Phantom and in vivo measurements of dose exposure by image-guided radiotherapy (IGRT): MV portal images v. kV portal images v. cone beam CT

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Introduction to radiotherapy

- Definition: Radiotherapy (radiation therapy) is the treatment of cancerous cells with ionizing radiation
- High energy x-rays in the megavolt MV range
  - 1 photon = millions of electron volts of energy
  - Goal: to damage cell DNA to stop their proliferation
- How do we ensure precise delivery of the therapy beam to the cancer cells with minimal exposure to normal tissues?

Image guidance

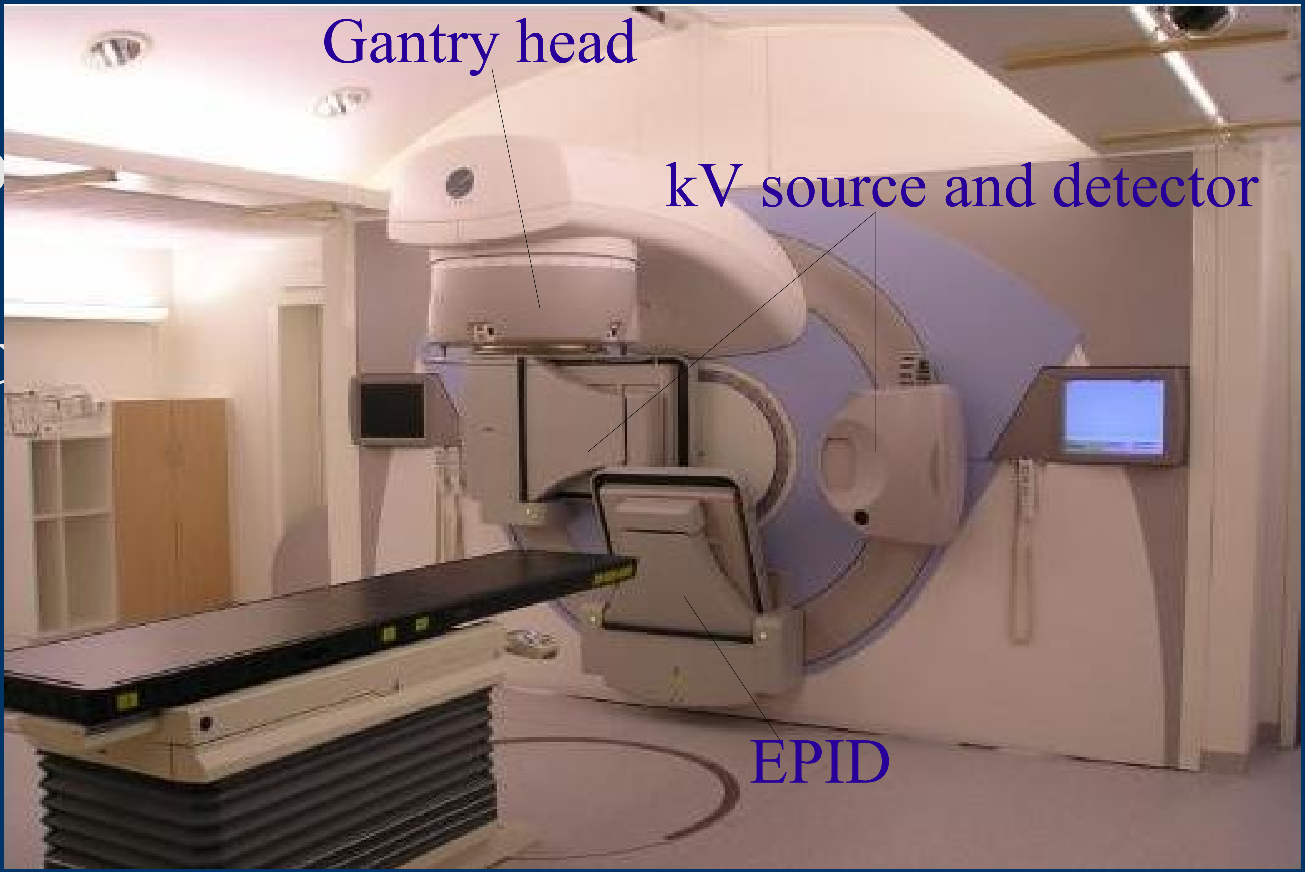
- Take an image of internal patient anatomy before and sometimes during treatment
- Efficient imaging techniques minimize the difference between clinical target volume and planning target volume
  - Clinical target volume: actual site and volume of the cancerous mass
  - Planning target volume: created to account for tumor/organ movement or change in size

What determines the effectiveness of an imaging technique?

