cGy
- kV imaging:
  - kV DR: ~ mGy (entrance dose)
  - kV-CBCT
    - Soft tissue: 0.1 - 4 cGy /acquisition
    - Bone: 0.3 - 8 cGy /acquisition

Summary cont...

- Imaged area is larger than the treatment field
- Imaging-guidance procedures are repeated daily
- kV DR imaging: high entrance dose
  - exit dose (~ 5% of entrance dose)
- MV EPID imaging: exit dose (~50% of entrance dose)

Summary cont...

- MV beam imaging:
  - Dose resulting from MV-CBCT is comparable to that of multiple portal imaging acquisitions
  - Negligible difference between dose to bone and dose to soft tissues
- kV x-ray imaging:
  - Dose resulting from kV-CBCT is much larger than that of multiple kV DR acquisitions
  - Dose to bone is 2-4 times higher than the dose to soft tissues
  - Compare radiation exposure from current kV-CBCT with conventional EPID for patient positioning
    - Dose from kV-CBCT < Dose from EPID

Summary cont...

- Techniques to reduce scan exposure
  - Use imaging guidance efficiently:
    - Choose the procedure and the frequency that is most suitable for the purpose
    - Develop protocols for using image guidance procedures
    - Pay attention to pediatric patients and imaged volume
  - Use latest version of scan software:
    - The imaging doses to patient resulting from OBI 1.4 are much lower than OBI 1.3. For some CBCT scans, the dose is more than 15 times less in OBI 1.4.
  - Rotating the x-ray source above or below the patient can result in a factor of 3 difference in the dose to the lens of the eye
  - The imaging dose to the patient can be further reduced (50%) in Pelvis Spot Light mode if the mode is calibrated with the full fan bow-tie filter.
  - X-ray source rotating above the patient in Pelvis Spot Light mode can minimize dose to the rectum (a 70% reduction)
  - Dose to a patient for an abdominal site can be reduced significantly (70% reduction) by selecting Low Dose Thorax scan instead of Pelvis scan for small (e.g., pediatric) patients.
  - Significant reductions in both the radiation dose (40%) and the volume can be achieved by reducing the scanned length when only a smaller region of interest is needed.
Future considerations

- Account imaging guidance dose for radiotherapy patients
- Calculate organ doses resulting from image guided procedures
- Account them as part of total dose to patients in radiotherapy treatment planning systems

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