TH-B-211-1

Patient Organ Doses From Imaging in IGRT: kV Radiograph vs. kV-CBCT vs. MV Portal Image vs. MV-CBCT

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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

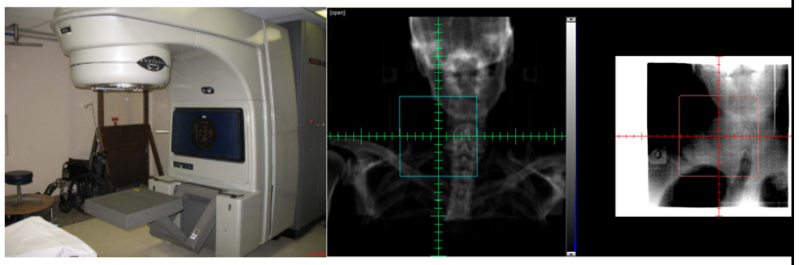
1. Understand the different available image guidance modalities and devices used in IGRT);
2. Understand the magnitude of the organ dose resulting from difference devices and acquisition procedures;
3. Understand the variation of patient imaging dose distributions among different imaging procedures;
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)
  - 2D images: portal images
  - 3D images: MV-CBCT
  - 3D images: MVCT
- kV x-ray devices integrated to treatment unit
  - 2D images: digital radiographs
  - 3D images: kV-CBCT

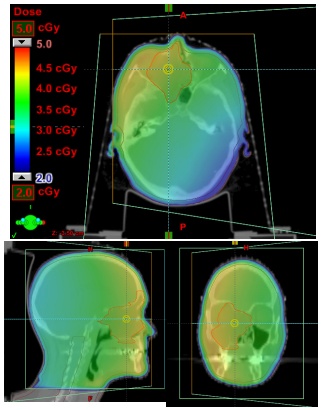
Electronic portal imaging device (EPID)

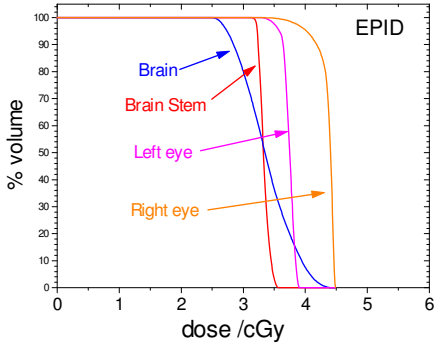


A typical MV setup field

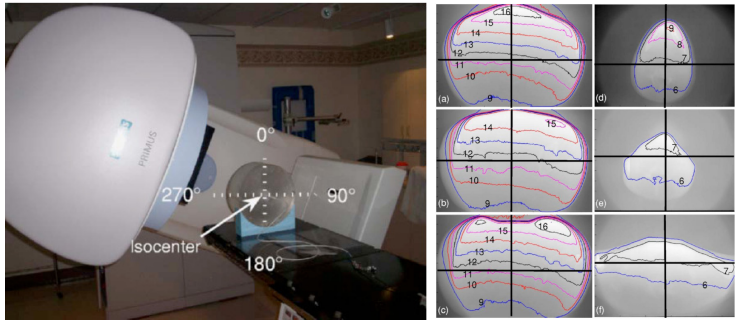
Imaging dose from MV portal images

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



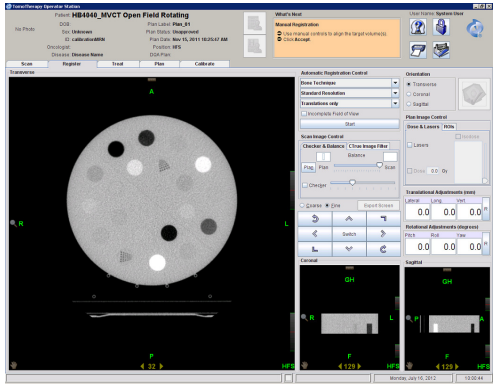


Imaging dose from MV-CBCT



Gayou *et al.*: Patient dose and image quality from MV-CBCT
Medical Physics, Vol. 34, No. 2, February 2007

Imaging dose from MVCT in Tomo



An MVCT image acquired during commissioning

Courtesy Edward Chao, Accuray Incorporated and T. Rock Mackie, UW, Madison, WI

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

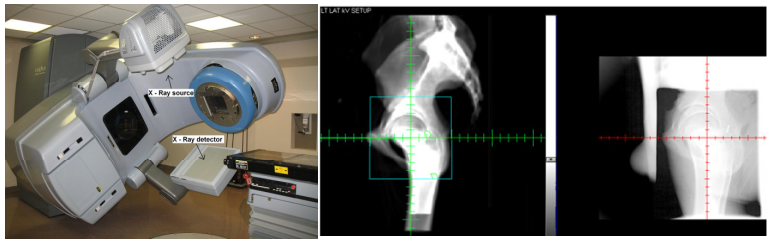
Fine pitch: 2.5 cGy
(4mm couch travel/rotation)

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.

