Declaration of Relevant Financial Interests or Relationships

Speaker Name: Andriy Fedorov

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

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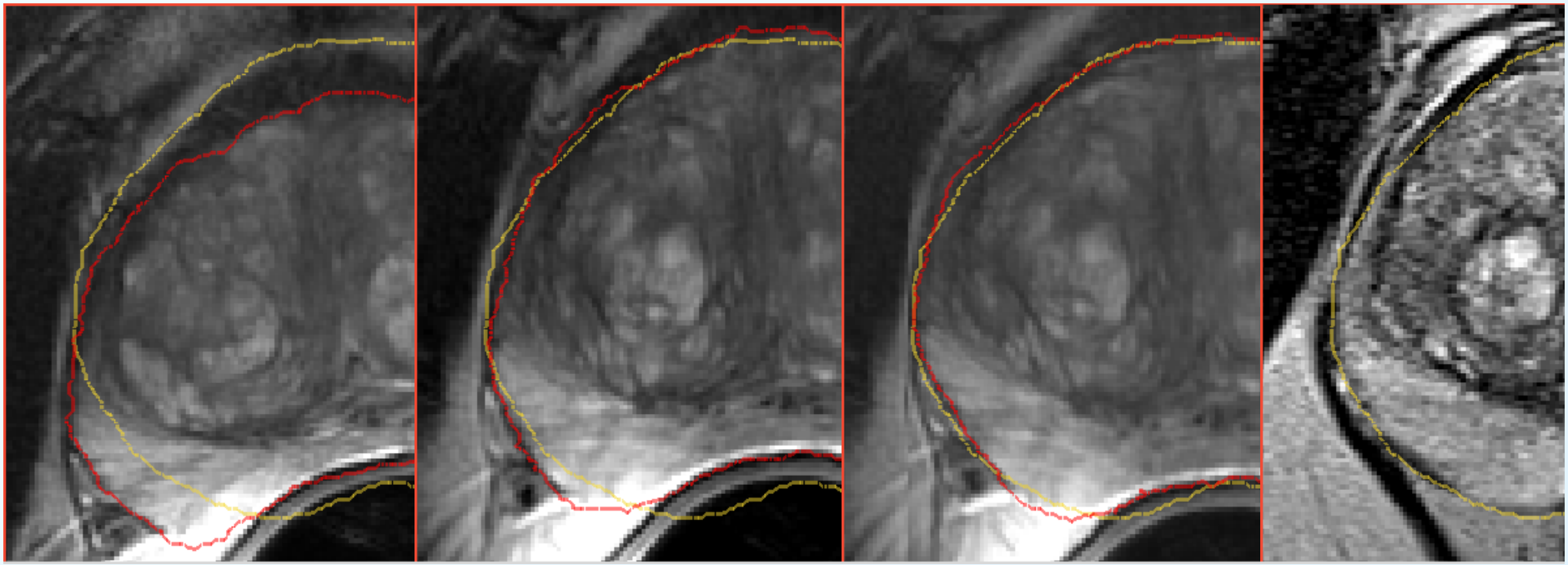

Support

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  - P41 RR013218
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  - U01 CA151261
- The content is solely responsibility of the authors and does not necessarily represent the official views of the US National Cancer Institute or the National Institutes of Health

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

[1] *Patel, U. 2004. TRUS and prostate biopsy: current status. Prostate cancer and prostatic diseases 7(3): 208-10*
[2] *Pondman, K. et al. 2008. MR-guided biopsy of the prostate: an overview of techniques and a systematic review. European urology 54(3): 517-27*

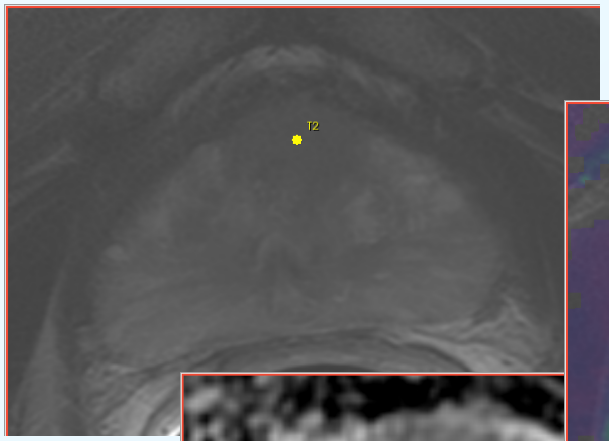
MR-guided Biopsy at BWH

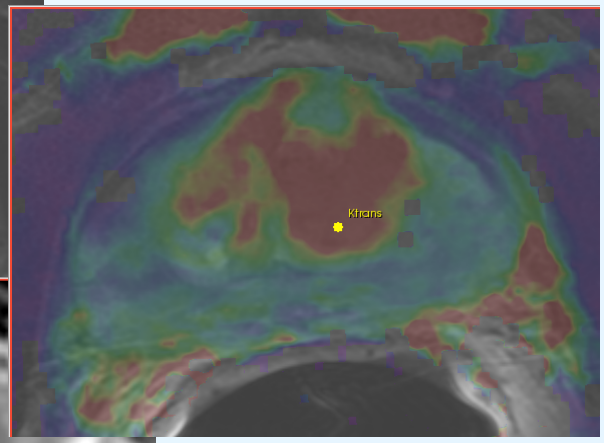
1. Diagnostic imaging and Planning
   - Multi-parametric MRI with endorectal coil at 3T [1]
   - Pharmacokinetic modeling from DCE MRI [2]
   - Biopsy target selection [3]
2. Biopsy procedure
   - Patient positioned in the wide bore (70 cm) 3T MRI [4]
   - No endorectal coil, lithotomy position
3. Registration
   - compensate for the intra-procedural change in orientation and deformation of the gland

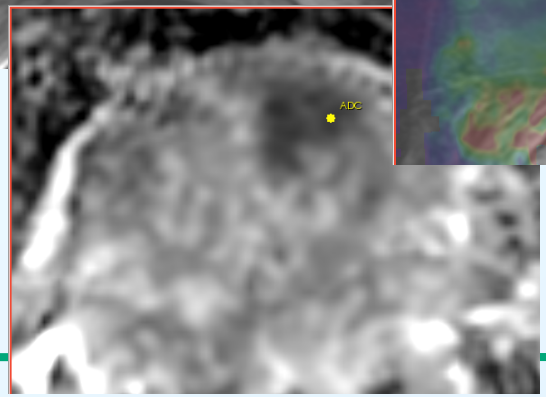
[1] *GE Signa HDx 15.0 3.0T (GE Medical Systems, Waukesha, WI), Endorectal Coil (Medrad, Pittsburgh, PA)*
[2] *AdvantageWorkstation Cinetool research software (GE Research, Niskayuna, NY)*
[3] *3D Slicer, http://slicer.org (Surgical Planning Laboratory, Boston, MA)*
[4] *Siemens MAGNETOM Verio VB17 3.0T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

