X-ray Imaging Dose from IGRT

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Introduction

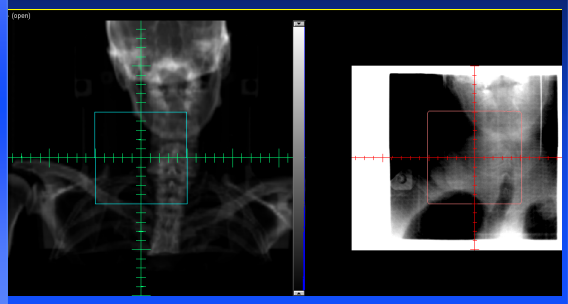
- Image-guided radiation therapy (IGRT) has dramatically improved the accuracy of radiotherapy
- IGRT has emerged as the new paradigm in radiotherapy.
- X-ray imaging, such as cone-beam CT (CBCT), for patient setup can add radiation dose to patients.
- Additional imaging dose may entail biological risk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

Imaging modalities and the use in radiotherapy

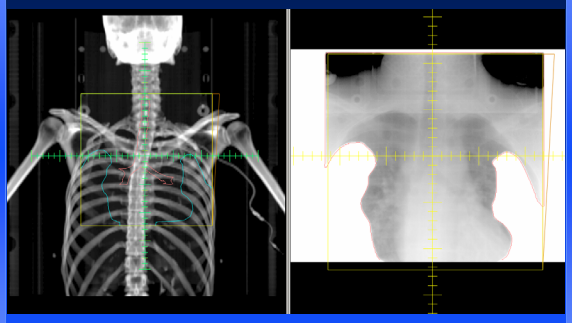
- electronic portal imaging device (EPID)
- kilovoltage digital radiography (kV DR)
- megavoltage cone-beam CT (MV-CBCT)
- kilovoltage cone-beam CT (kV-CBCT)
- CT-on-rails

Electronic portal imaging device (EPID)

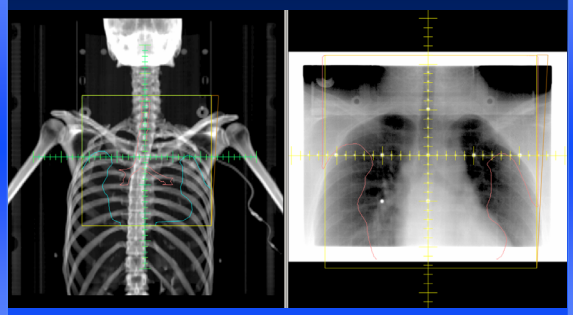
MV AP setup field (Head and Neck)



MV AP setup field



MV AP setup field (double exposure)



MVCT on Linac unit

Gayou *et al.*: Patient dose and image quality from MV-CBCT Med. Phys. 34 (2), February 2007

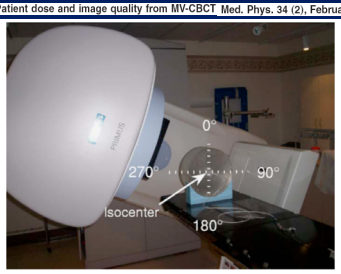


FIG. 1. The cylindrical acrylic phantoms measurement setup. A small volume chamber was placed at the isocenter as well as 1 cm below the surface at the 0°, 90°, 180°, and 270° positions.

MVCT images

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

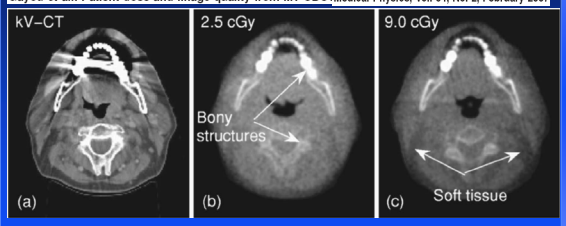


FIG. 8. Transverse slice of a head and neck patient imaged with (a) kV-CT, (b) 2.5 cGy MV-CBCT protocol, (c) 9.0 cGy MV-CBCT protocol. The lower dose is sufficient to show the bony structures on the MV-CBCT image. Soft tissue boundaries are more visible with the higher dose.