- High contrast
- Spatial resolution
- Low dose exposure to the patient
  - The most commonly used imaging techniques involve x-rays

Imaging modalities evaluated

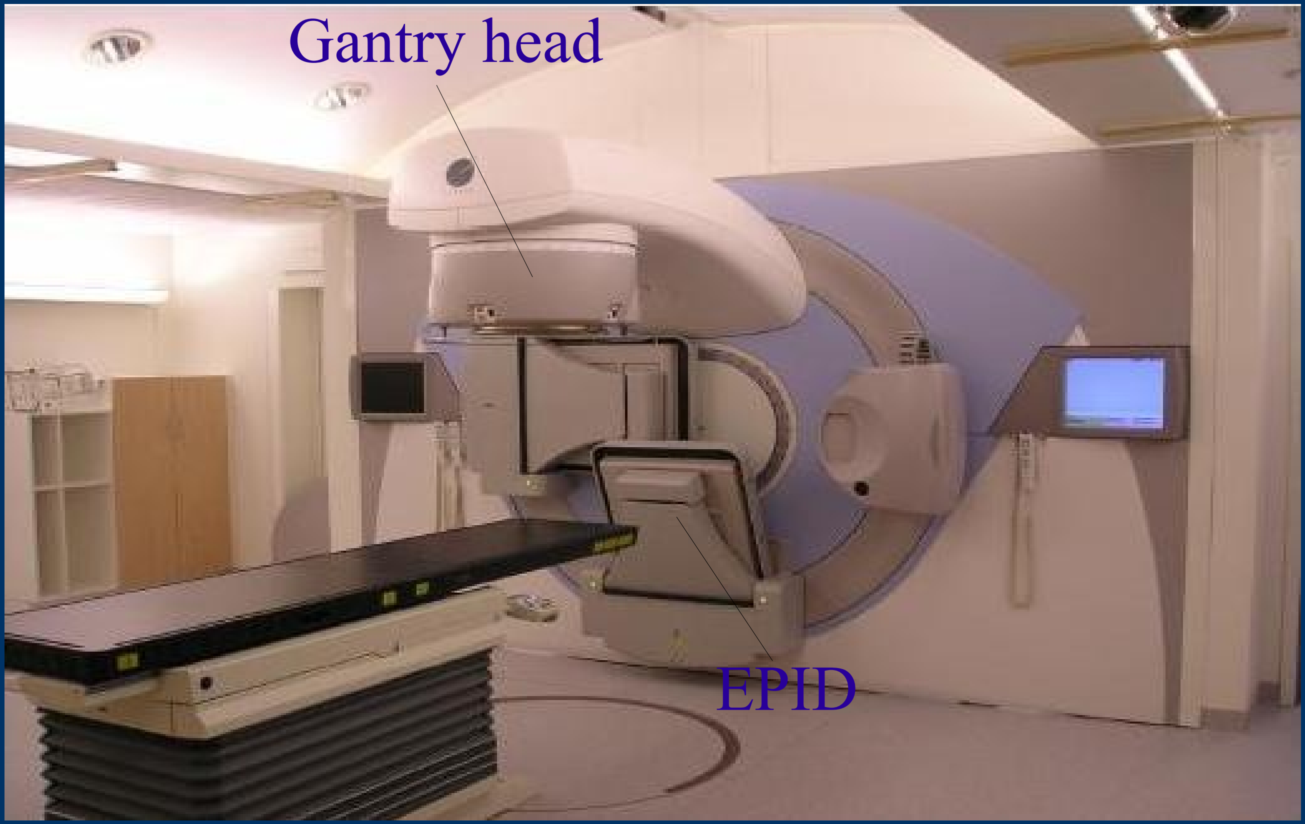
- MV p
- kV po
- Cone



Elekta Synergy System Linear Accelerator

MV and kV portal images

- Portal images
  - Imaging beam originates from the gantry head and is detected by the EPID (electronic portal imaging device)



Cone beam CT

- Cone beam x-ray configuration
  - Imaging beam originates from the online x-ray source which rotates

