In-room imaging for therapy guidance:
Ultrasound Localization

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Is in-room imaging necessary?
Why should we care?
How about the delivery of highly inhomogeneous dose distributions designed to increase TCP (Selective Boosting)

3D Daily Average Move of Prostate measured at our institution is 7.19mm +/- 3.74mm

Is in-room imaging necessary?
Why should we care?
How about the loss in TCP when using smaller margins due to setup error and organ motion

Orton and Tomé, Med. Phys. 31(10): 2845-48; 2004
Is in-room imaging necessary? Why should we care?

How about inducing a normal tissue complications one “planned” to avoid.

Mean Parotid Dose

Direction of shift:
(+): towards spared parotid
(-): away from spared parotid


Methods of In-room Volumetric Image Guidance

- CT-Guidance (KVCT, MVCT)
- MRI-Guidance
- US-Guidance
  - NOMOS: BAT™ system
    - 2D ultrasound with mechanical arm. Recently combined with optical guidance
  - Varian: Simantary™
    - Optically Guided 3D Ultrasound Target Localization System
  - Resonant Medical: Restitu Restore Prostate™
    - Optically Guided 3D Ultrasound Target Localization System

Optically Guided 3D Ultrasound Localization

Ultrasound Images are displayed for the operator in real time on the screen as they are acquired.
Calibration of an Optically Guided 3D Ultrasound System

\[ M_I : \text{position of point M in the Image Coordinate System} \]
\[ M_W : \text{Position of point M in the World Space Coordinate System, whose origin is the Radiation Isocenter of the LINAC}. \]

Then there exists a linear transformation \( R_{I \rightarrow W} \) in \( E(3) \) such that

\[ M_W = R_{I \rightarrow W} M_I \]

Using the group property of \( E(3) \), \( R_{I \rightarrow W} \) can be decomposed as follows:

\[ R_{I \rightarrow W} = R_{P \rightarrow W} R_{I \rightarrow P} \]

Once, we know two of three transformations the third can be easily found:

\[ R_{I \rightarrow P} = (R_{P \rightarrow W})^{-1} R_{I \rightarrow W} \]

The transformation \( R_{I \rightarrow P} \) is determined in an initial calibration.

Determination of the Probe to Image Transformation \( R_{I \rightarrow P} \)

\[ R_{I \rightarrow P} = (R_{P \rightarrow W})^{-1} R_{I \rightarrow W} \]

Stability of Ultrasound Calibration

- Transformation results on 10 calibrations
  - Average number of points: 508

<table>
<thead>
<tr>
<th></th>
<th>Translations (mm)</th>
<th>Rotations (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axial</td>
<td>Lateral</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Accuracy of Optically Guided 3D Ultrasound Image Localization (Focal Depth 15cm)**

<table>
<thead>
<tr>
<th>Target Depth</th>
<th>Translational Error (mm)</th>
<th>AP</th>
<th>Lateral</th>
<th>Axial</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td>Mean</td>
<td>0.7</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>0.4</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>100 mm</td>
<td>Mean</td>
<td>0.2</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
</tr>
<tr>
<td>150 mm</td>
<td>Mean</td>
<td>0.3</td>
<td>1.1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td>0.6</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**Preclinical Tests: Apparent Organ Motion Experiment**

- Phantom is aligned to Machine isocenter using lasers and the "Bony Anatomy" is defined by recording the phantom's position in Control Computer using the fiducial array attached to the couch.
- Known shifts in isocenter Position are introduced using a translation table and are measured by optically tracking the fiducial array attached to the phantom. Note: The Couch position did not change.
- In this way apparent organ motion can be introduced while maintaining a fixed bony anatomy.

**Optically Guided Ultrasound Target Localization for shifted Phantom**
Contours that have been generated using the CT anatomy at the time of treatment planning are moved to Match US Anatomy.

