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 portal image
- kV portal image
- Cone beam CT
- 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
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 \textit{in vivo} dose measurements were obtained per patient (one for each imaging modality)
- CTDI phantom for 3 cone beam CT dose measurements
Materials and methods

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

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

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

- CT chamber
  - 3.14cm³ measuring volume
  - 10cm sensitive distance
- Ionization chamber
  - 0.3cm³ 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)

<table>
<thead>
<tr>
<th>Dose (mGy)</th>
<th>MV</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>av</td>
<td>57.78</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>Rectum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>av</td>
<td>33.90</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.81</td>
<td></td>
</tr>
</tbody>
</table>

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

Fig 1. 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

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

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

- Result: 19.1 mGy
CTDI phantom results

• 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 with 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