A. Amer et al. "Imaging doses from the Elekta Synergy Cone beam CT system" 2007

Advantages and Disadvantages

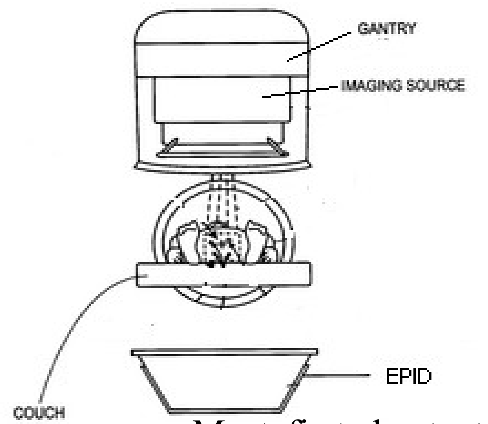
- MV portal imaging
  - Uses the actual treatment beam to acquire images (standard positioning procedure)

Advantage

  - Easy and readily available during the treatment which allows for patient repositioning if necessary

Disadvantages

  - Provides one 2D image per acquisition
  - MV beams usually only detect bone, treatment usually targets soft tissue



Mostafi et al patent

Advantages and Disadvantages

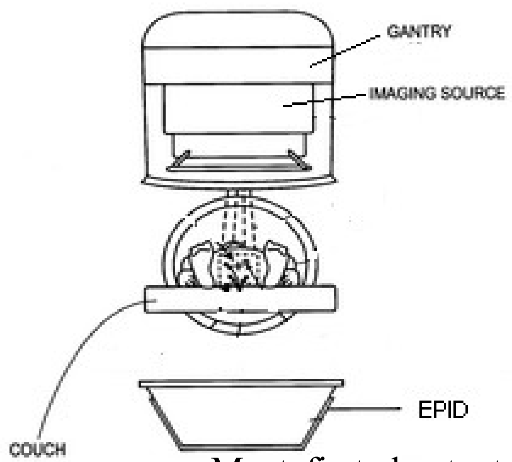
- kV portal imaging
  - Uses a lower energy version of MV x-ray

Advantages

  - Lower energy allows for detection of soft tissue structures
  - Lower energy = lower absorbed dose

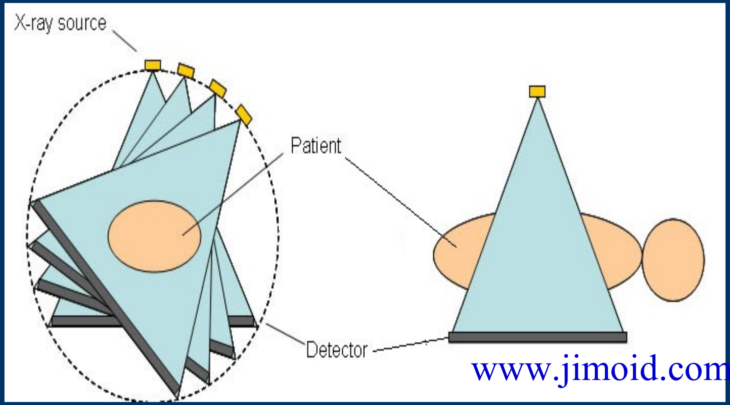
Disadvantage

  - Provides a 2D image



Mostafi et al patent

Advantages and Disadvantages



- Cone beam CT imaging
  - Uses a low energy kV x-rays

Advantages

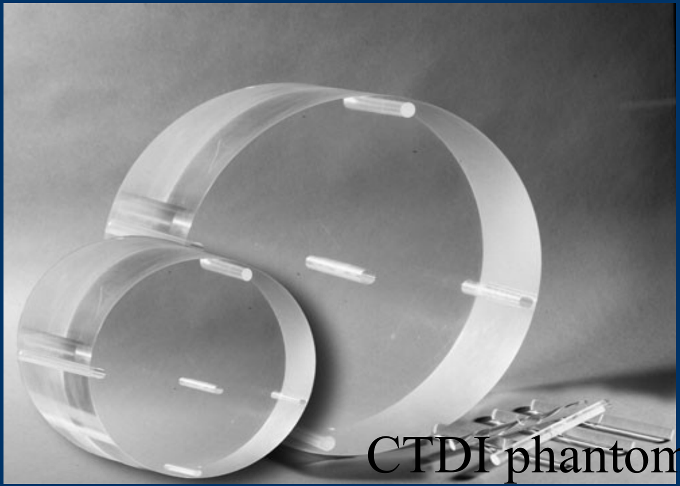
  - Lower energy allows for detection of soft tissue structures
  - CBCT apparatus rotates around the patient to obtain a 360 degree series of projections
    - Once reconstructed, the projections provide a 3D volumetric image of the patient's anatomy

