X-ray Imaging Dose to Patients in the Era of Image-Guided Radiation Therapy

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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
- How much are the imaging doses to patients?

Modalities used in imaging guidance

- 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

Electronic portal imaging device (EPID)
MVCT images


MVCT images

Images of MVCT Tomotherapy unit

MVCT on Tomotherapy unit

Fig. 4. The helical tomotherapy unit located at the University of Wisconsin. The left panel is with a cone open. The panel on the right is holding the CT on the Tomotherapy unit.
Images of MVCT Tomotherapy unit

CT-on-rail system

kV CBCT system
Monitoring treatment progress and ART

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

Feasibility of kV CBCT for treatment planning

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)
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)
- 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**
  - Monte Carlo
  - Density corrected
  - Bone slabs in water

Dose dependency on medium for kV beam

- **125 kVp**
  - Bone slabs in water
  - Monte Carlo
  - Density corrected

Slab of water
- 20 cm thickness
- X-rays (125 kVp)

Isodose distributions: single AP X-ray (CBCT beam) no bow-tie
- 125 kVp x-rays used for CBCT from Varian Trilogy
Isodose distributions: single AP 6 MV beam

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

Dose distributions resulting from a kV CBCT Head and Neck
Results of dose-volume-histogram analysis for H&N scan

Results of dose-volume-histogram analysis for chest scan

Dose distributions resulting from a kV CBCT
Chest
Results of dose-volume histogram analysis for a pelvic kV CBCT scan Large Adult

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

Dose distributions resulting from MV-CBCT: pelvic scan

Summary cont...
Doses from image-guided procedures
- **MV Imaging:**
  - MV-EPI: ~ 1-2 cGy /acquisition
  - megavoltage cone-beam CT (MV-CBCT)
    - Linac unit: ~ 5 - 20 cGy /acquisition
    - Tomotherapy unit: 8-12 cGy
- **kV Imaging:**
  - kV DR: ~ mGy (entrance dose)
  - kV-CBCT
    - Soft tissue: 2 - 8 cGy /acquisition
    - Bone: 8 - 25 cGy /acquisition
Summary cont...

- Imaged area is larger than the treatment field
- Imaging-guidance procedures are more frequent than diagnostic imaging
- Repeated imaging procedures can sum up significant dose to radiosensitive organs
- kV DR imaging: high entrance dose
  - exit dose (~5% of entrance dose)
- MV EPID imaging: exit dose (~50% of entrance dose)

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
- Dose to bone marrow? (see Kawakoe et al WE-E-332-04)

What to do now?

- Improve imaging technology (manufactures)
  - Increase image quality and decrease the dose to patients
  - Progress is being made
- 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
- 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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