MVCT images

Sillanpaa *et al.*: Gated megavoltage cone beam CT with aS500 EPID Medical Physics, Vol. 32, No. 3, March 2005

FIG. 12. 20 MU large-field scan registered to a diagnostic CT scan of the same phantom, using a CT-to-CT registration tool. Left: axial view; right upper: coronal view; right lower: sagittal view. MV reconstructions are in the lower-right and upper-left quadrants of each image.

MVCT on Tomotherapy unit

I. J. Radiation Oncology ● Biology ● Physics Volume 56, Number 1, 2003
Image-guided radiotherapy ● T. R. MACKIE *et al.*

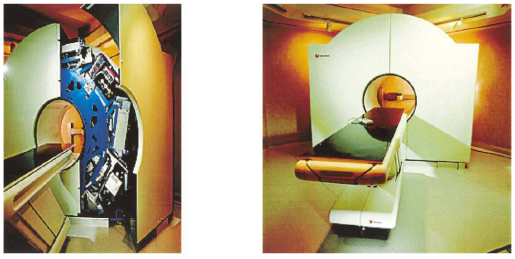
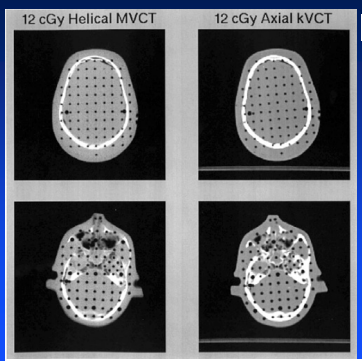


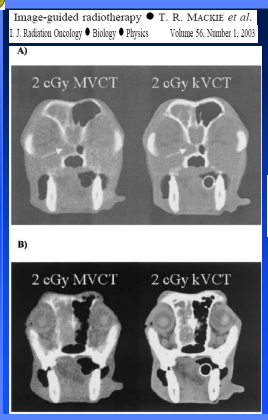
Fig. 3. The helical tomotherapy unit installed at the University of Wisconsin. The left panel is with a cover open. The panel on the right is looking along the CT table into the ring gantry bore.

MVCT Tomotherapy unit



K J Ruchala et al
Phys. Med. Biol. **44** (1999) 2597–2621

Figure 10. A comparison of the MVCT and kVCT for reconstructed slices of the Rando phantom.



Images of MVCT Tomotherapy unit

Fig. 4. Comparison of MVCT images to kVCT images. Shown are 2 CT slices from a dog with sarcoma of the sinus. (A) Erosion of the bone is shown with the white arrow. (B) The left sinus is filled with tumor. The MVCT image at 2 cGy does not have sufficient contrast for diagnosis but is sufficient for purposes of localization.

CT-on-rail system

Murphy *et al.*: Imaging dose during image-guided radiotherapy
Medical Physics, Vol. 34, No. 10, October 2007

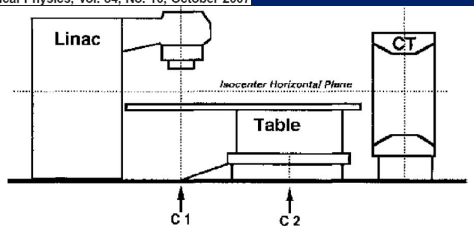
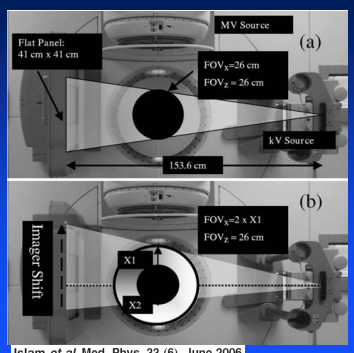