Questions

- Can a high contrast, spatially resolute image be acquired while limiting the radiation dose absorbed to the patient?
- More specifically, which of these imaging modalities is the most efficient for purposes of image-guided radiotherapy?

Materials and methods

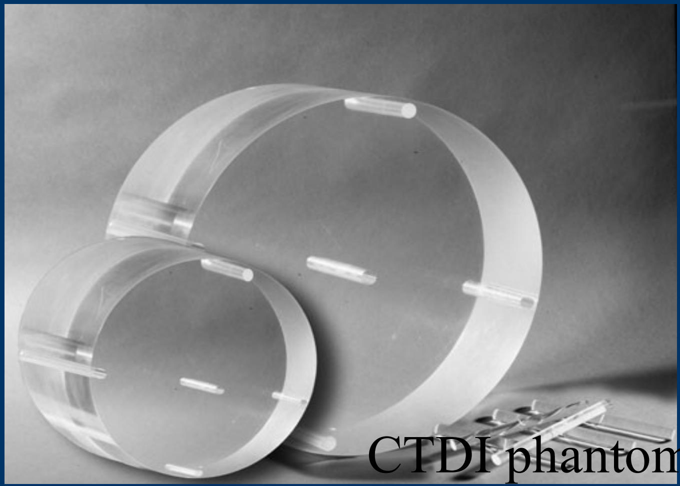
- Elekta Synergy system 6 MV linear accelerator
- 5 prostate radiotherapy patients
  - 3 *in vivo* dose measurements were obtained per patient (one for each imaging modality)
- CTDI phantom for 3 cone beam CT dose measurements



CTDI phantom

Materials and methods

- Quantities measured
  - MV portal image
    - anterior/posterior and lateral dose was measured *in vivo* both on skin and in rectum
  - kV portal image
    - anterior/posterior and lateral dose was measured *in vivo* both on skin and in rectum
  - Cone beam CT
    - *In vivo* dose measured inside rectum only
    - Dose inside CTDI phantom



CTDI phantom

In vivo dose measurements

- A semi-flexible ionization chamber was fixed to the patient's skin
  - PTW 31003
  - 0.3cm³ sensitive volume

- Rectal measurements were performed with a micro-chamber
  - PTW 23323
  - 0.1cm³ sensitive volume

CTDI phantom measurements

- CT chamber
  - $3.14 cm^3$ measuring volume
  - 10cm sensitive distance
- Ionization chamber
  - $0.3 cm^3$ in size
- The two chambers were irradiated over the full length so the entire irradiated volume (length > 10cm) could be measured

Results: in vivo measurements

Table 1
Results of in-vivo dose measurements (mGy)

Dose (mGy)	MV
	AP
Surface	
av	**57.78**
SD	1.17
Rectum	
av	**33.90**
SD	1.81

Bold values are used to emphasize the average value of dose measurements.