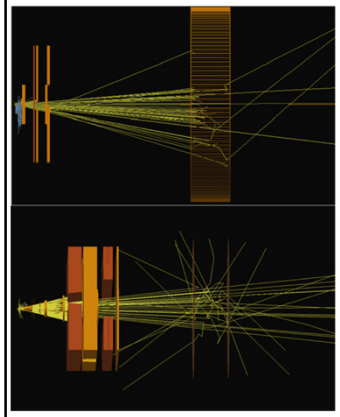
kV x-ray devices on treatment unit

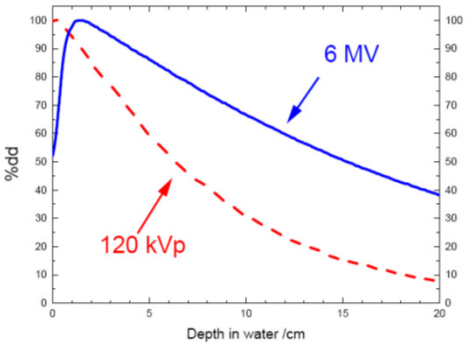


Phys. Med. Biol. **52** (2007) 1595–1615

2D images: digital radiograph

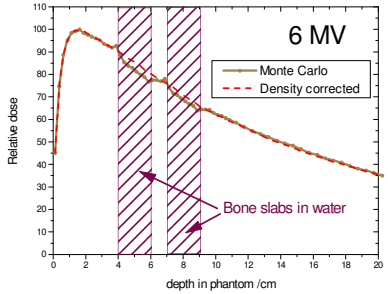
Dose dependency on depth for kV and MV

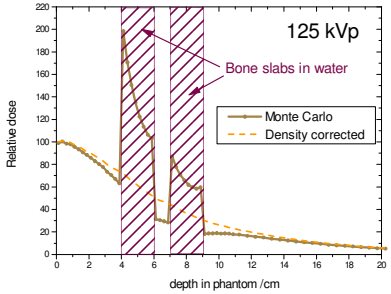




Dose dependency on medium for kV and MV

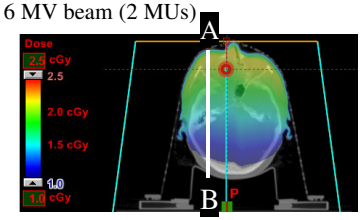
Single beam incident from right



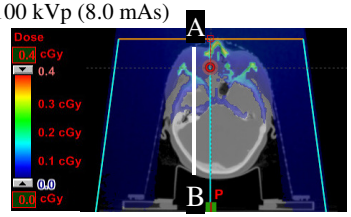


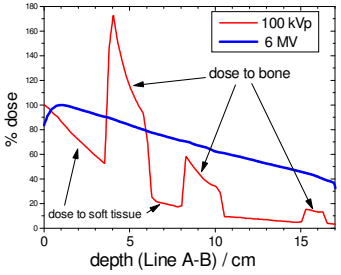
Patient dose from an anterior field for kV and MV

6 MV beam (2 MUs)



100 kVp (8.0 mAs)





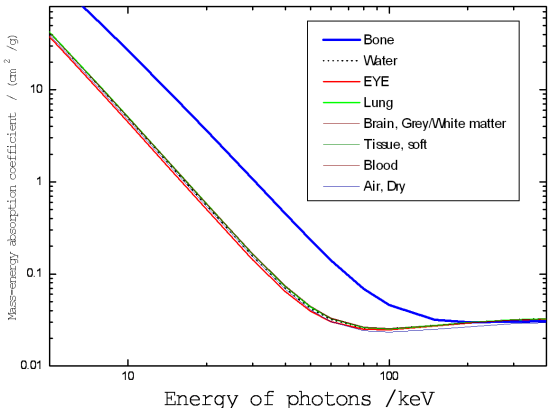
MV: 100% dose = 2.17 cGy
kV: 100% dose = 0.094 cGy

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)
  - X-ray source output calibration for each specific procedure (Med Phys v35, pp.1135-44, 2008 and Phys Med Biol, v55, 5231-5248, 2010)
- Validation of calculated dose:
  - Experimental verifications: calculation predicted dose vs. measured dose

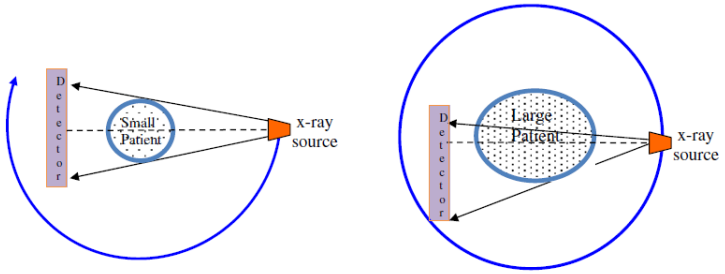
kV x-ray medium dependency: soft tissues vs. bone



Data from: J. H. Hubbell and S. M. Seltzer, "Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients," National Institute of Standards and Technology, Gaithersburg, MD NISTIR 5632, 1995.

