Patient Setup for Precision Proton Therapy

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Content

• What’s so special about setup for PT?
• Anything different in immobilization?
• Imaging systems
• Organ motion issues
• Future tools
What Precision Is Needed?

• Clinical data show significant decrease in tumor control (≥ 5%) when tumor dose decreased by 4 - 5 %
• Therefore, “significant” portion of CTV cannot fall outside high dose region more than once in fractionated course of radiation

Vehey UCSF
What Precision Is Needed?

• The uncertainty of the target position is more important than the uncertainty of the dosimetry
  – Daily dose errors of $\geq 20\%$ possible with positioning error
  – Dose errors due to errors in dose calculation probably not more than 5 - 10%

L. Vehey UCSF
Proton Dose Distribution Extra Sensitive

Very Sensitive to WED Variations

Over or Undershoot!
WED Variations due to Set Up

- Body posture variations
  Intra or inter-fractional
  Causes different tissue build up in beam path
  Requires solid immobilization/registration

- Lateral displacement
  Causes misalignment of compensator
  Setup tolerance must be consistent
  not only with planning margins
  but also with compensator smearing
Inter-fraction Set Up Variation

Pelvis

Head and Neck

Rosenthal
2004
Potential Range Perturbation

Hair

- Style & Placement
- Clips (even plastic)
- Gel & Water

Rosenthal 2004
Immobilization

• Generic requirements
  Small inter- and intra-fractional variation
  Uncertainty well-understood
  Patient comfortable
  Fixed to treatment table, if possible
  Practical

• Proton specific
  No potential range perturbations
    e.g., passing part of the frame
  Hardware clearance
No Small Matter

- Dedicated group (3)
- Dedicated equipment
- Dedicated session
  before CT
# Immobilization devices

<table>
<thead>
<tr>
<th>Rigid Devices</th>
<th>Non-rigid Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base of Skull *</td>
<td>Alpha Cradle</td>
</tr>
<tr>
<td>IC-Mask (reinforced)</td>
<td>Bean Bag</td>
</tr>
<tr>
<td>Modified GTC</td>
<td>Duncan Head Rest</td>
</tr>
<tr>
<td>Neck Cast *</td>
<td>Leg Abductor</td>
</tr>
<tr>
<td>Para-Nasal Sinus *</td>
<td>Wing Board</td>
</tr>
</tbody>
</table>

* indicates high possibility for additional patient movement or generating motion artifact.

Engelsman 2005
Immobilization For Proton Therapy

Base of Skull (BOS)
Immobilization For Proton Therapy

Intra-Cranial (IC)

Rosenthal 2004
Table 1A: Measured motion between set-up and post treatment film pairs using the PNS immobilization system (N=20).
(Mean time between films = 16 ± 4 minutes (SD))

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-P</td>
<td>0.3 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>S-I</td>
<td>0.0 mm</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>Lat.</td>
<td>-0.4 mm</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>3-D Displacement</td>
<td>0.9 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>2-D Displacement</td>
<td>0.7 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Roll</td>
<td>0.07 degrees</td>
<td>0.45 degrees</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.03 degrees</td>
<td>0.42 degrees</td>
</tr>
<tr>
<td>Turntable</td>
<td>-0.14 degrees</td>
<td>0.67 degrees</td>
</tr>
</tbody>
</table>

Rosenthal 2004
In-House Devices

Radionics Gill-Thomas-Cosman (GTC) Frame
  Occipital Cup with Heavy-Body Reprosil®
  Velcro Head Restraint
  Bite Mold

Bussiere 2006
GTC Modifications

Replace High Density Occipital Cup with Moldcare™ Cushion

Bussiere 2006
GTC Modifications

Cushion

Bussiere 2006
Immobilization For Proton Therapy

Medulloblastoma Frame
Full Body Prone Mold
Mask, Head/Body Articulation Minimal

Rosenthal 2004
CSI (Cranio-Spinal Immobilization)
Medulloblastoma – CSI + posterior fossa boost