Portal image Results

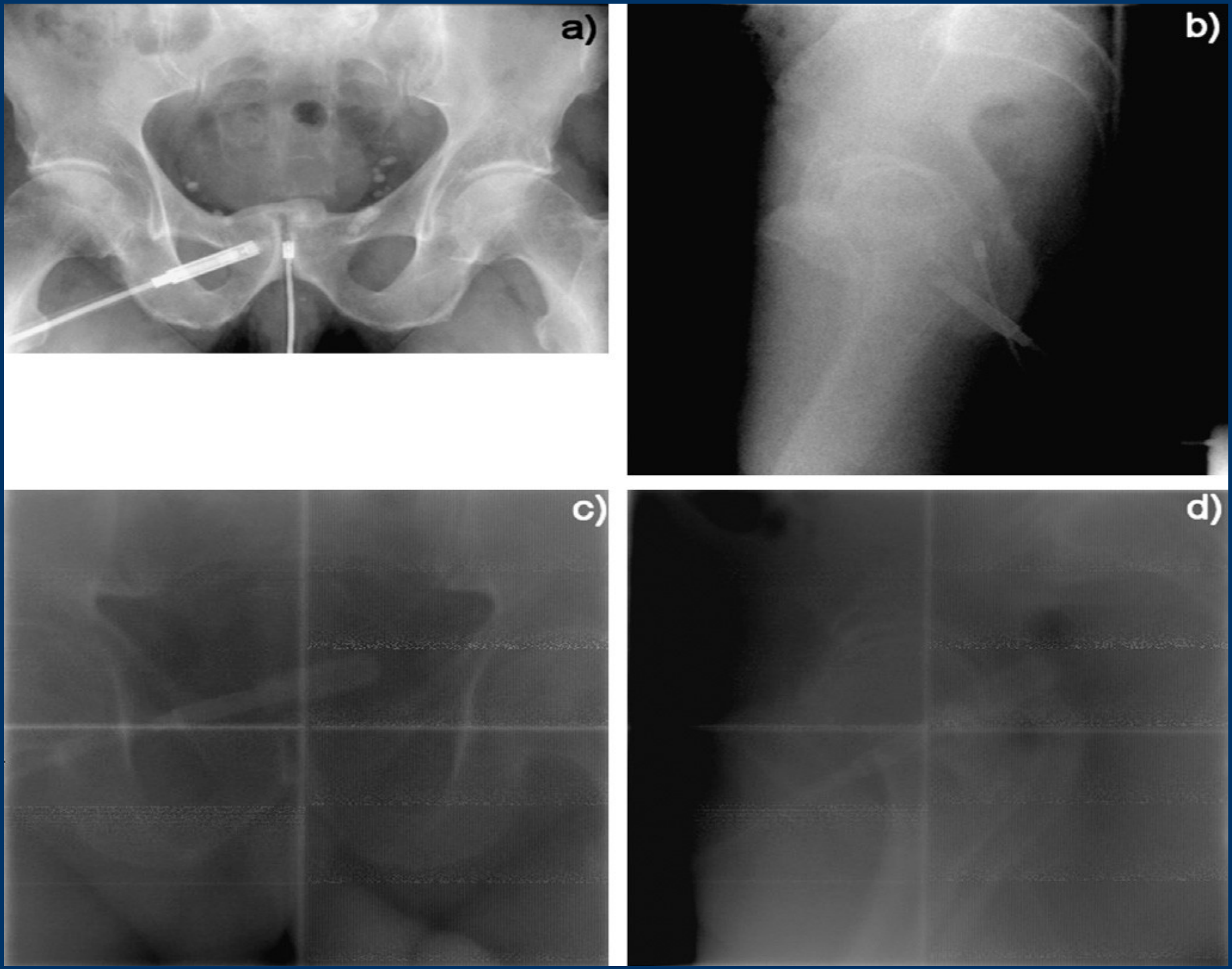


Fig1. Portal images
(a) kV-source 0,
(b) kV-source 90,
(c) MV-source 0
and
(d) MV-source 90.