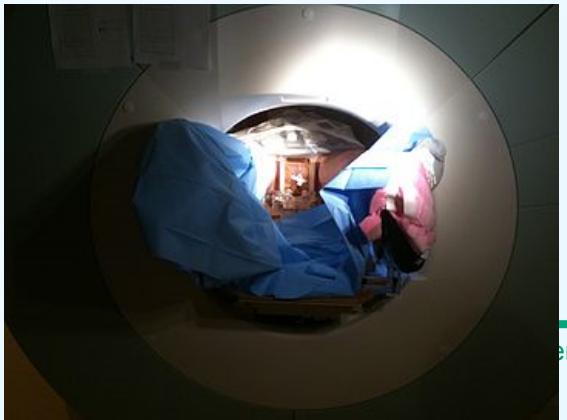
Diagnostic imaging and planning

- 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]
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- Biopsy target selection

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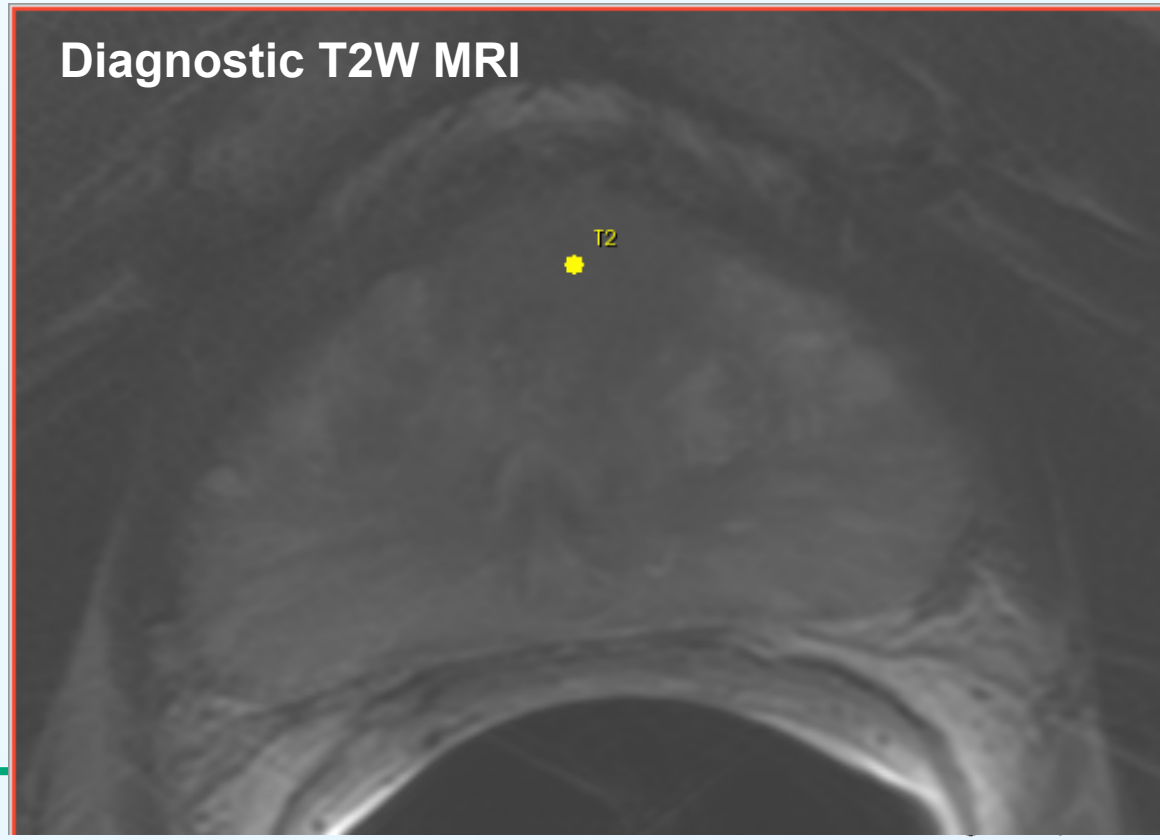