Results of Apparent Organ Motion Experiment

<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±0.06</td>
<td>-0.03±0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>5.0</td>
<td>0.6±0.52</td>
<td>-0.3±0.61</td>
<td>4.9±0.12</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>-5.0</td>
<td>0.5±0.53</td>
<td>-0.2±0.58</td>
<td>-5.2±0.67</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>-5.0</td>
<td>0.0</td>
<td>0.5±0.53</td>
<td>4.9±0.17</td>
<td>-0.2±0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>-5.0</td>
<td>5.0</td>
<td>0.2±0.06</td>
<td>-5.5±0.17</td>
<td>5.3±0.27</td>
</tr>
</tbody>
</table>

Torre et al. Med. Phys. 29(8), 1761-1788 (2002)

For what sites have we used optically guided 3D-ultrasound target localization:

- Metastatic Pelvic Lesions
- Prostate
- Post Prostatectomy
- Bladder Cancer
Possible limitations of Ultrasound as an Imaging Modality for In-room therapy guidance

1) accuracy of localization
2) interuser variation in localization
3) intrafraction motion
4) abdominal pressure might affect measurement
5) contour/anatomy differences


We have investigated points 1-4 for the in-room imaging of prostates that have been immobilized with the aid of a rectal balloon using an optically guided 3D US localization system:

- Accuracy of localization
- Interver user variability in localization
- Intrafraction organ motion
- Pressure due to probe might affect measurement

Point 5: contour/anatomy differences
- Changes in prostate shape must be included in margins (unless one replans for every fraction at the time of imaging)

3D-US Localization: Statistics for All Patients Treated at UW

<table>
<thead>
<tr>
<th></th>
<th>2001-2</th>
<th>2003</th>
<th>2004-4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># fractions</td>
<td>1581</td>
<td>1661</td>
<td>1483</td>
<td>4626</td>
</tr>
<tr>
<td>mean A-P</td>
<td>1.36 ± 6.01</td>
<td>1.16 ± 4.07</td>
<td>0.92 ± 2.28</td>
<td>1.16 ± 4.65</td>
</tr>
<tr>
<td>std</td>
<td>1.02 ± 4.06</td>
<td>0.97 ± 4.17</td>
<td>0.92 ± 3.23</td>
<td>0.24 ± 4.93</td>
</tr>
<tr>
<td>mean I-S</td>
<td>1.17 ± 3.96</td>
<td>0.95 ± 4.30</td>
<td>0.93 ± 4.45</td>
<td>1.01 ± 4.16</td>
</tr>
<tr>
<td>magnitude</td>
<td>7.22 ± 3.63</td>
<td>7.22 ± 3.63</td>
<td>6.89 ± 2.66</td>
<td>7.19 ± 3.74</td>
</tr>
<tr>
<td>mean AP</td>
<td>4.81 ± 3.02</td>
<td>3.89 ± 2.34</td>
<td>6.99 ± 3.44</td>
<td>4.30 ± 3.54</td>
</tr>
<tr>
<td>shift</td>
<td>3.17 ± 2.00</td>
<td>3.19 ± 2.07</td>
<td>3.79 ± 2.53</td>
<td>3.93 ± 2.73</td>
</tr>
<tr>
<td>mean rotation</td>
<td>2.91 ± 2.00</td>
<td>3.46 ± 2.05</td>
<td>3.10 ± 2.02</td>
<td>3.14 ± 2.00</td>
</tr>
</tbody>
</table>

# patients: 221, 98, 66, 57
Possible limitations of Ultrasound as an Imaging Modality for In-room therapy guidance

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2) Interuser variability in localization
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5) Contour/anatomy differences

Localization Verification using MVCT

- 8 patients were localized using both ultrasound and MVCT prior to treatment (60 fractions) on a helical tomotherapy unit
- MVCT localization used for treatment
- US analyzed by an experienced user who had no knowledge of the shifts indicated and made from the MVCT-CT fusion

RESULTS:
- US improved localization for 6 of the 8 patients
- Two patients were not good candidates for ultrasound

For more detail please see our Poster TU-EE-A4-1

Localization Verification using MVCT for 6 of the 8 patients that were good candidates for Ultrasound