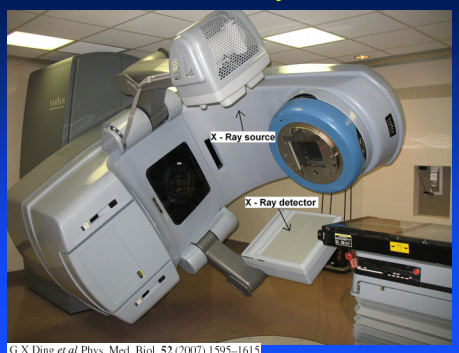
FIG. 3. The schematic geometry for a CT-on-rails system showing the two rotation axes of the couch: C1 being the conventional rotational axis with respect to the Linac isocenter and C2 being the axis to rotate the couch into alignment with the CT scanner, which moves on rails along the scan axis.

kV CBCT system



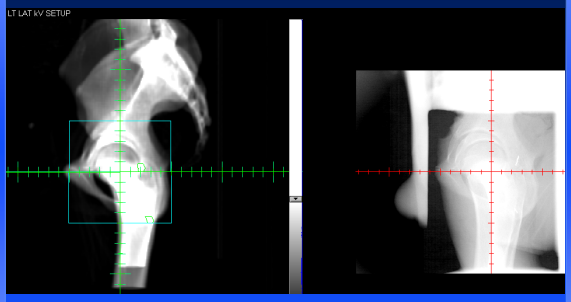
Islam *et al.* Med. Phys. 33 (6), June 2006