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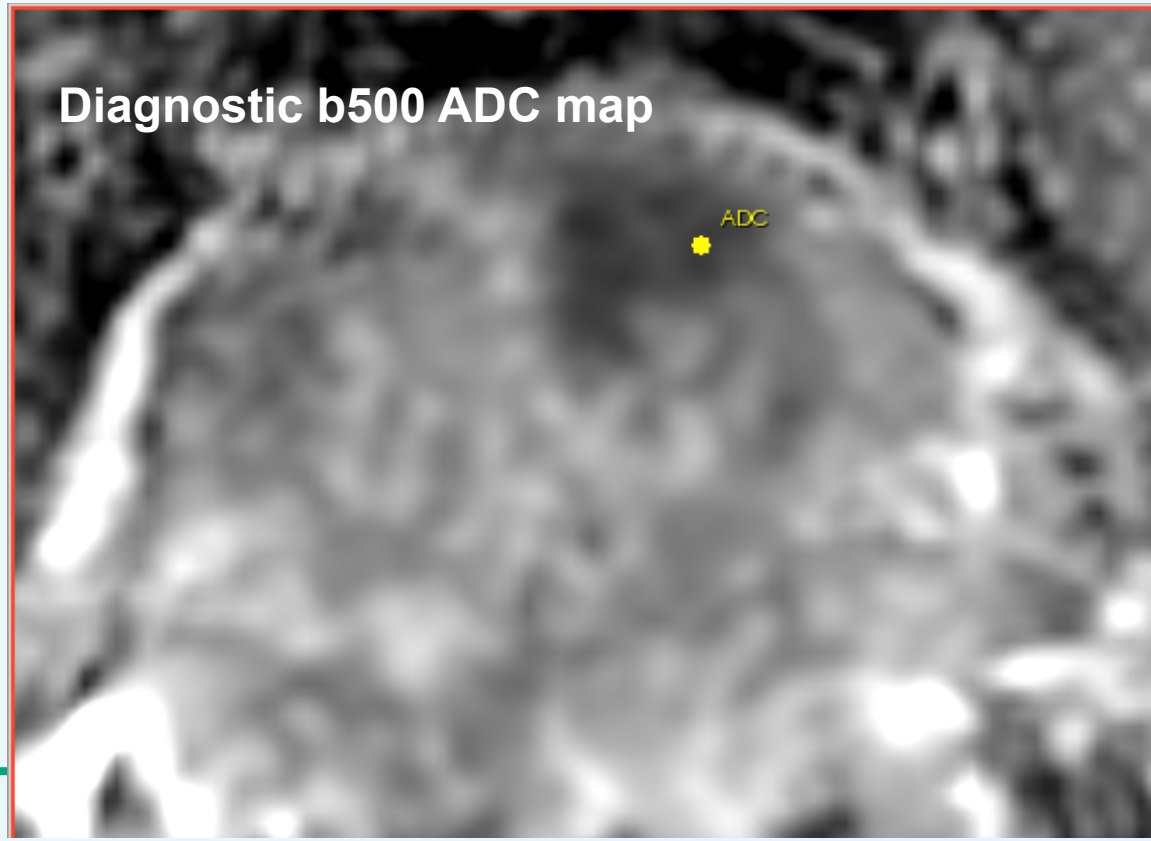
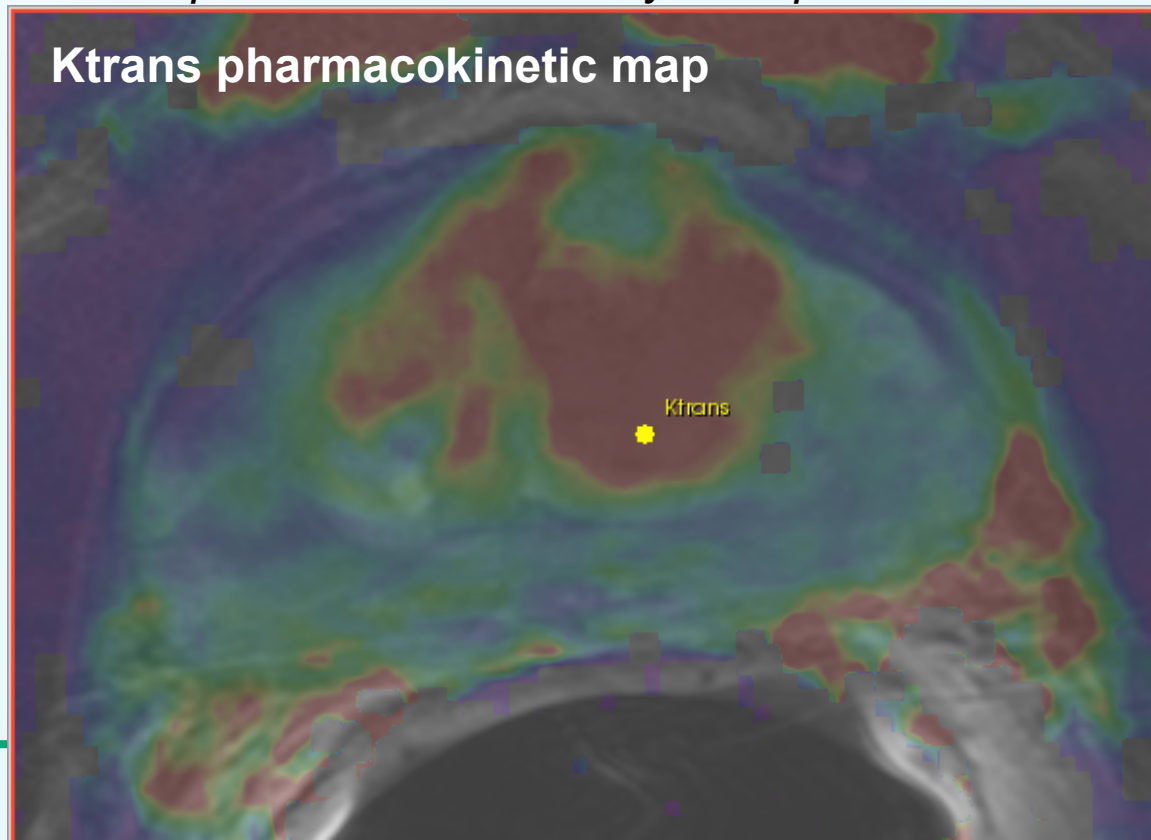


Diagnostic imaging and planning

- 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 AdvantageWorkstation Cinetool research software (GE Research, Niskayuna, NY)*



Diagnostic imaging and planning

- Multi-parametric MRI with endorectal coil at 3T
- Pharmacokinetic modeling from DCE MRI
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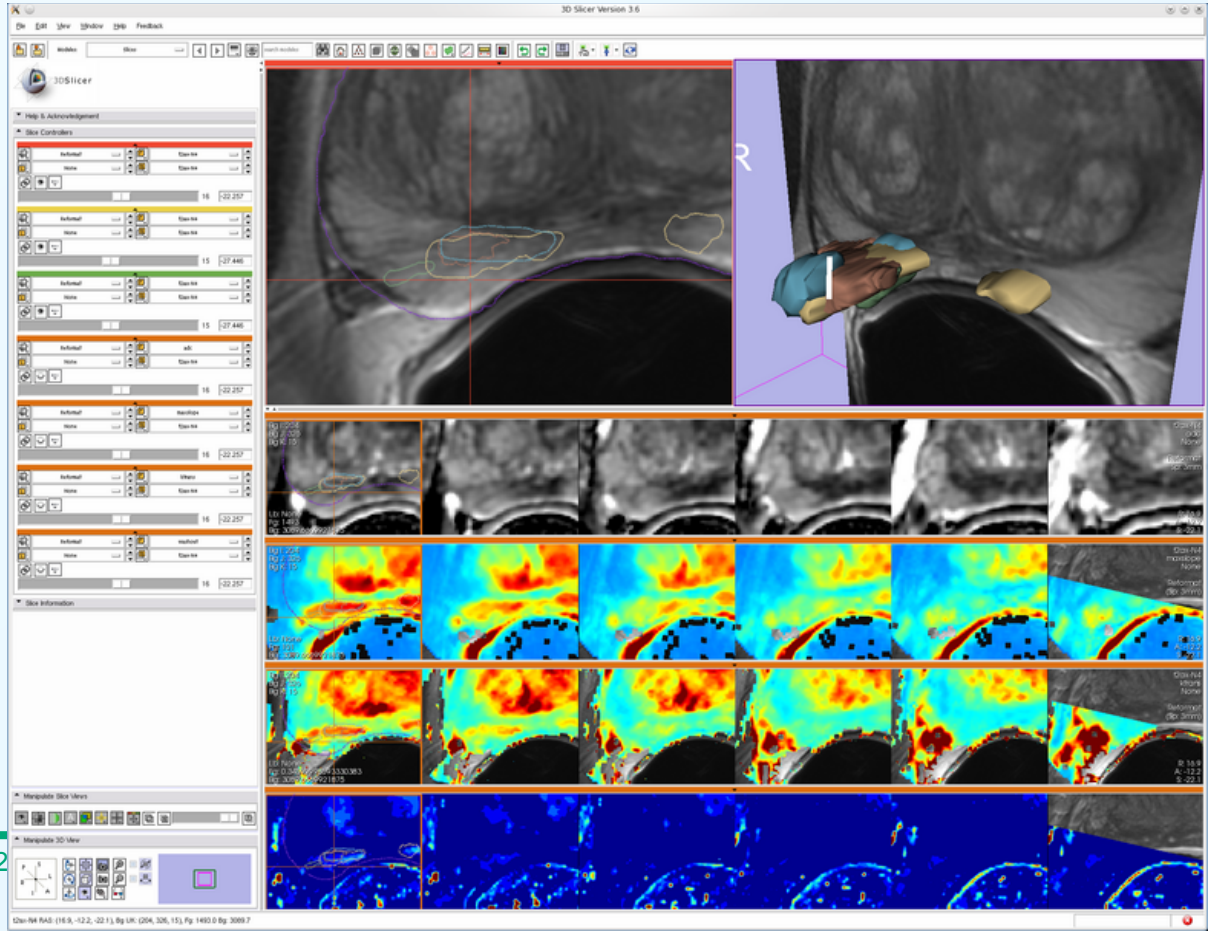
3DSlicer Version 3.6

