Declaration of Relevant Financial Interests or Relationships

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I have no relevant financial interest or relationship to disclose with regard to the subject matter of this presentation.
Hierarchical Image Registration for Improved Sampling during 3T MRI-guided Transperineal Targeted Prostate Biopsy


Brigham and Women's Hospital, Boston, USA
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Prostate Cancer

- Estimated incidence at 450K by 2015 in US
- **Challenge: early accurate detection of the disease**
- **Detection:**
  - Digital rectal exam
  - Prostate Specific Antigen
  - MRI
- **Confirmation:**
  - Biopsy + histological analysis
Prostate Biopsy

- Standard of care: TRUS-guided biopsy
  - ~50% of cancers are isoechoic in TRUS \[1\]
  - Up to 30% of cancers are missed \[1\]
- MRI-guided biopsy \[2\]
  - Multi-parametric MRI (mpMRI) for target selection
  - Targeted sampling of suspicious areas
  - Confirmation of needle location

MR-guided Biopsy at BWH

1. Diagnostic imaging and Planning
   - Multi-parametric MRI with endorectal coil at 3T \(^1\)
   - Pharmacokinetic modeling from DCE MRI \(^2\)
   - Biopsy target selection \(^3\)

2. Biopsy procedure
   - Patient positioned in the wide bore (70 cm) 3T MRI \(^4\)
   - No endorectal coil, lithotomiy position

3. Registration
   - compensate for the intra-procedural change in orientation and deformation of the gland

\(^1\) GE Signa HDx 15.0 3.0T (GE Medical Systems, Waukesha, WI), Endorectal Coil (Medrad, Pittsburgh, PA)
\(^2\) AdvantageWorkstation Cinetool research software (GE Research, Niskayuna, NY)
\(^3\) 3D Slicer, http://slicer.org (Surgical Planning Laboratory, Boston, MA)
\(^4\) Siemens MAGNETOM Verio VB17 3.0T (Siemens Medical Solutions, Erlangen, Germany)
Diagnostic imaging and planning

- Direct transperineal sampling based on pre-biopsy MRI to define targets
- Target sampling is guided by 3D Slicer
- Targets defined based on DWI/DCE/T2W
Diagnostic imaging and planning

- Multi-parametric MRI with endorectal coil at 3T [1]
- Pharmacokinetic modeling from DCE MRI
- Biopsy target selection

[1] GE Signa HDx 15.0 3.0T (GE Medical Systems, Waukesha, WI), Medrad Endorectal Coil (Medrad, Pittsburgh, PA)
Diagnostic imaging and planning

- Multi-parametric MRI with endorectal coil at 3T \(^{[1]}\)
- Pharmacokinetic modeling from DCE MRI
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Diagnostic imaging and planning

- Multi-parametric MRI with endorectal coil at 3T
- Pharmacokinetic modeling from DCE MRI * [1]
- Biopsy target selection

- ISMRM’11: 3320: Fennessy et al. A comparison between arterial input function approaches for high temporal resolution pharmacokinetic analysis of prostate cancer at 3.0T

[1] GE Advantage Workstation Cinetool research software (GE Research, Niskayuna, NY)
Diagnostic imaging and planning

- Multi-parametric MRI with endorectal coil at 3T
- Pharmacokinetic modeling from DCE MRI
- Biopsy target selection \[^{[1]}\]

[^{[1]}]: 3D Slicer, http://slicer.org (Surgical Planning Laboratory, Boston, MA)
Biopsy procedure

- Wide-bore (70 cm) scanner
- Surface and body coils used for imaging (no endorectal coil)
- Patient is in lithotomy position, template-guided needle insertion
- Related ISMRM’ 11 presentations from our group:
  - 53: Tuncali K. et al. 3T MRI-guided Transperineal Targeted Prostate Biopsy: Clinical Feasibility, Safety, and Early Results.
Registration Approach

1. Preprocessing (before the procedure)
   - Bias field inhomogeneity correction
   - Gland contouring in the planning T2W image

2. Registration Initialization
   - Gland contouring in intra-procedural T2W image

3. Hierarchical registration based on image content
   - Multi-step approach using Mutual Information similarity metric
Preprocessing

- Prostate gland contoured on T2W image by a non-clinical operator – contours are used for registration indirectly
- Strong signal intensity inhomogeneity at 3T
- We use retrospective inhomogeneity correction approach \[1\]

\[1\] Tustison et al. 2010. N4ITK: Improved N3 bias field correction, IEEE TMI
Inhomogeneity Correction

Original axial T2W MRI

Inhomogeneity corrected T2W MRI
Registration Initialization

- Intra-procedural T2W scan is contoured manually
- Centroids of the segmented pre- and intra-procedural gland configurations are aligned
- Gland orientation is initialized by sparse regular search for maximum similarity in the small neighborhood
Registration Initialization

- Intra-procedural T2W scan is contoured manually
- Centroids of the segmented pre- and intra-procedural gland configurations are aligned
- Gland orientation is initialized by sparse regular search for maximum similarity in the small neighborhood

