Patient Positioning Using Optical and Ultrasound Techniques

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Acknowledgements
• Collaborators
  – University of Iowa
  – University of Florida
  – University of Wisconsin
• Funding
  – Whitaker Foundation
  – National Cancer Institute
  – ZMed

Objectives
Precision Radiation Therapy

• Optical Tracking in Radiation Therapy
  – What is it?
  – How does it work?
  – How well has it worked?
• Ultrasound Guidance in Radiation Therapy
  – What is it?
  – How does it work?
  – How well has it worked?

What is Optical Tracking?
• Optical tracking is a means of determining in real-time the position of an object by tracking the positions of either active or passive infrared markers attached to the object. The position of the point of reflection is determined using a camera system.

How Does it Work?
Optical Tracking
How Does it Work?

**Calibration of Optical camera**

- For high-precision intracranial radiotherapy and frameless radiosurgery, we use optical guidance to track the actual patient position using passive markers and a bite-plate linkage.

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**Frameless Stereotaxis**

- Passive Array – Reflective Markers serve as fiducials in both image and real space.

**Immobilization During CT Scan**

Patients can move – immobilize using custom pillow, aquaplast, etc.

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**Frameless Stereotaxis**

- Passive Array – CT Scan

Fiducials must be visible in CT scan – use adequate field of view (typically 35–40 cm depending on distance of bracket from patient).

**Frameless Localization**

Frameless Stereotaxis

Equation can be solved numerically using optimization algorithms (Hook and Jeeves, etc.), or closed form solutions such as single value decomposition or Horn’s method (quaternions).

Optical Tracking – BrainLab System

X-ray Guidance Setup
(original model, x-ray tubes above patient)
Optical Tracking System QA

- System Commissioning and QA
- Patient Specific QA

Thermal Drift

Reproducibility

Test with Absolute Phantom

- Localize AI target in images (CT)

Frameless Localization Accuracy (Mechanical Standard)

<table>
<thead>
<tr>
<th>No.</th>
<th>AP</th>
<th>Lateral</th>
<th>Axial</th>
<th>RMS</th>
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<tbody>
<tr>
<td>1</td>
<td>0.48</td>
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<td>0.91</td>
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<td>-0.05</td>
<td>0.46</td>
<td>0.50</td>
<td>0.69</td>
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<tr>
<td>3</td>
<td>0.33</td>
<td>-0.20</td>
<td>-0.53</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>-0.46</td>
<td>-0.15</td>
<td>-0.13</td>
<td>0.50</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
<td>-0.15</td>
<td>-0.13</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Average 0.65 ± 0.17 mm
Putting it All Together - Hidden Targets Test with Absolute Phantom

- Localize Al target in images (CT)
- Place on linac using image localized coordinates and optical guidance.

Frameless Localization Accuracy (Film Tests)

- Localize Al target in images (CT)
- Replace Al target with Tungsten target, and place on linac using image localized coordinates.
- Take films from various gantry and table orientations.

Frameless Localization (Patient)

Overall error = 0.789mm

Predicted error:
- Z-Pixel Size = 1.25mm
- X-Pixel Size = 0.703 mm
- Y-Pixel Size = 0.703 mm
- Predicted Error = 1.59mm

Results:
- Z: 0.49 mm to T
- X: 0.35 mm to A
- Y: 0.50 mm High
- **Overall error = 0.789mm**

Frameless Localization (10 Patients)

Average ± s.d. 1.1 ± 0.3 mm

compared to conventional stereotactic localization

Can we predict localization errors?

Analogue to frame-based stereotaxis, we have an over-defined fiducial system with a known geometry.
Can predict accuracy of patient positioning at isocenter

Meeks, Bova et al., IJROBP, 2000
Mean Registration Error

Error between CT model and the real array after registration. Provides indication of reference array integrity and patient motion.

Frameless Localization (In Phantom)

Mean Registration Error (Phantom)

Mean Registration Error (Patient)

Indicative of motion during scan.

Frameless Localization (Patient)

Motion During Scan
Minimizing the distance from the center of the fiducial array to isocenter minimizes the effect of the mean registration error at isocenter.