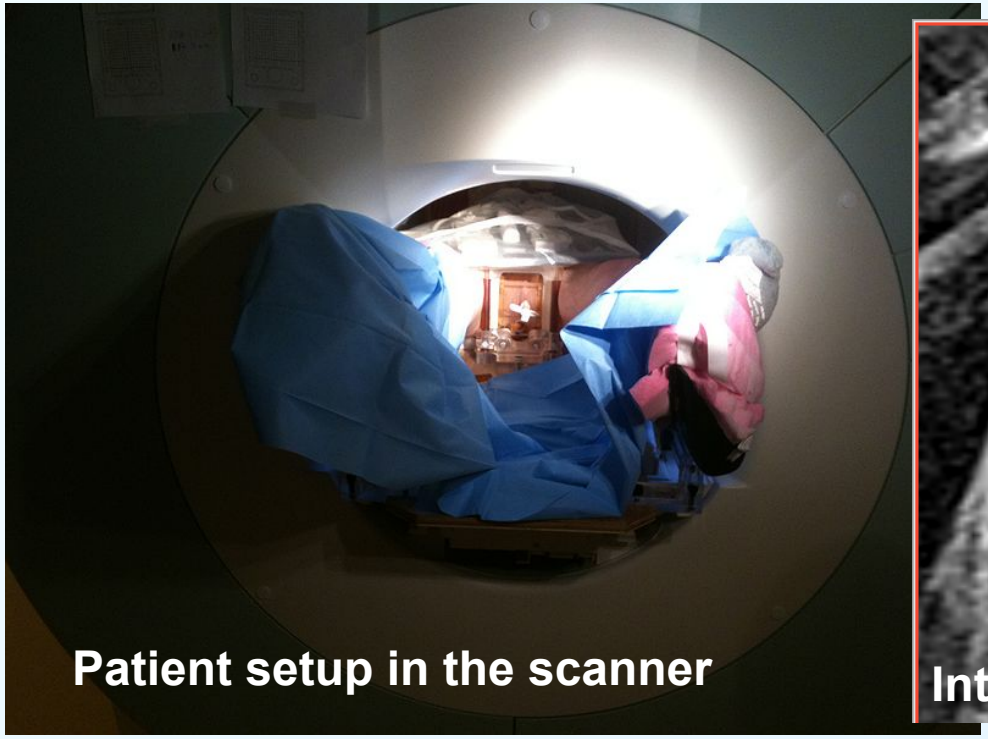
http://slicer.org

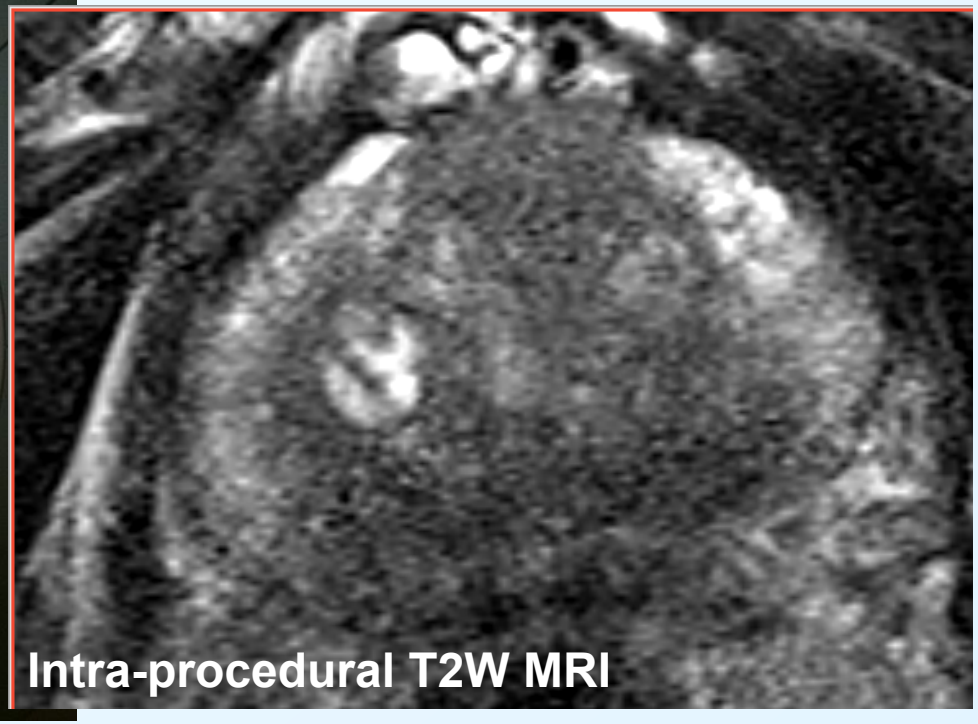


[1] *3D Slicer, http://slicer.org (Surgical Planning Laboratory, Boston, MA)*

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.
  - 3761: Tokuda J. et al. Preliminary Accuracy Evaluation of 3T MRI-guided Transperineal Prostate Biopsy with Grid Template.





