Imaging Dose in Proton Beam Therapy

Indra J Das, PhD, Victor Simoneaux, BS, RTT, Chris Allgower, PhD, Archana S Gautam, MS, Peter AS Johnstone, MD

Department of Radiation Oncology, Indiana University School of Medicine, & IU Health Proton Therapy Center, Indiana, USA
Preface

- Proton beams provide superior dose distribution due to finite range and minimum integral dose
- Particle Therapy is true IGRT
- Every port is imaged daily before treatment
  - It adds imaging dose
  - Little data exist
- Improved survival and pediatric patients
  - Awareness of imaging dose
  - RISC: radiation induced second cancer
  - Added dose to target volume
Imaging in Proton Beam

- **Orthogonal Imaging**
  - Flat panel based
    - DIPS: Digital Image Positioning System
    - Verisuite
  - Simple, Cheaper and Popular
  - Relevant publications
    - Murphy et al, TG-75, Med Phys, 34, 4041-63, 2007
    - Steiner et al Radiother Oncol, 109, 409-413, 2013

- **Cone Beam CT (CBCT)**
  - Dose ≈ cGy/image

- **CT on rail**
- **Proton radiography**
- **Proton tomography**
Imaging Panels; DIPS
## Imaging System Characteristics

<table>
<thead>
<tr>
<th>Description</th>
<th>X-ray position and orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam line</td>
<td>G-90 (Lateral)</td>
</tr>
<tr>
<td>Source to axis distance, SAD (cm)</td>
<td>157</td>
</tr>
<tr>
<td>Source to imager distance, SID (cm)</td>
<td>316.5</td>
</tr>
<tr>
<td>HVL (mm Al)</td>
<td>4.1</td>
</tr>
</tbody>
</table>

**Typical Exposure at surface, mR; (80 kVp, 160 mAs)**

<table>
<thead>
<tr>
<th>Focal spot</th>
<th>Large Focal spot</th>
<th>Small Focal Spot</th>
<th>Relative Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>237.8</td>
<td>66.7</td>
<td>112.1</td>
</tr>
<tr>
<td></td>
<td>233.4</td>
<td>66.9</td>
<td>113.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative Exposure</th>
<th>1</th>
<th>1/3</th>
<th>1/2</th>
</tr>
</thead>
</table>
Daily Portal Verification

(1) Line → (2) Subtraction → (3) Point

Reference X-p

X-p of the day

Setup Corrections to A060087 position:

lat  -0.41 cm
long -0.24 cm
vert -0.25 cm
ROT  0.22 deg
PITCH 2.23 deg
ROLL  N/A
Imaging Devices

Heidelberg Ion Therapy, Germany

Siemens Primatom CT on rail
Measurements

- Exposure to dose conversion
  \[ X = k \times V^n \times \text{mAs/d}^2 \]
  \[ D = X \times f \times F \times \text{PDD} \]
  Uncertainty due to backscattering materials and use of proper parameters for calculation

- Measurements
  - **Rando Phantom**
    Steiner et al Radiother Oncol, 109, 409-413, 2013
  - **Detectors**
    - TLD
    - OSL
    - **Ion chambers (used)**
      - Victoreen 4000MT
      - RaySafe (Fluke Biomedical, Hopkinton, MA)
Need For Repeat Image

DRR from TPS  |  First Image  |  Final Image

First Image Shift

| lat  | 0.18 cm |
| long | -1.18 cm |
| vert | 0.35 cm |
| ROT  | -0.26 deg |
| PITCH| 3.39 deg |
| ROLL | 2.16 deg |

Final Image Shift

| lat  | 0.05 cm |
| long | -0.01 cm |
| vert | -0.04 cm |
| ROT  | -0.35 deg |
| PITCH| -0.03 deg |
| ROLL | 0.35 deg |
# Imaging Estimate (Repeat image)

<table>
<thead>
<tr>
<th>Average Technique</th>
<th>Mean # Exposures per Fraction</th>
<th>Mean # Fractions</th>
<th>Mean # Exposures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pediatric</td>
<td>80 kVp, 16 mAs</td>
<td>4.2</td>
<td>28.8</td>
</tr>
<tr>
<td>Gantry Prostate</td>
<td>125 kVp, 63 mAs</td>
<td>5</td>
<td>44</td>
</tr>
<tr>
<td>Stationary Beam Prostate</td>
<td>125 kVp, 63 mAs</td>
<td>6.6</td>
<td>44</td>
</tr>
<tr>
<td>Head/Neck</td>
<td>80 kVp, 16 mAs</td>
<td>4.5</td>
<td>40</td>
</tr>
</tbody>
</table>

**Diagram:**

- Prostate/Pelvis
- Head & Neck
- Pediatrics
- Other (Thorax and Extremities, etc.)

**Labels:**
- Number of patient (%)
- Number of fields
# Measured Parameters and Dose in DIPS

<table>
<thead>
<tr>
<th>Selected Station</th>
<th>PTC X-ray Dose, Measured Parameters</th>
<th>Beam-Axis X-ray Dose at Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KV</td>
<td>mAs</td>
</tr>
<tr>
<td>KV</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>63</td>
</tr>
</tbody>
</table>
Depth Dose of Imaging X-Rays Used in Proton Beam

- **4 mm Al HVL**
- **8 mm Al HVL**
- **Fit (4mm Al)**
- **Fit (8 mm Al)**

### Graph Details
- **Y-axis**: Dose (%)
- **X-axis**: Depth (cm)
- **Legend**:
  - Yellow triangles: 4 mm Al HVL
  - Green squares: 8 mm Al HVL
  - Yellow line: Fit (4mm Al)
  - Green line: Fit (8 mm Al)
Typical Dosage

- **External beam (Photon)**
  - MV Imaging: 20-100 mGy
  - On Board Imaging (CBCT): 4-6 mGy
  - Radiographic imaging: 0.4-0.8 mGy

- **Particle beam**
  - Steiner et al, 2013: ~1 mGy/image
  - IUHPTC, Indiana: ~2-3 mGy/image
Site Dose

The graph represents the dose in cGy for different site/units:
- Pediatric/Gantry
- Prostate/Gantry
- Prostate/Fixed Beam
- Head-Neck/Gantry

The y-axis represents the dose in cGy, ranging from 0 to 100. The x-axis lists the site/unit categories.
Dose from Other Centers

Steiner et al, Radiother Oncol, 109, 409-13, 32013
Conclusions/Summary

- Imaging dose vary significantly for each system and should be estimated periodically.
- Dosimetry should be performed for each imaging system as variation on the order of 3 is observed in different systems in a same room.
- Focal spot does not play role in exposure.
- Repeat imaging should be avoided by choosing proper imaging panels and techniques.
- Whole body dose can be computed accurately (~ mGy/exp).
- DIPS imaging dosage are insignificant (~ 0.5% of the prescribed dose).
- Imaging dose should be given importance in proton beam therapy, especially for CBCT and other imaging modalities with order of magnitude higher dose.
Thanks