Implanted Target Surrogates for Radiation Treatment Verification

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OBJECTIVES
- To discuss various types of markers and implantation techniques
- To discuss various marker detection techniques
- To discuss marker application on various treatment sites
- To discuss gating applications and real-time tracking with implanted markers
- To discuss quality assurance issues
- To discuss risk and patient safety issues

DISCLOSURES
None

OUTLINES
- Introduction
- Marker types
- Detection techniques
- Marker applications in different disease sites
- Gating and tracking
- Quality assurance issues

Dr. Kothary (marker implantation techniques, imaging guidance for implantation, tissue interaction and marker stability, risk management and patient safety)

INTRODUCTION
- Fiducial markers to achieve better localization.
- PTV margin reduction
- Intra-fractional and inter-fractional motion
- In-room imaging / IGRT
- Gating and real-time tracking
- Sites: prostate, lung, liver, pancreas, breast...
- AAPM TG 199: AAPM Recommendations on Implanted Target Surrogates for Radiation Treatment Verification
  Z. Wang (Chair), F. Yin (Co-Chair), J. Salter, T. Willoughby, H. Shirado, P. Kupelian, J. Kruse, S. Park, K. Shinozaka, M. Wahidi, N. Kothary

MARKER TYPES
- Gold markers (seeds, coil, coupled)
- Surgical clips
- Brachytherapy seeds
- Electro-magnetic markers
- Implanted dosimeters
- Carbon marker
- Polymer marker
**Implanted Marker Detection**

- 2D MV imaging: EPID
- 3D MV imaging: MV CBCT
- 2D kV imaging: OBI, fluoroscopic imaging
- 3D kV: kV CBCT, DTS, in-room CT
- 4D kV: DTS, CBCT
- Electromagnetic system

**Marker Detection**

**2D MV**

**3D MV**

- MV Cone-Beam CT

**Balter et al., IJROBP, 33(5), p1281-86, 1995**

**Marker Detection: 2D KV**

**Room-Mounted X-Ray Systems**

- CyberKnife® imaging system
- Novalis® imaging system

**Gantry-Mounted X-Ray Systems**

- Elekta system
- Varian system

**Calypso System**

- Elekta system
- Varian system
**PROSTATE: Simulation/Planning**

- 2D kV with Markers vs CBCT with Markers vs CBCT Soft-tissue

<table>
<thead>
<tr>
<th>Comparison of image-guided modality</th>
<th>Orthogonal MV</th>
<th>Cone-beam CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose</td>
<td>8 Gy</td>
<td>2.1±0.3 Gy</td>
</tr>
<tr>
<td>Correction scheme</td>
<td>Live 3D</td>
<td>2.1±0.3 Gy</td>
</tr>
<tr>
<td>Marker selection</td>
<td>100 markers</td>
<td>Manual match and re-acquisition</td>
</tr>
<tr>
<td>Imaging accuracy</td>
<td>0.05 mm</td>
<td>0.12 mm</td>
</tr>
<tr>
<td>Acquisition time</td>
<td>2 s</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>Largest center of metastaic</td>
<td>4.0 mm</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>Marker localisation</td>
<td>1.0 mm</td>
<td>2.0 mm</td>
</tr>
</tbody>
</table>


**PROSTATE: Localization**

**Marker Migration**

- Kupelian et al, 56 patients, 168 markers

<table>
<thead>
<tr>
<th>Inter-marker distance (mm)</th>
<th>Standard deviation (mm)</th>
<th>Difference @ 1 month (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>0.44</td>
<td>1.52</td>
</tr>
<tr>
<td>B-C</td>
<td>1.40</td>
<td>0.96</td>
</tr>
<tr>
<td>C-A</td>
<td>1.58</td>
<td>1.96</td>
</tr>
<tr>
<td>1.40</td>
<td>0.40</td>
<td>0.96</td>
</tr>
<tr>
<td>2.00</td>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>1.03</td>
<td>0.03</td>
<td>0.23</td>
</tr>
<tr>
<td>0.37</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>0.88</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>0.68</td>
<td>0.06</td>
<td>0.12</td>
</tr>
<tr>
<td>0.21</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Pouliot et al., UROBP, 56(3), p862-66, 2003
**Tissue Deformation**


<table>
<thead>
<tr>
<th>Change in distance from CFM to CP</th>
<th>Mean</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLR-L/NL/2-MEI #1</td>
<td>0.0</td>
<td>0.0 ± 0.1</td>
</tr>
<tr>
<td>2AP-L/NL/2-MEI #1</td>
<td>0.7</td>
<td>0.0 ± 1.2</td>
</tr>
<tr>
<td>S2/PEL/NL/2-MEI #1</td>
<td>0.4</td>
<td>0.0 ± 0.6</td>
</tr>
<tr>
<td>ABS-2D(MRI &amp; MEI #1)</td>
<td>1.8</td>
<td>0.3 ± 2.3</td>
</tr>
<tr>
<td>ABS-3D(MRI &amp; MEI)</td>
<td>0.8</td>
<td>4.0 ± 4.0</td>
</tr>
</tbody>
</table>

**LUNG**

Shirado et al., IJROBP, 48(4), p1187–95, 2005


**Breath-Hold Sim CT**

**Breath-Hold CBCT**

**LIVER: Sim and Planning**
LIVER: Localization

PANCREAS

Jayachandran et al., IJROBP, 76(2), p603-7, 2010

BREAST: Sim and Planning

BREAST: Sim and Planning

BREAST: Localization

Surgical Clips for PBI

N=28

Weed et al., UROBP, 60(2), p484-92, 2004
GATING AND TRACKING

- Implanted marker for real-time tracking
- Implanted marker for external gating treatment verification

Tracking with Fluoroscopic Imaging

- Harada et al., Cancer, 95(8), p1720-27, 2002

Tracking with Fluoroscopic Imaging

- Shimizu et al., IJROPB, in printing, 2011

Tracking with Calypso

- Willoughby et al., IJROPB, 65(2), p229-34, 2006
- Kupelian et al., IJROPB, 67(4), p1088-98, 2007

Tracking with EPID Phantom Study


GATING VERIFICATION
GATING VERIFICATION

Liver case study
Berbeco et al.,
Phys. Med. Biol., 50,
p3669-79, 2005

8 lung cases
Berbeco et al.,
Phys. Med. Biol., 50,
p3655-67, 2005

END-TO-END TEST WITH PHANTOM

Balter et al., IJROBP, 33(5), p1281-86, 1995

QUALITY ASSURANCE ISSUES

- End-to-end test
  - Marker visibility
  - Imaging accuracy
  - Tracking accuracy
  - Tracking system latency
- Marker migration
- Tissue deformation
- Min number of markers
- Dose perturbations (especially with proton beams)

SUMMARY

- Implanted markers as target surrogates have been used in various treatment sites, including prostate, lung, liver, pancreas, breast, etc.
- Various imaging and marker detection techniques have been used for treatment guidance.
- Implanted markers have been used for real-time tracking and gating verification.

Dr. Kothary: Marker Implantation

Thank You