Registration Approach

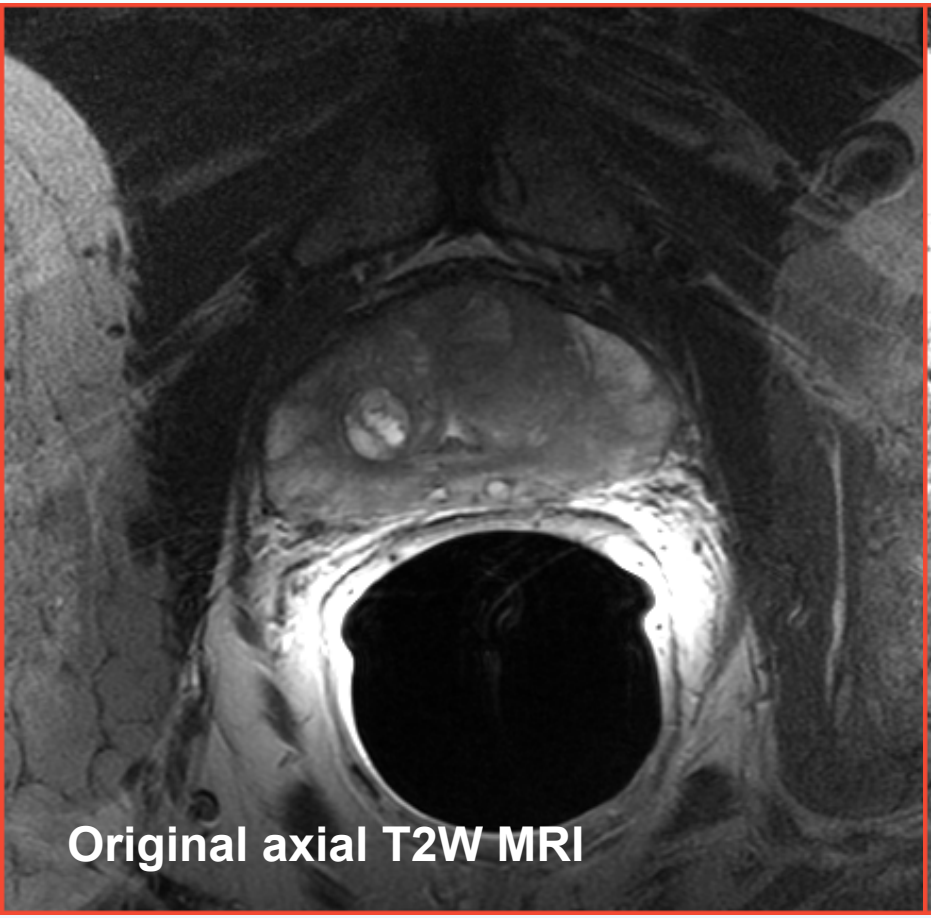
1. Preprocessing (before the procedure)
   - Bias field inhomogeneity correction
   - Gland contouring in the planning T2W image
2. Registration Initialization
   - Gland contouring in intra-procedural T2W image
3. Hierarchical registration based on image content
   - Multi-step approach using Mutual 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]

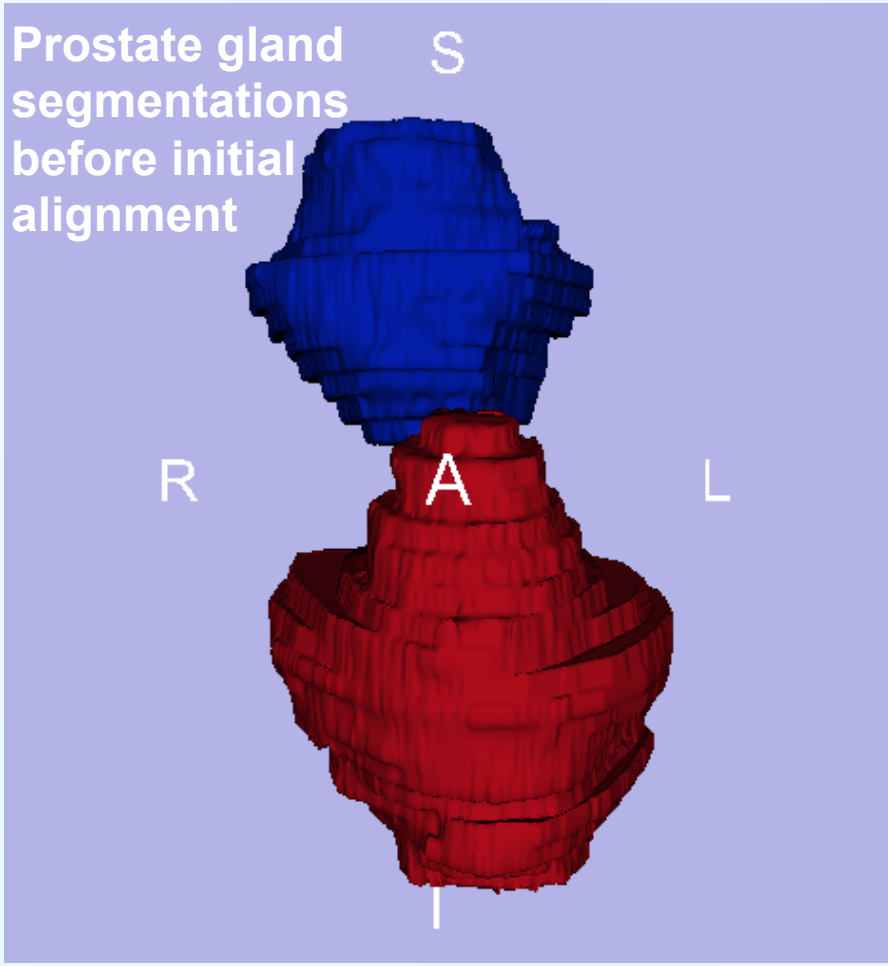
[1] *Tustison et al. 2010. N4ITK: Improved N3 bias field correction, IEEE TMI*