kV CBCT system

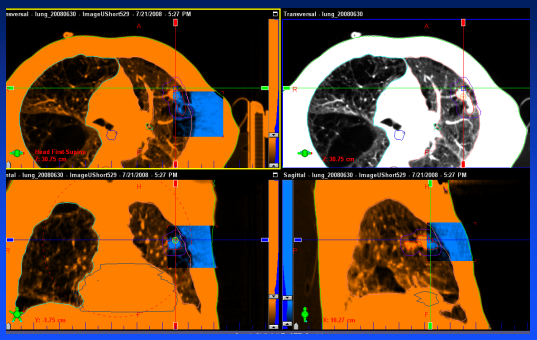


G X Ding *et al* Phys. Med. Biol. **52** (2007) 1595–1615

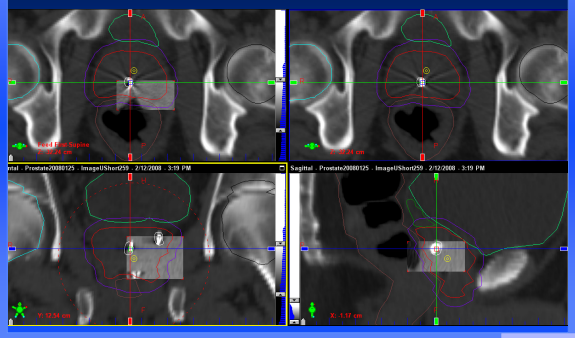
kV Lat setup field



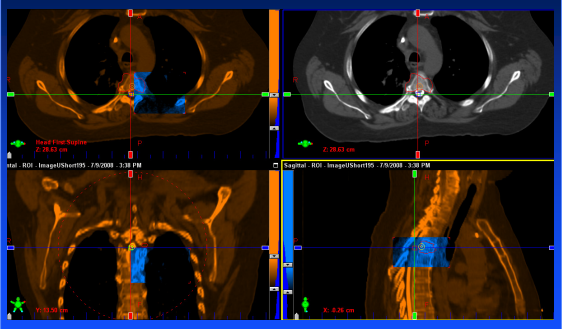
kV CBCT application for SBRT- Lung



kV CBCT application for SBRT- Prostate

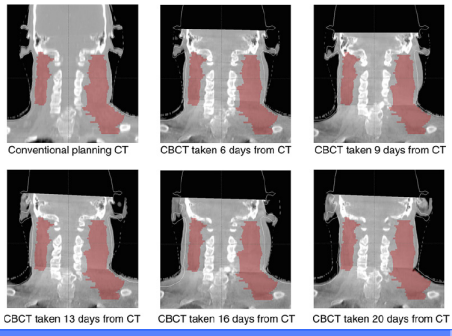


kV CBCT application for SBRT- spine



Monitoring treatment progress and ART

G.X. Ding et al. / Radiotherapy and Oncology 85 (2007) 116–125



Feasibility of treatment target margin reduction

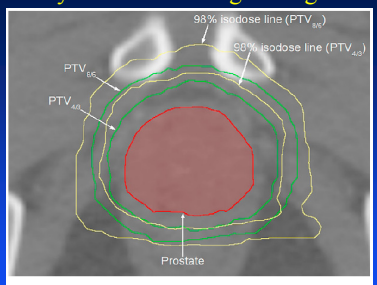


Fig. 1. Axial cross-section view from patient 5 showing 98% isodose lines (yellow) for treatment plans optimized to the current PTV margins ($PTV_{8/6}$) and reduced margins ($PTV_{4/3}$) (green).

Dose reduction to OARs in prostate cancer patients ● J. M. Pawlowski *et al.*
I. J. Radiation Oncology ● Biology ● Physics Volume 76, Number 3, 2010

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 saggittal 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)

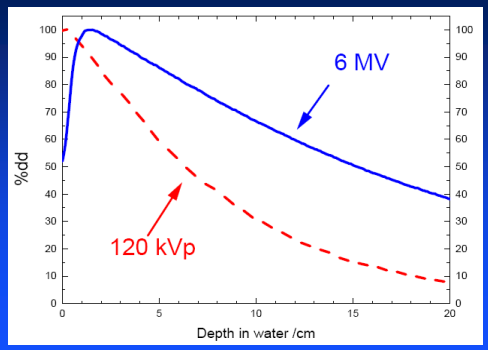
Radiation doses cont…

- 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

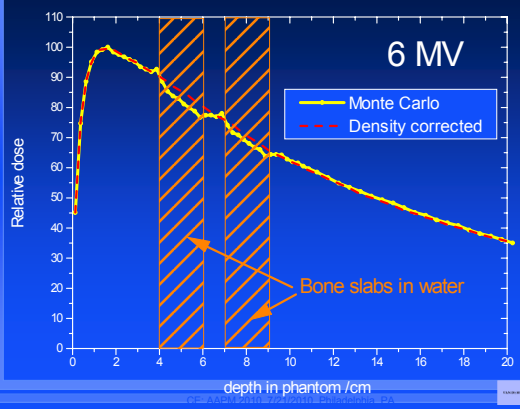
Radiation doses cont…

- 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 ↑)