3D images: kV CBCT

G.X. Ding et al. / Radiotherapy and Oncology 97 (2010) 585–592



200 degree source rotation and the detector is centered

(a) Full fan type scan

360 degree rotation and the detector is shifted to one side

(b) Half fan type scan

Fig. 1. 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 20° 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.

Organ dose dependency on scan techniques: Head

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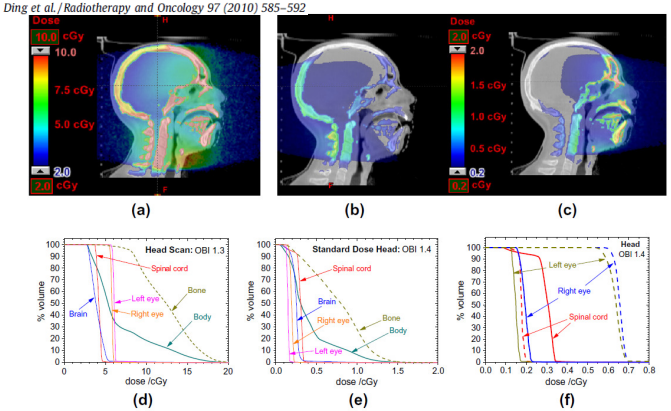
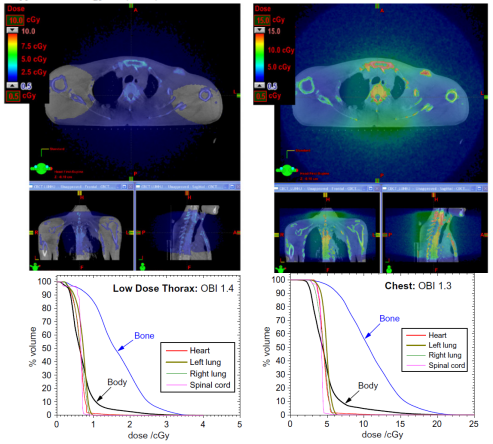


Fig. 2. The OBI 1.3 scan doses are shown in (a) color-wash and (d) dose–volume histogram analysis for specific radiosensitive organs; OBI 1.4 Standard-Dose Head scan doses are shown in (b) and (e). Note that the abscissa in (d) is 10 times larger than in (e). For 200° scans, the effect when rotating 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

G.X. Ding et al./Radiotherapy and Oncology 97 (2010) 585–592



Radiation dose dependency on scanned length: Pelvis

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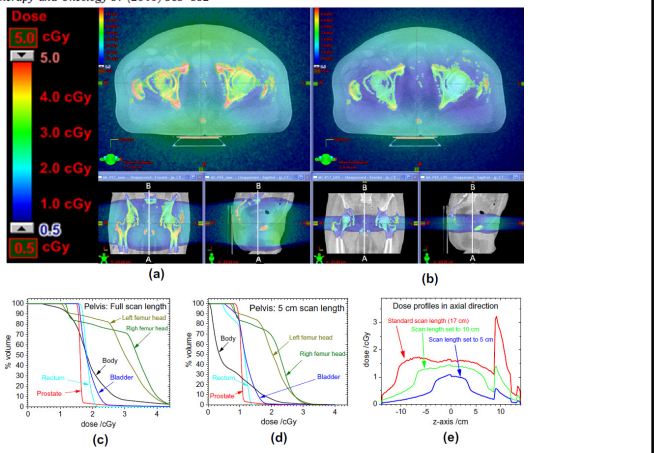

Dose dependency on scan techniques and filters: Pelvis Spot Light

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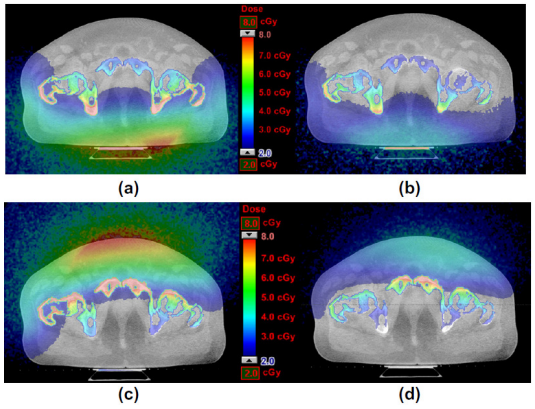

Fig. 4. (a) and (b) Axial view showing dose distributions in color-wash resulting from current Pelvis Spot Light scan with half Bow-tie and with full bow-tie, respectively; (c) and (d) dose distributions in color-wash resulting from OBI 1.4 Pelvis Spot Light scan with half fan bow-tie and with full fan bow tie, respectively. (e), (f), (g) and (h) Corresponding dose–volume histograms for the specific organs.