Inhomogeneity Correction



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



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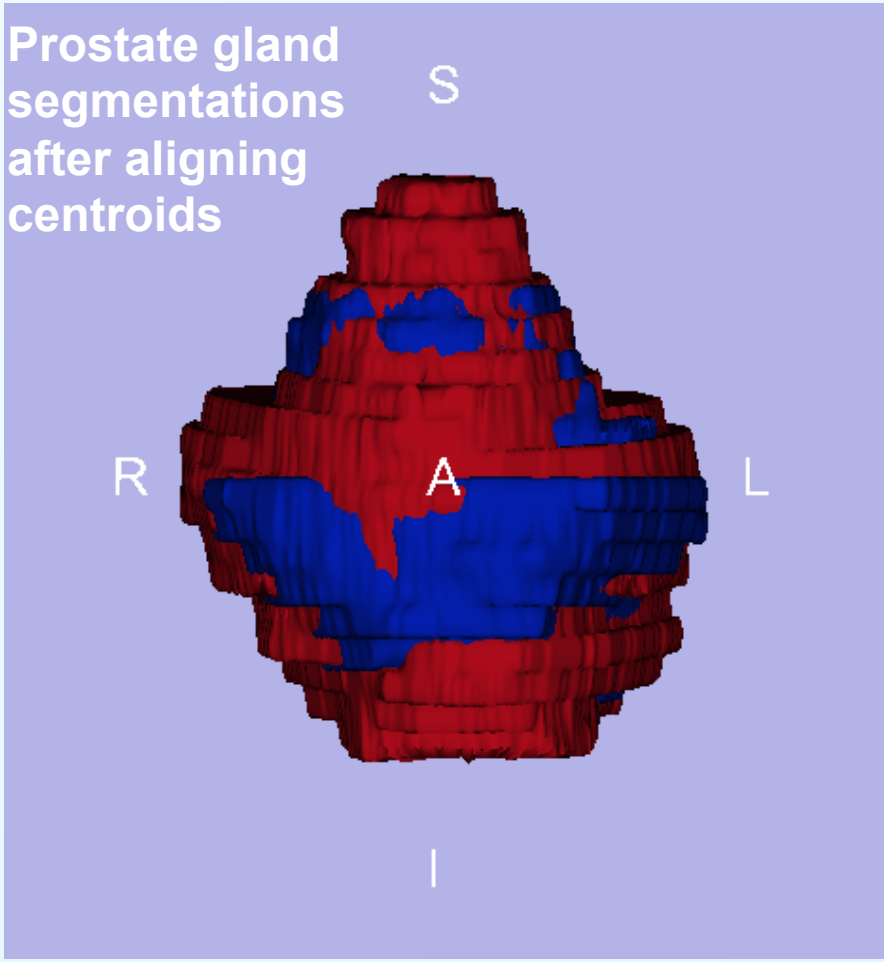
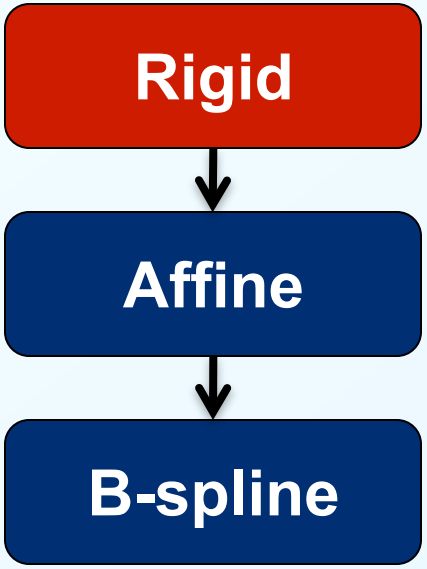
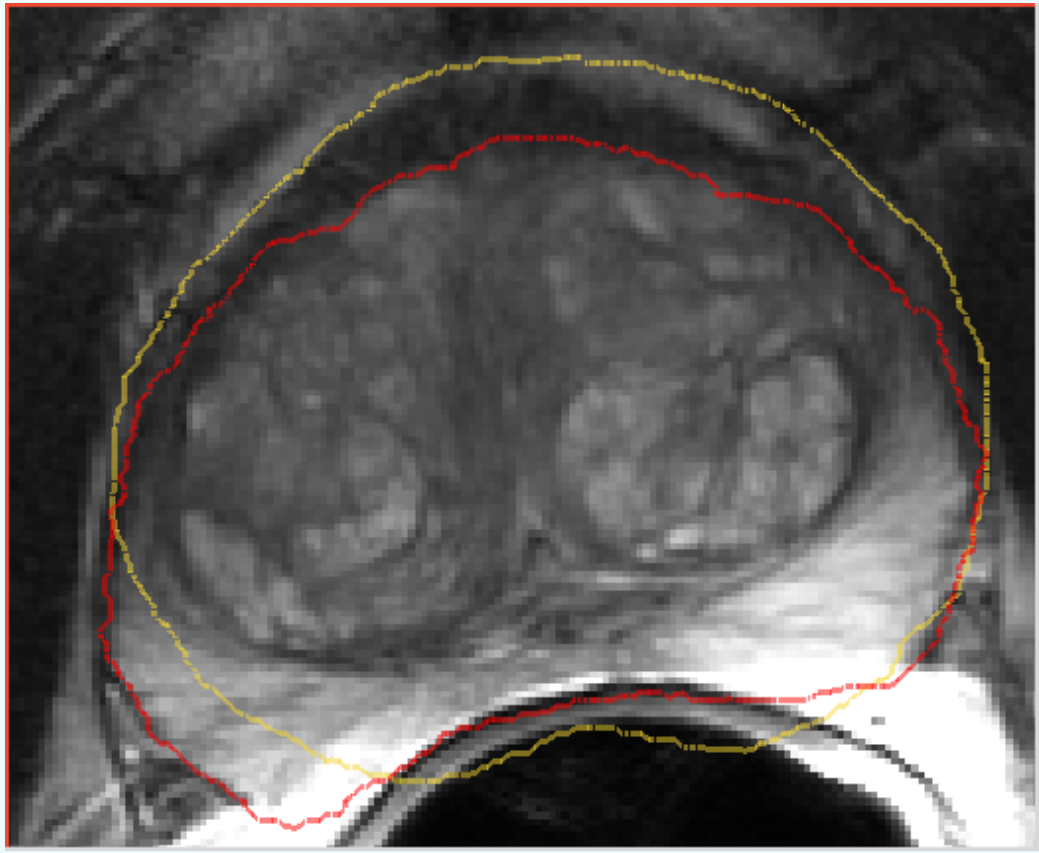


Hierarchical Transformation Model

- From rigid to more flexible transformation models:



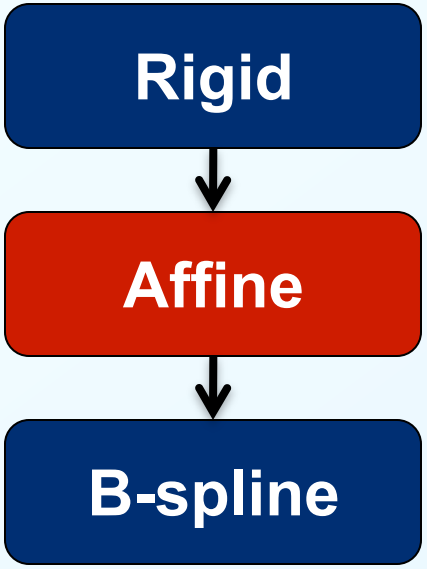
- Gradient descent optimizer
- Intensity sampling for MI calculation is limited to the contoured gland region