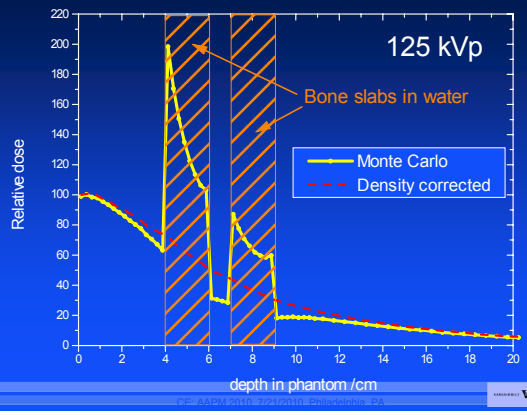
Dose dependency on depth

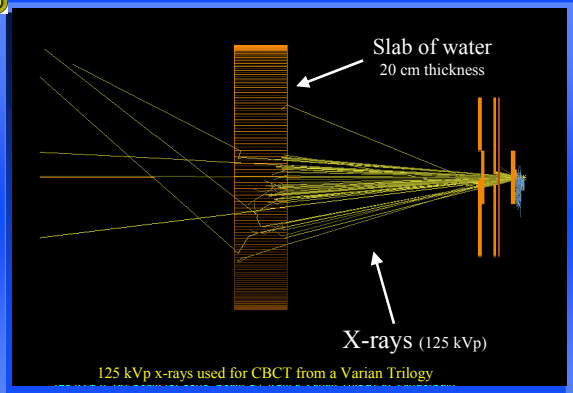


Dose dependency on medium for MV beam



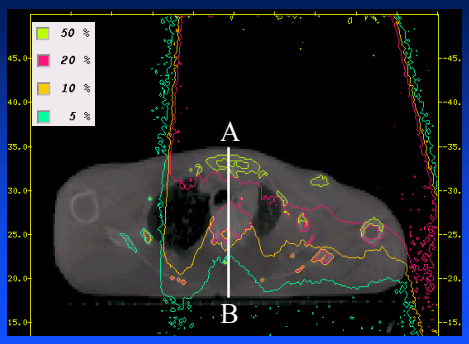
Dose dependency on medium for kV beam



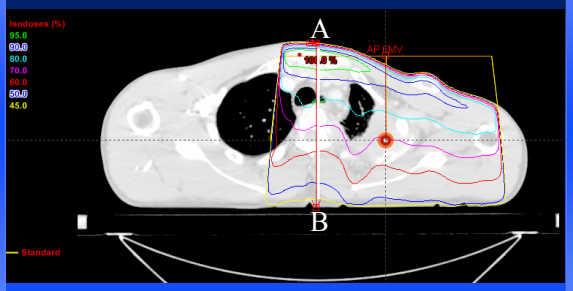


125 kVp x-rays used for CBCT from a Varian Trilogy

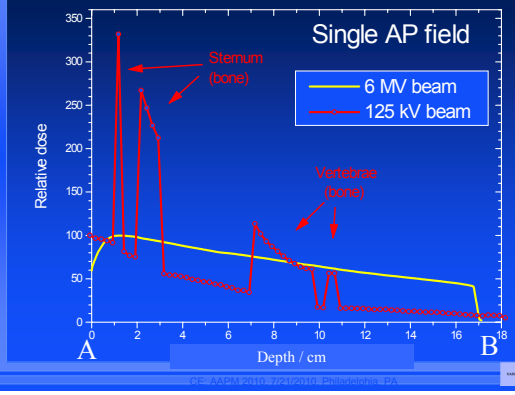
Isodose distributions: single AP X-ray (CBCT beam) no bow-tie

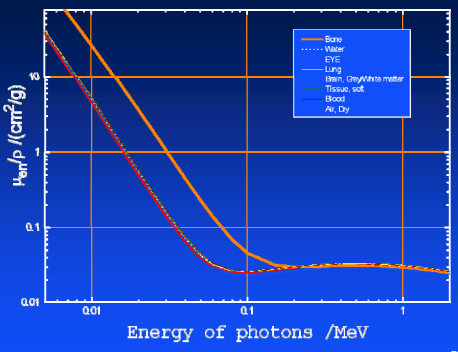


Isodose: single AP 6 MV beam



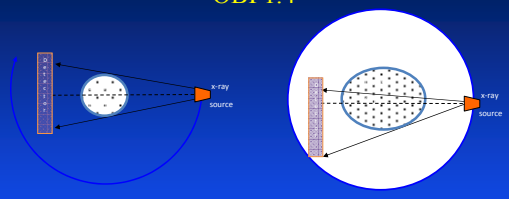
Dose profiles along the **line A-B** on chest CT: kV vs. MV





Data are 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.