Bracket allows adjustment of fiducial array relative to patient.

Keep camera “line of sight” in mind – if you rotate too far back, the fiducials will not be visible to the camera in the treatment room.

Reseat Test

Treatment Start: Verification of Setup Using Laser
Online Monitoring of Patient Position during Treatment

Optical Guidance in Radiotherapy
- Long-Term Experience
  University of Florida – started 1994
- High Accuracy
- Excellent Dose Conformality
- Excellent Clinical Results

June, 2000 – Frameless Radiosurgery - Why Not?

Frameless Radiosurgery
- 64 patients with intracranial metastases treated from June, 2000 - September, 2002
  - 1-6 mets (median 2)
  - Rx Dose = 12.5-20 Gy (median = 17.5 Gy)
  - Local Control = 88%
  - Median Survival = 8.7 Months (Max = 30.1 months)
- Results indistinguishable from framed SRS

High Precision Radiotherapy Beyond the Brain

Optical Tracking – BrainLab System
Diaphragmatic Pressure/Optically Guided Body Frame

Extracranial Stereotactic Radiotherapy Solution

• Tumor localization using real-time imaging at the treatment machine
  – Digital X-Ray Images
  – CT
  – Ultrasound

Troccaz et al., 1995

3D Ultrasound Imaging

What is 3DUS guided RT?

How Does it Work?

Ultrasound Calibration
**How Does it Work?**

**Freehand 3D-Ultrasound Acquisition**

- Interpolation to smooth the acquired 3D-ultrasound image

**3D Ultrasound Image Guidance**

Registration of 3D US to planning CT

- Image misregistration is due to patient misalignment with isocenter (setup error, shift of internal anatomy, etc.)

**Correlation of US with Planning CT**

- Provides direct 3D-visualisation, localization and orientation of the tumor volume in the treatment room
- Calculating correction to patient position to place the planning target volume at room isocenter
- Mechanism for real-time tracking of patient position relative to isocenter

**What is 3DUS guided RT?**

- Provides direct 3D-visualisation, localization and orientation of the tumor volume in the treatment room
- Calculating correction to patient position to place the planning target volume at room isocenter
- Mechanism for real-time tracking of patient position relative to isocenter
Ultrasound Guidance QA


Tracking Accuracy

Using Optical Tracking as Standard

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>AP Distance (mm)</th>
<th>Lateral Distance (mm)</th>
<th>Axial Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All depths</td>
<td>0.03 ± 0.4</td>
<td>-1.2 ± 0.4</td>
<td>-0.7 ± 0.5</td>
</tr>
</tbody>
</table>

Pre-Clinical Prostate Phantom Tests

- Using Optical Guidance known shifts are introduced using a translation table.
- Optical Guided System is blinded to introduced shifts by recording the position of a fiducial array that is fixed to the couch.

Optically Guided Ultrasound Target Localization for shifted Phantom

Contours are moved to Match US Anatomy

Results

<table>
<thead>
<tr>
<th>Exp</th>
<th>AP (mm)</th>
<th>Lat (mm)</th>
<th>Ax (mm)</th>
<th>AP (mm)</th>
<th>Lat (mm)</th>
<th>Ax (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6±0.46</td>
<td>-0.3±0.69</td>
<td>-0.0±0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>5.0</td>
<td>0.67±0.52</td>
<td>-0.38±0.61</td>
<td>4.95±0.12</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>-5.0</td>
<td>0.55±0.53</td>
<td>-0.25±0.58</td>
<td>-5.3±0.67</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>-5.0</td>
<td>0.0</td>
<td>0.55±0.53</td>
<td>4.95±0.17</td>
<td>-0.22±0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>-5.0</td>
<td>5.0</td>
<td>0.25±0.06</td>
<td>-5.85±0.17</td>
<td>5.3±0.27</td>
</tr>
</tbody>
</table>