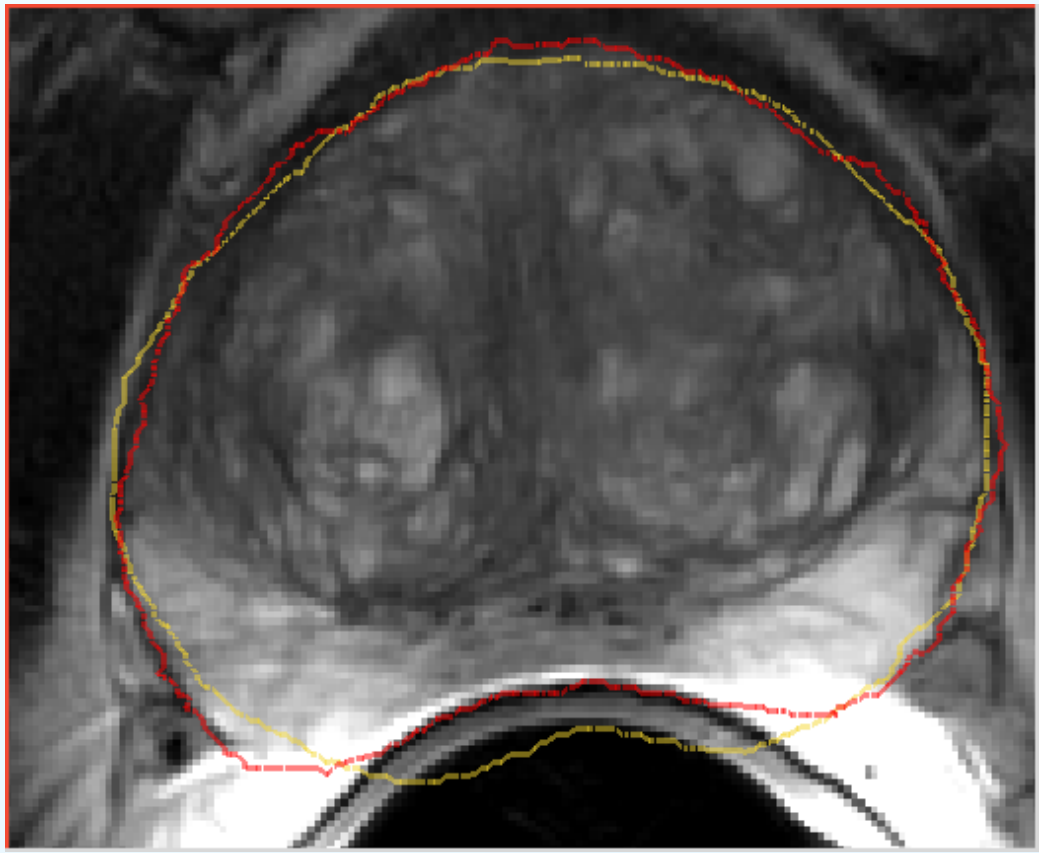
Diagnostic T2W MRI registered to intra-procedural T2W scan with Rigid transform. Intra-procedural gland contour is in yellow.

Hierarchical Transformation Model

- From rigid to more flexible transformation models:



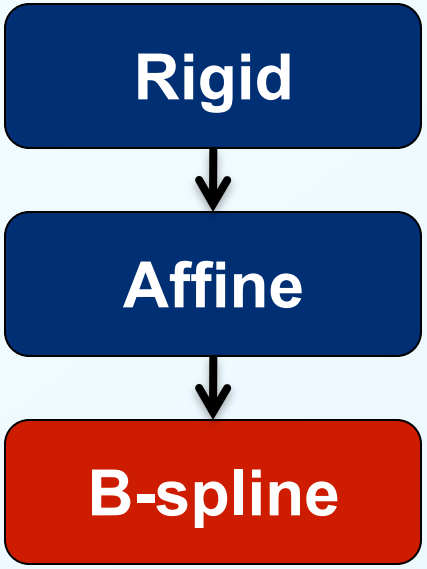
- Gradient descent optimizer
- Intensity sampling for MI calculation is limited to the contoured gland region



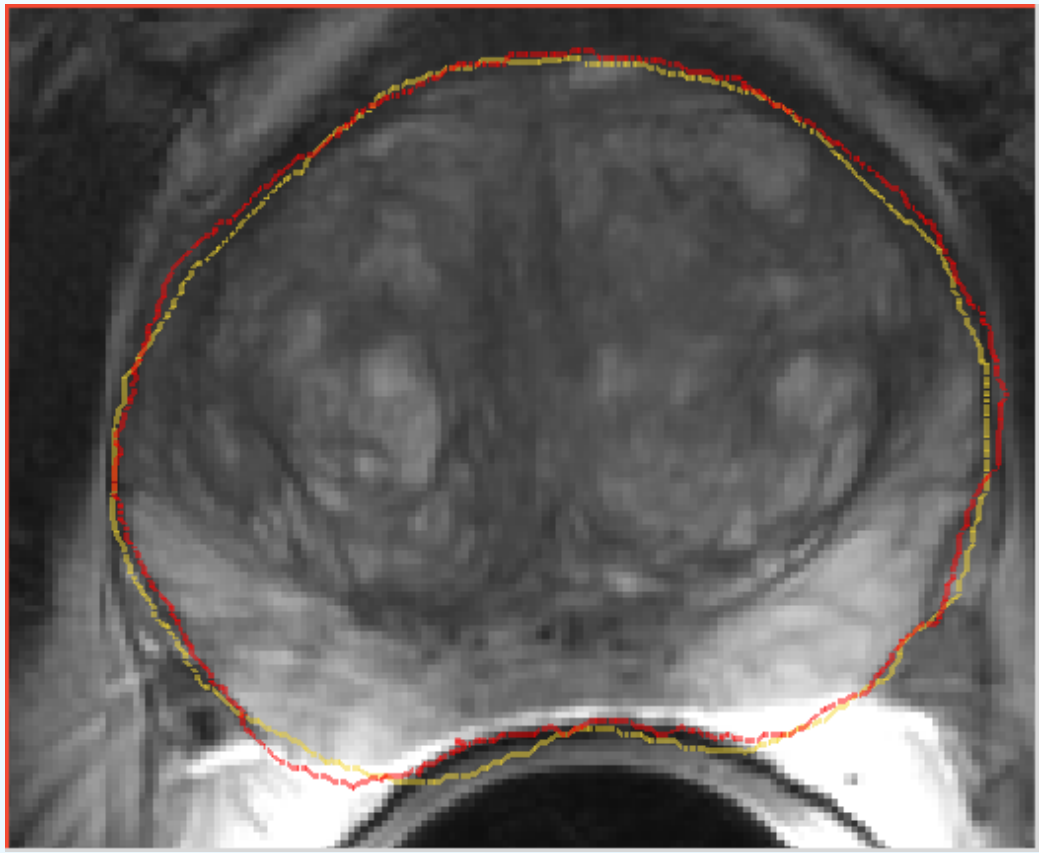
Diagnostic T2W MRI registered to intra-procedural T2W scan with Affine transform. Intra-procedural gland contour is in yellow.