kV-CBCT scans
OBI 1.4



200 degree source rotation and the detector is centered

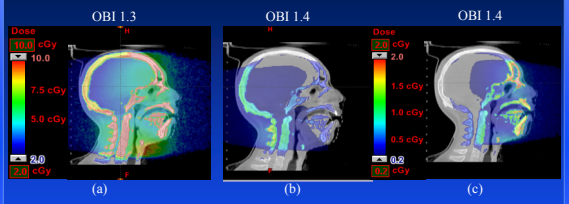
(a) Full fan type scan

360 degree rotation and the detector is shifted to one side

(b) Half fan type scan

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



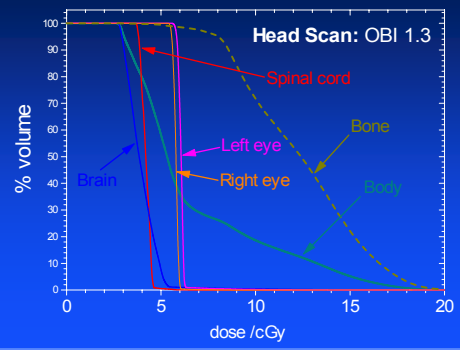
Dose distributions in color wash saggittal views resulting from

(a) OBI 1.3 Head scan in which the kV x-ray source rotated 370 degrees

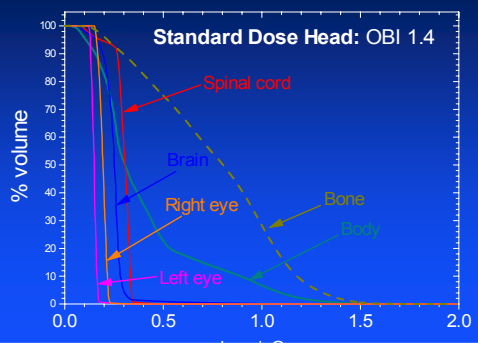
(b) OBI 1.4 Standard Head scan in which the x-ray source rotates 200 degrees below the patient

(c) OBI 1.4 Standard Head scan in which the x-ray source rotates 200 degrees above the patient

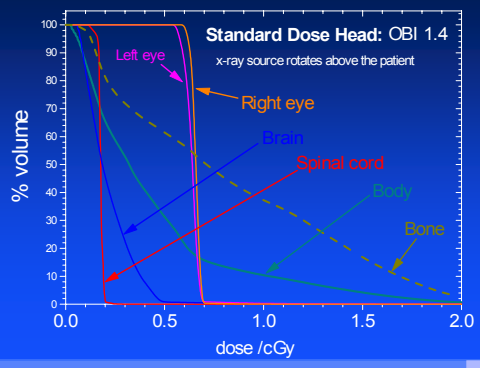
OBI 1.3 Head scan: x-ray source rotated a full circle (360 degrees +10)



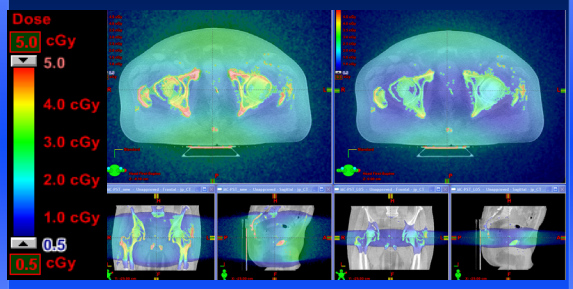
Head scan: x-ray source rotated 200 degrees below the patient



Head scan x-ray source rotated 200 degree above the patient

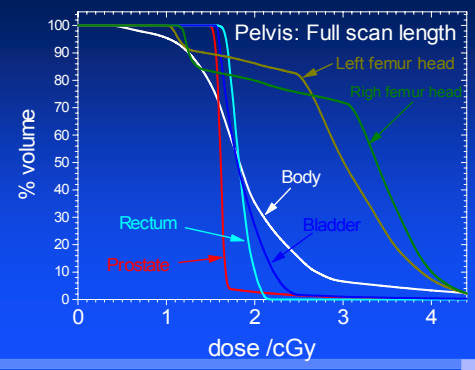


Radiation dose dependency on scanned length: Pelvis

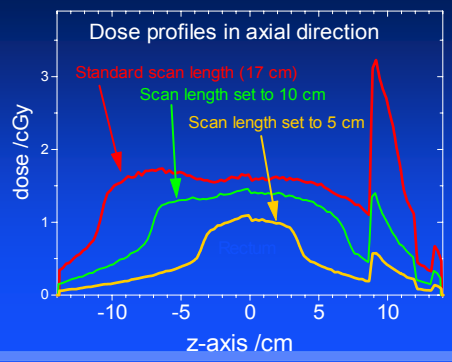


Full length (17 cm) Reduced length (5 cm)