Coronal Plane

Transverse Plane

Sagittal Plane

MVCT-US
MVCT-skin
Markers
Localization Verification using MVCT

<table>
<thead>
<tr>
<th>Patient</th>
<th>MVCT - Ultrasound</th>
<th>MVCT - Skin Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.84 ± 1.01</td>
<td>3.48 ± 1.75</td>
</tr>
<tr>
<td>2</td>
<td>5.20 ± 1.45</td>
<td>5.49 ± 1.61</td>
</tr>
<tr>
<td>3</td>
<td>3.78 ± 2.48</td>
<td>4.80 ± 1.56</td>
</tr>
<tr>
<td>4</td>
<td>3.65 ± 1.85</td>
<td>5.15 ± 2.07</td>
</tr>
<tr>
<td>5</td>
<td>3.53 ± 0.90</td>
<td>6.46 ± 3.27</td>
</tr>
<tr>
<td>6</td>
<td>5.75 ± 1.51</td>
<td>5.96 ± 1.18</td>
</tr>
<tr>
<td>7</td>
<td>3.30 ± 0.64</td>
<td>6.25 ± 3.28</td>
</tr>
<tr>
<td>8</td>
<td>2.06 ± 1.90</td>
<td>4.77 ± 2.48</td>
</tr>
</tbody>
</table>

BUT: not all patients are good US candidates

Large patient unable to maintain an adequate bladder filling

Typical patient with adequate bladder filling

Possible limitations of Ultrasound as an Imaging Modality for In-room therapy guidance

1) Accuracy of localization
2) Interuser variation in localization
3) Intrafraction organ motion
4) Pressure due to probe might affect measurement
5) Contour/anatomy differences
Interuser Localization Test

- Four experienced operators performed shifts for the same 5 patients for 5 consecutive fractions
- Note that for these users for shifts larger than 3mm:
  
  Standard Deviation << Mean Shift

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Intrafraction Motion Test

- US localization repeated after treatment for 6 patients/29 fractions
- Prostate is immobilized with a rectal balloon and patients are treated with a full bladder
- Post-treatment shifts were within the localization uncertainty for 25/29 fractions

<table>
<thead>
<tr>
<th>days w/ shifts</th>
<th>≤2mm</th>
<th>&gt;2-3mm</th>
<th>&gt;3-4mm</th>
<th>&gt;4mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
<td>10</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>avg time</td>
<td>0:13:12</td>
<td>0:12:42</td>
<td>0:12:40</td>
<td>0:18:27</td>
</tr>
</tbody>
</table>

Max shift = 4.1 mm left
Possible limitations of Ultrasound as an Imaging Modality for In-room therapy guidance

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2) Interuser variation in localization
3) Intrafraction organ motion
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Effect of Abdominal Pressure on Prostate Position

- McNeeley et al. (ESTRO 2003) – MRI study showed that displacement of prostate due to probe pressure is not clinically significant.
- Our statistics for 5005 Ultrasound prostate localizations and our US-MVCT comparisons also indicate that the displacement of the prostate due to probe pressure is not clinically significant.

<table>
<thead>
<tr>
<th></th>
<th># patients</th>
<th># localizations</th>
<th>2006</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean shift</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-P</td>
<td>0.10 ± 0.19</td>
<td>0.10 ± 0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-L</td>
<td>0.48 ± 0.58</td>
<td>0.48 ± 0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-S</td>
<td>0.03 ± 0.14</td>
<td>0.03 ± 0.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Summary

- Optically guided 3D-Ultrasound target localization is an inexpensive in-room imaging technique that can easily be added to existing treatment machines
- However, the interpretation of Ultrasound images is difficult
- Therefore, for this in-room imaging technology to be a valuable target alignment tool users need to be adequately trained in the interpretation of Ultrasound images
- In fact, these systems present a valuable tool for aligning patients and allow for the use of reduced margins and more aggressive fractionation schedules if and only if they are used by well-trained and experienced users.