Prostate gland segmentations after aligning centroids
Hierarchical Transformation Model

- From rigid to more flexible transformation models:
  - Rigid
  - Affine
  - B-spline

- Gradient descent optimizer
- Intensity sampling for MI calculation is limited to the contoured gland region

Diagnostic T2W MRI registered to intra-procedural T2W scan with Rigid transform. Intra-procedural gland contour is in yellow.
Hierarchical Transformation Model

- From rigid to more flexible transformation models:
  - Rigid
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  - B-spline

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Diagnostic T2W MRI registered to intra-procedural T2W scan with Affine transform. Intra-procedural gland contour is in yellow.
Hierarchical Transformation Model

• From rigid to more flexible transformation models:
  - Rigid
  - Affine
  - B-spline

• Gradient descent optimizer

• Intensity sampling for MI calculation is limited to the contoured gland region

Diagnostic T2W MRI registered to intra-procedural T2W scan with B-spline transform. Intra-procedural gland contour is in yellow.
Non-rigid Registration Component

- Free-form deformation based on B-splines \([1]\)
- Sparse 3x3x3 registration grid
- B-spline grid is initialized over the gland region
- Metric calculation is restricted to the gland region

Implementation

- All steps are performed in 3D Slicer\(^1\)
  - MRI review
  - Target identification
  - Contouring
  - Registration
    - Insight Toolkit for core functionality\(^2\)
    - Technology adopted from brain MRI registration application\(^3\)

\(^1\) Surgical Planning Laboratory, Boston, MA, [http://slicer.org](http://slicer.org)
\(^2\) Kitware Inc., Clifton Park, NY
\(^3\) Johnson H. et al. 2007. Mutual Information Registration, Insight Journal
Results: Computation Time

- Evaluation performed on pre/intra-procedural scans for 10 consecutive biopsy patients
- Contouring of the gland in intra-procedural T2W MRI is ~ 2 minutes
- Registration computation time within 3 minutes (single-thread on Intel Xeon 2.4GHz PC)

Cumulative computation for all the registration stages is within 2 minutes
Results: Accuracy

- Total Gland, Central & Peripheral zone contoured by an expert (15 years of experience in prostate MRI)

- Quality of overlap assessed with Dice Similarity Coefficient (DSC) – measure between 0 and 1

Mean DSC for the total gland after registration is 0.89
Results: Accuracy

- Statistically significant improvement in the overlap for TG and PZ
  - *Rigid vs Affine and Affine vs B-spline (p<0.05)*

![Spatial overlap between the intra-procedural and registered contours (Dice Similarity Coefficient)](image-url)
Results: Accuracy

- Hausdorff Distance (HD): maximum point-wise distance between the two sets of points sampled over the surfaces
- 95% HD measured

- No statistically significant improvement observed for 95% HD
- Open questions:
  - How to separate segmentation error from registration error
  - Is 95% HD appropriate measure?
Landmark Accuracy Assessment

- Up to 3 landmarks defined for each case
- Registration accuracy assessed as the distance between the landmark centroids
- Results averaged over 10 cases

<table>
<thead>
<tr>
<th>Transformation</th>
<th>Mean error (mm)</th>
<th>Maximum error (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid</td>
<td>1.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Affine</td>
<td>1.5</td>
<td>2.9</td>
</tr>
<tr>
<td>B-spline</td>
<td>1.3</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Diagnostic

Intra-procedural

Consecutive slices

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Related work

Previously evaluated approaches on B-spine deformable registration for brachytherapy application \[^{[1,2]}\]

- More laborious: Accurate segmentation\[^{[2]}\] or Segmentation and manual cropping and rigid alignment \[^{[1]}\] is required
- 1.5T MRI \[^{[1,2]}\]: registration is not as challenging due to less prominent intensity inhomogeneity effect
- Different deformation patterns: intra-procedural imaging done with the rectal obturator in place \[^{[1,2]}\]

- **Accuracy comparison:**
  - TG/CG/PZ DSC: current study: 0.89/0.86/0.75 vs 0.91/0.89/0.79 \[^{[1]}\] vs 0.94/0.86/0.76 \[^{[2]}\]
  - LRE: current study: 1.3 vs 2.3 \[^{[1]}\] vs 1.1 \[^{[2]}\] vs 3mm slice thickness!

- **Evaluated on different patient groups using different contouring protocols and different landmarks!**

\[^{[1]}\] Oguro et al. (2009) MRI signal intensity based B-spline nonrigid registration […]JMRI 30(5)
Summary

- Developed hierarchical registration approach for MR-guided prostate biopsy
- Implemented in 3D Slicer
- Reduced operator involvement, no radiology expertise required
- Computation time is compatible with the clinical time constraints
- Objective accuracy comparison with the previously published methods is not possible
Conclusions

• The developed approach is suitable for intra-procedural use in clinical research applications
• More detailed performance evaluation is in progress
• Publicly available annotated datasets are required for objective comparison of the registration methodology across different groups
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