Radiation dose to organs: DVH analysis

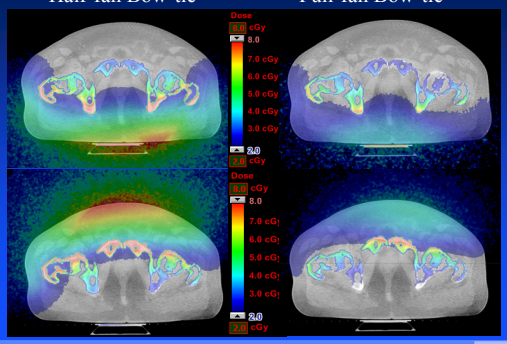


Radiation dose dependency on scanned length



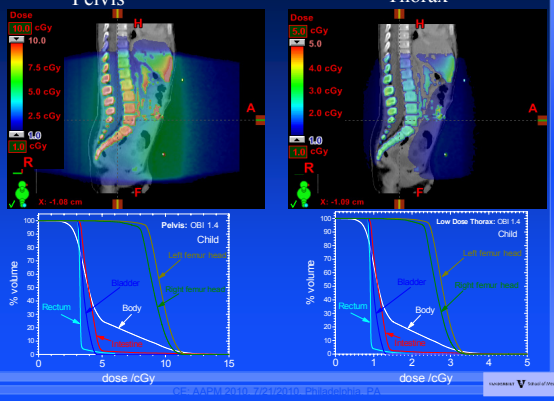
Radiation dose dependency on scan techniques and filters: Pelvis Spot Light

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

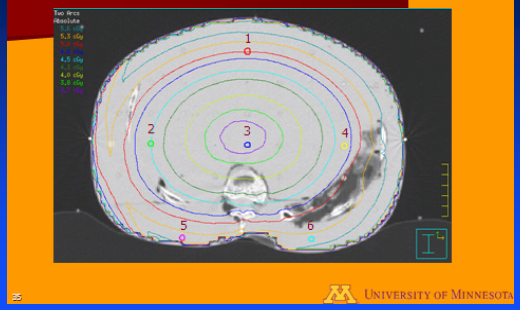


Radiation dose dependency on patient size and scan techniques

Pelvis | Thorax



Dose Calculations-Elekta XVI



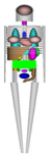
University of Minnesota

Courtesy of Parham Alaei

Rensselaer

PET Dose Results Using the OLINDA Code: Effective Dose

^{18}F-FDG PET emission scan using ICRP-106 Biokinetics



Phantom	ICRP-60 ED (mSv/MBq)	Admin. Activity (MBq)	ED (mSv)
Adult Male	1.85×10^{-2}	555	10.3
Adult Female	2.41×10^{-2}	555	13.4

Courtesy of George Xu

Dose distributions resulting from MV-CBCT: pelvic scan

Miften *et al.*: IMRT incorporating MV-CBCT dose — Medical Physics, Vol. 34, No. 10, October 2007

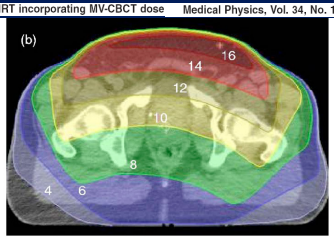


FIG. 1. (a) Examples of transverse images from a MV-CBCT dataset acquired with a dose of 10 cGy at isocenter using the 15 MU protocol. The bony anatomy, and soft tissue such as prostate, seminal vesicles, rectum, and bladder can be identified. (b) Distribution of dose deposited in the pelvis by a single fraction of CB imaging for the same prostate patient, with 10 cGy at isocenter. The isodose lines are labeled in cGy.

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

Summary cont...

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

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.

Techniques to reduce scan exposure

- 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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