Dose dependency on scan techniques and filters: Pelvis Spot Light

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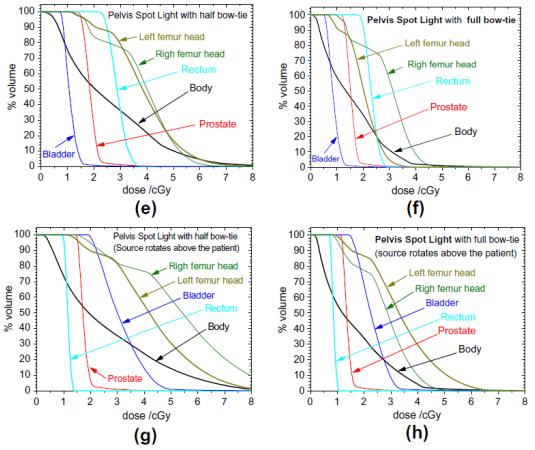
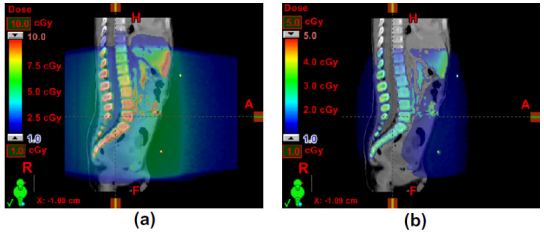
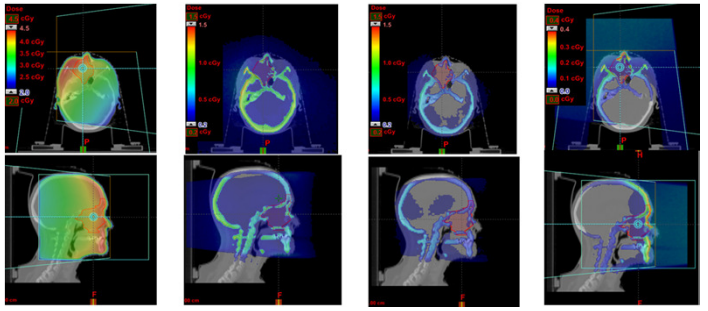


Radiation dose dependency on patient size and scan techniques



MV(EPID), kV-CBCT(OBI 1.4), kV-CBCT(TrueBeam), kV radiographs



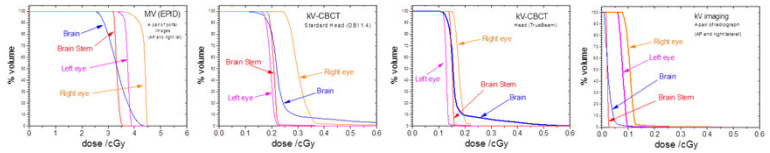
EPID (MV)
(AP + Rt Lat)
Dose color wash scale
2.0 - 4.5 cGy

kV-CBCT
(OBI 1.4)
Dose color wash scale
0.15 - 1.5 cGy

kV-CBCT
(TrueBeam)
Dose color wash scale
0.15 - 1.5 cGy

kV-radiograph
(AP + Rt Lat)
Dose color wash scale
0.04 - 0.40 cGy

MV(EPID), kV-CBCT(OBI 1.4), kV-CBCT(TrueBeam), kV radiographs



EPID (MV)
(AP + Rt Lat)

kV-CBCT
(OBI 1.4/1.5)

kV-CBCT
(TrueBeam)

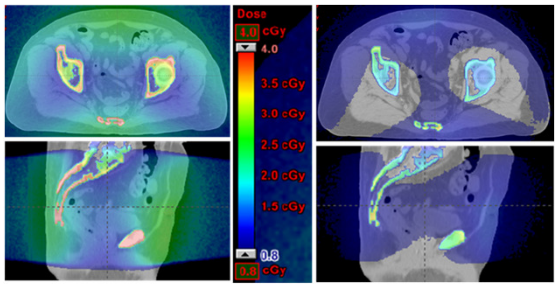
kV-radiograph
(AP + Rt Lat)

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.

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



kV-CBCT from Trilogy

kV-CBCT from TrueBeam

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

Summary

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 (on-going 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 .