Match lines

Rosenthal 2004
2 Spine fields matching at anterior cord surface

Protons

Photons

Dose %
110
105
102
100
90
80
50
10

Non-aligned divergence

Rosenthal

2004
Imaging System

Current

• Orthogonal X-ray images (DIPS)
  Digital image panels
  Integrated with TPS
  Landmark matching to DRR
  (bony anatomy or implants)
  6D correction

• Ultrasound (prostate only)
History proton X-ray positioning

1980  Radiographic Set Up w. Diagnostic X-rays
      DRR From CT

1993  Implanted Fiducials Digitized from Film 3D
      - High Accuracy - 1/2 mm (Gall, Verhey ‘93)

1996  Digital Radiography – Filmless CCD Camera

1999  Flat Panel Imager Receptors at NPTC
      Smaller Lighter Device, Accurate Couch, High Resolution

2001  Digirad – Application Integrates Planning and Set Up

2003/4  DIPS™2 – Dicom Database, TCS Integration Ready,
         Feature Matching Automation

Rosenthal  2004
Repositioning For Proton Therapy

Orthogonal X-ray Tubes

Simultaneous Lateral and AP Radiographs

Proton Beam

Rosenthal 2004
Repositioning For Proton Therapy

X-Ray Tubes

Nozzle

Snout (with aperture & compensator)

6-axis patient positioner

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Hitachi gantry with orthogonal X-ray system
Repositioning For Proton Therapy

Amorphous Silicon Flat Panel Imagers

Rosenthal 2004
Repositioning For Proton Therapy

Gold Seeds in Prostate

Rosenthal 2004
Diagnostic x-ray positioning

- DIPS™ Relies on Identifying Landmarks

Rosenthal 2004
Setup Process

1) Patient immobilization
2) Initial positioning (lasers and skin marks)
3) Take AP/LAT orthogonal image pair
   General position adjustment
   (translation and rotation)
4) Take beam-line image (BEV)
   Small adjustment (translation only)
   (*Tolerance must agree with smearing*)
Set Up Uncertainty - Summary

Digestive and Muscular Variation:

- Prostate
- Bladder
- Rectum
- Abdomen

Highly Unpredictable

Daily Verification or Tracking Required

Rosenthal 2004
Ultrasound for Prostate
Sonarray System
3D ultrasound to CT contours
Ultrasound to Ultrasound
The RESTITU Platform

CT-Sim Room

Treatment Room

U/S-SIM

U/S-GUIDE

Workstation
Fixed Beam SRS/SRT

STAR (Stereotactic Alignment radiosurgery)

Bussiere 2006
Imaging/Alignment for STAR

Film (3D) → Digital (2+D) → Digital 3D

Varian PaxScan 4030: 127 μm pixel (Gadolinium Oxysulfide Scintillator)

Bussiere 2006
Ocular Treatment

Bussiere 2006
Organ Motion

Imaging uncertainty due to respiration

- Instant X-ray image
- Averaged DRR from 3D CT
Proton Range Variation

Example:
Liver
RL field
Use same range, mod, compensator for 50% and 0% phases

In many cases, gating is the only option
Patient Set Up for Gating

- Gated imaging
- Use bony landmarks for pitch, roll, and rotation
- Use seed implants for translation
Future – Surface Imaging

- Verify patient posture
- Verify treatment position correction
- Monitor intra-fractional motion
- Respiratory gating by tracking multiple points

Bert, C. 2004
Future – Fluoroscopy

- Fast digital fluoroscopy panels
- Organ motion management
- Direct target volume tracking
- Respiratory gating by target position
Fluoroscopic Tracking - Liver

Visualize Clips

Computer Tracks Clips

Rosenthal 2004
Future – Cone Beam CT/CT

- 3D target verification
- Adaptive therapy
- On-line range verification
In Vivo Range Verification
Activated PET imaging, in-beam, or offline

Parodi, et al, PTCOG 45
TP Dose  MC PET  Meas. PET

The ultimate proof!
But, post-analysis only, non-interactive
What not Point Dose Measurement
Detectors: MOSFET, TLD, Diodes
Surface, cavity or implant

Widely practiced in photon/electron therapy
Not So Easy for Protons

Dose at point A does not verify distal coverage at point B

Also need *residual proton range* at point A
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......
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