Introduction

• Image-guided radiation therapy (IGRT) significantly improves the accuracy of radiotherapy.
• It plays an essential role in the accurate delivery of highly conformal dose to target.
• IGRT is the new paradigm in radiotherapy.
• X-ray imaging procedures for patient setup may add additional radiation dose to patients.
• Imaging dose may entail risk to patients.

Learning Objectives

1. Understand the different available image guidance modalities and devices used in IGRT;
2. Understand the magnitude of the organ dose resulting from different devices and acquisition procedures;
3. Understand the variation of patient imaging dose distributions among different imaging procedures;
4. Understand how patient dose distributions from an image procedure are calculated;
5. Understand why dose-to-bone is much higher than dose-to-soft tissue for kilovoltage x-rays;
6. Learn the techniques to reduce the imaging dose to patients and sensitive organs;
7. Update on the progress of AAPM TG-180 report.

Image Guidance Modalities

Commonly used x-ray image devices

• MV electronic portal imaging device (EPID)
  o 2D images: portal images
  o 3D images: MV-CBCT
  o 3D images: MVCT
• kV x-ray devices integrated to treatment unit
  o 2D images: digital radiographs
  o 3D images: kV-CBCT
**Electronic portal imaging device (EPID)**

A typical MV setup field

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**Imaging dose from MV portal images**

An Anterior and a Right lateral field (2 MUs for each field)

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**Imaging dose from MV-CBCT**

Gayou et al.: Patient dose and image quality from MV-CBCT

Medical Physics, Vol. 34, No. 2, February 2007

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**Imaging dose from MVCT in Tomo**

Dose at the center of s to a 30 cm water phantom:

- Fine pitch: 2.5 cGy
  (4mm couch travel/rotation)
- Normal pitch: 1.25 cGy
  (8mm couch travel/rotation)
- Coarse pitch: 0.83 cGy
  (12mm couch travel/rotation)

Statistics:
73% of Tomo customer imaging procedures are done using the Coarse pitch.
24% are done using the Normal pitch.

An MVCT image acquired during commissioning

Courtesy Edward Chao, Accuray Incorporated and T. Rock Mackie, UW, Madison, WI
**kV x-ray devices on treatment unit**

2D images: digital radiograph

**Dose dependency on depth for kV and MV**

**Dose dependency on medium for kV and MV**

Single beam incident from right

**Patient dose from an anterior field for kV and MV**

6 MV beam (2 MUs)

MV: 100% dose = 2.17 cGy
kV: 100% dose = 0.094 cGy

MV: exit dose 40%
kV: exit dose 4%
Dosimetry of imaging dose for kV and MV

- MV beam dose:
  - Model based algorithms or Monte Carlo (beams from linear accelerators commissioned in TPS)
  - Reference beam output calibration (dosimetry protocols)

- kV beams dose:
  - Monte Carlo methods (beams from X-ray tubes simulated)

- Validation of calculated dose:
  - Experimental verifications: calculation predicted dose vs. measured dose

kV x-ray medium dependency: soft tissues vs. bone


3D images: kV CBCT

Organ dose dependency on scan techniques: Head

Fig. 3. Illustration of (a) the source rotation range for full fan type scan in which the X-ray source starts from the patient’s left side and ends at 29° past the 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.

Fig. 5. The CBCT scan dose data shown in (a) (b) (c) dose and (d) dose-volume histogram analysis for specific substructure organs. CBCT 1.3 Standard Dose Head scan dose data are shown in (b) and (c). Note that the dose data in (d) is 10 times larger than in (e). For 2D scans, the effect when placing the X-ray source below (b) and above (c) the patient is also compared quantitatively in (f).
**Imaging dose reduction OBI 1.3 vs 1.4: Thorax scan**


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**Radiation dose dependency on scanned length: Pelvis**


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**Dose dependency on scan techniques and filters: Pelvis Spot Light**


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**Dose dependency on scan techniques and filters: Pelvis Spot Light**

Radiation dose dependency on patient size and scan techniques

Progress in technology continues to reduce imaging dose

Example: a new kV x-ray source in TrueBeam results reduced dose mainly due to:
- An additional kV beam hardening filter
- Less lower energy photons in the energy spectrum

Organ doses expressed by dose volume histograms (DVHs) for each corresponding image procedure. Note that the abscissa for MV imaging is 10 times larger than for kV imaging.
Summary

• Imaged area is larger than the treatment area
• Repeated imaging procedures may sum up additional doses to radiosensitive organs
• Current x-ray imaging procedures in IGRT:
  – 2D imaging (two orthogonal or oblique fields)
    – MV (setup fields using EPID)
    – kV (digital radiographs)
  – 3D volumetric imaging
    – MVCT / MV-CBCT
    – kV-CBCT

MV imaging:
– dose to bones is ~ dose to soft tissues
– exit dose (~ 50% of entrance dose)

kV imaging:
– Dose-to-bone is 2-4 times ~ dose-to-soft tissues
– exit dose (~ 5% of entrance dose)

Summary

Doses from image-guided procedures

MV imaging:
– EPID: 4 - 6 cGy from two orthogonal portal images
– MVCT (TOMO): 1 - 3 cGy
– MV-CBCT: 1 - 16 cGy

kV imaging:
– kV DR: 0.1 - 1.0 cGy
– kV-CBCT
  • Soft tissue: 0.1 - 3 cGy /acquisition
  • Bone: 0.3 - 6 cGy /acquisition

Summary

Imaging dose comparison from different imaging procedures in descending order:
– MV-CBCT (3D imaging)
– MV (EPID) (2D imaging)
– kV-CBCT (3D imaging)
– kV radiograph (2D imaging)
Future

- Improve imaging technology (ongoing progress by manufacturers)
  - reduce imaging doses and improve image quality.
- Use x-ray imaging efficiently:
  - Choose the procedure and the frequency that is most suitable for the purpose
  - Develop protocols for using imaging procedures
  - Pay attention to pediatric patients and reduce imaged region of interest if possible
- Account and document imaging dose for radiotherapy patients
  - Calculate organ doses resulting from image guided procedures / estimate organ doses by using tabulated values resulting from typical imaging procedures
  - Account imaging dose as part of total dose to patients in radiotherapy treatment planning systems

AAPM TG-180

TG-180 Specific list of charges

1. To identify the important issues such as the large variations between dose to bone (or bone marrow) and dose to soft tissues for x-rays at kilovoltage energy range.
2. To provide an overview on the general approach to clinical implementation of accounting for the imaging guidance dose from x-ray imaging procedures in radiotherapy include megavoltage electronic portal imaging (MV EPID), kilovoltage digital radiography (kV DR), tomotherapy MVCT, megavoltage cone-beam CT (MV-CBCT) and kilovoltage cone-beam CT (kV-CBCT).
3. To provide general guidelines for
   - commissioning an imaging beam in a treatment planning system
   - various verification techniques and experimental methods to assure an accurate imaging beam model commission process
   - specific recommendations on the dose calculation accuracy from an imaging procedure in a treatment planning system.

TG-0180 draft report v.2 is being distributed and discussed in the group.