**BAT Tracking Accuracy in Patient Using CT as Standard**

<table>
<thead>
<tr>
<th></th>
<th>Axial Distance (mm)</th>
<th>Lateral Distance (mm)</th>
<th>Axial Distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>-0.09 ± 2.3</td>
<td>-0.16 ± 2.4</td>
<td>-0.03 ± 2.3</td>
</tr>
</tbody>
</table>


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**How Do I Use it Clinically?**

**Basic Process**

1. Immobilize and CT Scan
2. Treatment Planning
3. Laser patient positioning
4. Treatment Delivery
5. Target positioning
6. 3D-ultrasound acquisition

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**How Do I Use it Clinically?**

**Treatment Planning**

- BEV conformal or IMRT treatment planning using Pinnacle
- CT and structure contours transferred to SonArray using Dicom-RT or RTOG

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**3D Ultrasound Image Guidance**

Initial Alignment from CT Simulation

- Skin marks
- Lasers
**3D Ultrasound Image Guidance**

Acquire 3D Ultrasound Data

Analogous to CT acquisition – acquire multiple axial using freehand ultrasound probe manipulation.

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**How Do I Use it Clinically?**

**Target Localization**

Correlation of 3D-ultrasound image with Treatment Plan

**Actual position of target as determined from the 3D-ultrasound**

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**US/CT Correlation - Prostate**

Interface between prostate and bladder

Sem ves
Bladder
Nothing below bone!

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**How Do I Use it Clinically?**

**Patient Positioning**

Align Patient

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**Verify Shifts using Portal Images and DRRs**

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**Proceed With Normal Treatment...**
Pitfalls in Ultrasound Guidance
What happens with inter- and intra-fraction organ motion?

Probe Placed over treatment isocenter
Probe Placed displaced by 1 cm superiorly from treatment isocenter.

Pitfalls in Ultrasound Guidance: User Variability in Image Quality

Pitfalls in Ultrasound Guidance: Ultrasound Interpretation

Retrospective registration of 15 different data sets by 9 different users; 4 users with experience and 5 trained in use of the software, but not US imaging.

Treatment Planning
US-Guided Prostate

• Sensible PTV may be larger than Minimum
• Remember user variability can vary, which increases required PTV
• In practice, we create a PTV with a variable (5-10 mm) margin on the CTV.

Work in Progress – Automated Ultrasound Registration
US-Guided Prostate Trial

• NCI-supported Phase III Randomized Multi-Center Clinical Trial
  – Arm 1 - With ultrasound
    • Initial fields: 46 Gy/23 fractions, PTV = 1 cm margins on prostate, seminal vesicles, and nodes
    • 32 Gy/16 fractions, PTV = 2 mm margin on prostate only
  – Arm 2 - With conventional localization
    • Initial fields: 46 Gy/23 fractions PTV = 1.5 cm margins on prostate, seminal vesicles, and nodes
    • 32 Gy/16 fractions, PTV = 1 cm margin on prostate only

US-Guided Prostate Trial Preliminary Results

<table>
<thead>
<tr>
<th>Grade</th>
<th>Acute GI Toxicity</th>
<th>Acute GU Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Arm 1</td>
<td>Arm 2</td>
</tr>
<tr>
<td>Grade 0</td>
<td>25%</td>
<td>89%</td>
</tr>
<tr>
<td>Grade 1</td>
<td>0%</td>
<td>11%</td>
</tr>
<tr>
<td>Grade 2</td>
<td>75%</td>
<td>0%</td>
</tr>
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</table>

p= 0.014  p=0.45

3D Ultrasound Image Guidance

Other Applications at UIHC (to date)

• Liver
• Low neck
• Paraspinal
• Metastatic pelvic lesions
• Chest wall

Extracranial US-Guidance
Clinical US Example
Residual neurofibroma at C2-3

Clinical US Example
Liver

Metastasis to iliopsoas muscle

Future Development/Questions
- Reliable Automated image registration techniques – important for all image registration modalities (CT, x-ray, US)
- Technical improvements in organ motion management
- Clinical Trials defining true benefits of image-guidance and IMRT.
- Defining dose/volume tolerances for hypofractionated regimens – Rigorous Phase I dose-seeking studies are required