Trans-perineal ultrasound guidance for prostate radiotherapy: technology, performance, promise, and challenges

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To be discussed:

- Trans-perineal ultrasound guidance (TPUS): technology
- TPUS Inter-fraction IGRT
  - Process
  - Performance
  - Potential venues for improvement
- TPUS intra-fractional imaging and tracking
  - Phantom evaluation: design and challenges
  - In-vivo evaluation: designs, results, and challenges
- Summary
Trans-perineal Ultrasound (TPUS) IGRT technology

Clarity® Autoscan device.


Li M et al, Strahlenther Onkol (2017) 193:221–228
TPUS IGRT process
CT-3DUS fusion establishes desired position of 3DUS defined target (prostate) with respect to the treatment isocenter. This position needs to be reproduced prior at treatment.
**TPUS IGRT process**

**Green volume**: prostate contoured at planning.

**Red volume**: prostate manually localized in pre-treatment 3DUS. Indicates current prostate position with regard to treatment isocenter.

Accuracy of shifts depends on how well the user localizes (segments) prostate in pre-treatment 3DUS.

*Li M et al, Strahlenther Onkol (2017) 193:221–228*
TPUS IGRT Process

Prostate position changes with pressure but remains known at all times.
Accuracy of 3D TPUS IGRT

Li M et al, Strahlenther Onkol (2017) 193:221–228
Zhou et al. Radiation Oncology (2019) 14:22
Accuracy of 3D TPUS IGRT

Real-time motion tracking

KV Image pair acquisition

Treatment and MV image acquisition

N. Zhu, M. Najafi, B. Han, S Hancock, and D Hristov, PhD, Technology in Cancer Research & Treatment, V 18: 1-11, 2019
## Accuracy of 3D TPUS IGRT

<table>
<thead>
<tr>
<th>Study</th>
<th>Percent Agreement within 5 (3) mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Superior-Inferior</td>
</tr>
<tr>
<td>Fargier-Voiron et al.</td>
<td>95</td>
</tr>
<tr>
<td>Zhou et al.</td>
<td>67</td>
</tr>
<tr>
<td>Li et al.</td>
<td>99 (86)</td>
</tr>
<tr>
<td>Zhu et al.</td>
<td></td>
</tr>
</tbody>
</table>

Large variability. Accuracy likely to be considerate currently inadequate for prostate IGRT.
Accuracy of 3D TPUS IGRT

ANC: Normalized similarity metric in Elastix.
proposed: pre-trained CNN

Accuracy of 3D TPUS IGRT: need for improvement

Accuracy of 3D TPUS IGRT: need for improvement

(a) true positives  
(b) false negatives

(c) true negatives  
(d) false positives
Accuracy of 3D TPUS IGRT: need for improvement

ANC: Normalized similarity metric in Elastix.
proposed: pre-trained CNN

Accuracy of 3D TPUS IGRT: need for improvement

Similarity based on pre-trained CNN decrease error but further improvement is needed.

ANC: Normalized similarity metric in Elastix.
proposed: pre-trained CNN

Occasional large and sudden transitions occur.

3D TPUS IGRT tracking: how good is it?


3D TPUS IGRT tracking: how good is it?

Challenges for experimental designs


3D TPUS IGRT tracking: how good is it?

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3D TPUS IGRT tracking: how good is it?

Experimental design validation

3D TPUS IGRT tracking: how good is it?

Experimental design validation: 3D TPUS tracking reduces position uncertainty to within ~1mm in phantom

3D TPUS IGRT tracking: how good is it?

Magnitudes of the position differences (scaled at isocenter) between mean predicted and mean actual (MV segmented) fiducial positions for individual patients. Predicted positions are calculated with and without ultrasound tracking.

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Without tracking</th>
<th>With tracking</th>
<th>At 95% relative cumulative occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.3</td>
<td>1.8</td>
<td>Without tracking: 1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With tracking: 1.2</td>
</tr>
<tr>
<td>2</td>
<td>3.1</td>
<td>1.7</td>
<td>Without tracking: 2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With tracking: 1.3</td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
<td>1.3</td>
<td>Without tracking: 1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With tracking: 1.0</td>
</tr>
<tr>
<td>4</td>
<td>3.9</td>
<td>3.3</td>
<td>Without tracking: 2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With tracking: 2.1</td>
</tr>
<tr>
<td>5</td>
<td>1.9</td>
<td>1.5</td>
<td>Without tracking: 1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>With tracking: 1.2</td>
</tr>
</tbody>
</table>

3D TPUS IGRT tracking: how good is it?

Maximum localization error reduced by 20% on average.

3D TPUS IGRT tracking: how good is it?

<table>
<thead>
<tr>
<th>Limit of agreement</th>
<th>u-Axis, mm</th>
<th>v-Axis, mm</th>
<th>2D magnitude, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>−0.2 to 0.3</td>
<td>−0.2 to 0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>50%</td>
<td>−0.5 to 0.6</td>
<td>−0.5 to 0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>75%</td>
<td>−0.9 to 1.0</td>
<td>−1.1 to 1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>95%</td>
<td>−2.0 to 2.1</td>
<td>−2.5 to 1.9</td>
<td>2.6</td>
</tr>
<tr>
<td>$</td>
<td>\tilde{E}</td>
<td>$</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Summary

- Trans-perineal ultrasound offers non-ionizing near real time volumetric imaging conceptually attractive for prostate intra- and inter-fractional image guidance.

- Current TPUS accuracy appears insufficient for demanding indications such as prostate SBRT (aka SABR).
  - User-variability in acquisition and interpretation a dominant factor in performance
  - Need for approaches to mitigate/eliminate this source of uncertainty

- TPUS intra-fractional tracking can flag target deviations exceeding ~2-3 mm, but effort/benefit analysis perhaps only justifiable for prostate SBRT scenarios.