CBCT image results

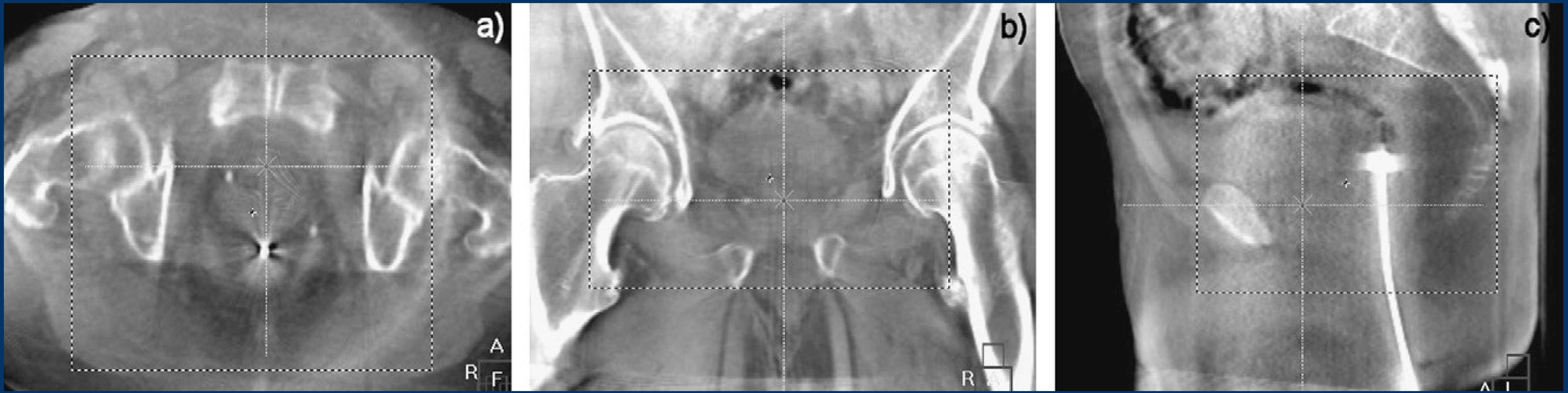
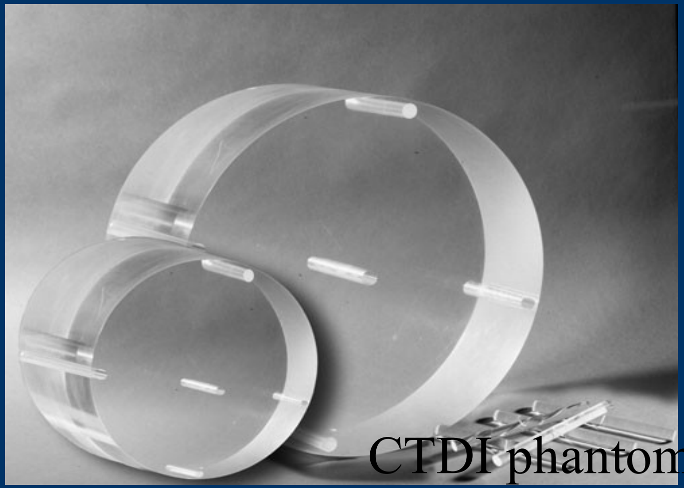


Fig. 2. (a) Transversal, (b) coronal and (c) sagittal reconstruction of a 360° volume scan.

CTDI phantom results



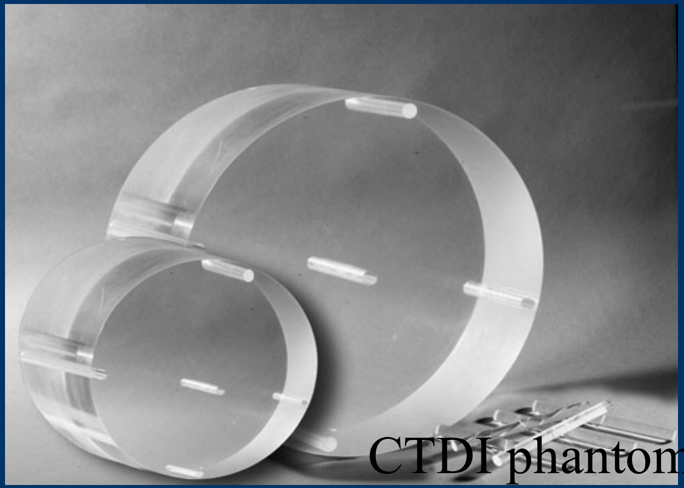
CTDI phantom

- CT chamber
  - Avg CTDI in center: 10.2 mGy
  - Avg CTDI in periphery: 23.6 mGy
- From these averages, the <u>weighted</u> CTDI was calculated:

$$CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p$$

- Result: 19.1 mGy

CTDI phantom results


CTDI phantom

- 0.3cm³ ionization chamber
  - Avg CTDI in center: 11.4 mGy
  - Avg CTDI in periphery: 25.4 mGy
- From these averages, the weighted CTDI was calculated:

$$CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p$$

- Result: 20.7 mGy
- Both chamber measurements concur wth the *in vivo* measurements (17.23 mGy +/- 2.76)

Statistics

- kV portal image dose was 98-99% lower than MV
  - Comparing both skin and rectal dose measurements
- Cone beam CT dose was 73% lower than MV
  - Comparing only rectal dose

Conclusions

- Gantry-mounted kV source (kV portal imaging) is a reliable tool for fast position verification
  - Low dose
  - Better image quality
- The tested kV-cone beam CT is well suited for daily position verification
  - Provides critical information about 3D patient alignment