Hierarchical Transformation Model

- From rigid to more flexible transformation models:



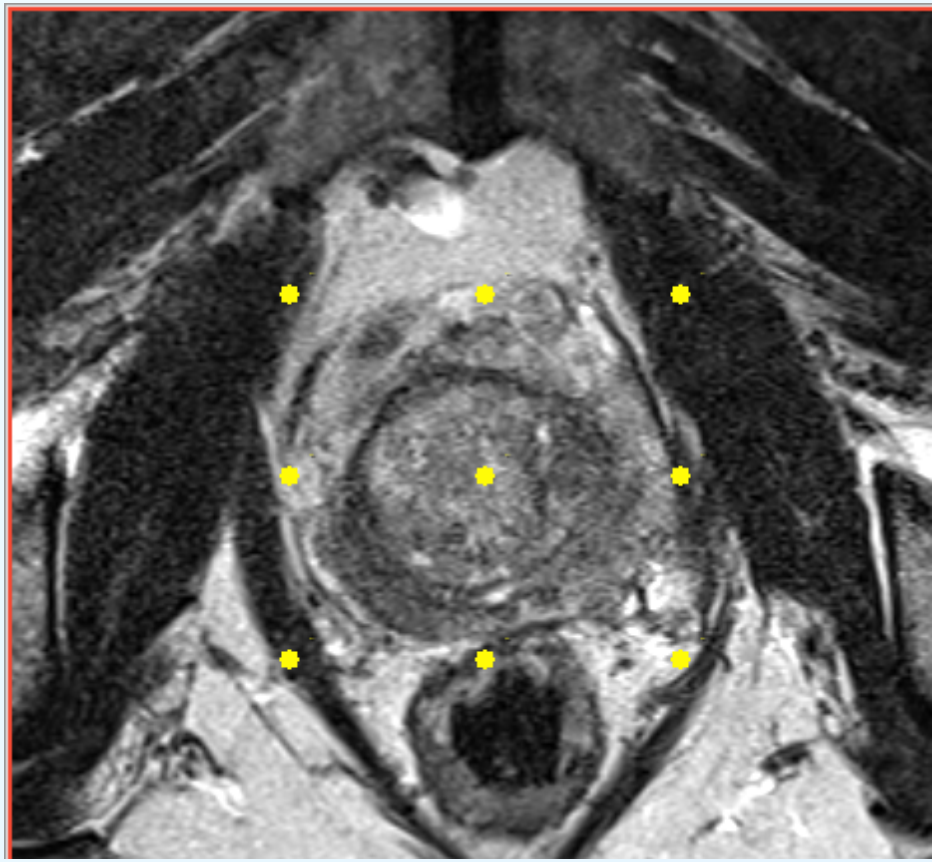
- Gradient descent optimizer
- Intensity sampling for MI calculation is limited to the contoured gland region



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

Non-rigid Registration Component

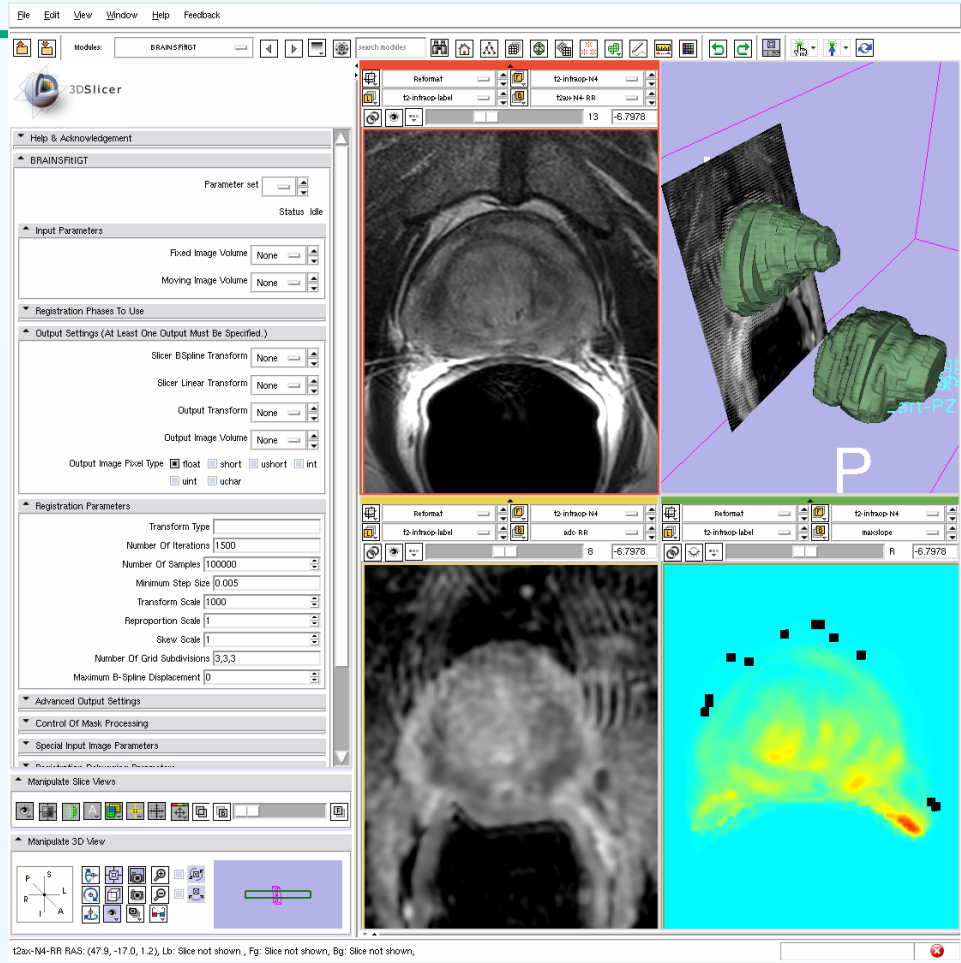
- Free-form deformation based on B-splines [1]
- Sparse 3x3x3 registration grid
- B-spline grid is initialized over the gland region
- Metric calculation is restricted to the gland region



[1] *Rueckert D. et al. 1999. Non-rigid registration using free-form deformation. Medical Imaging.*

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]

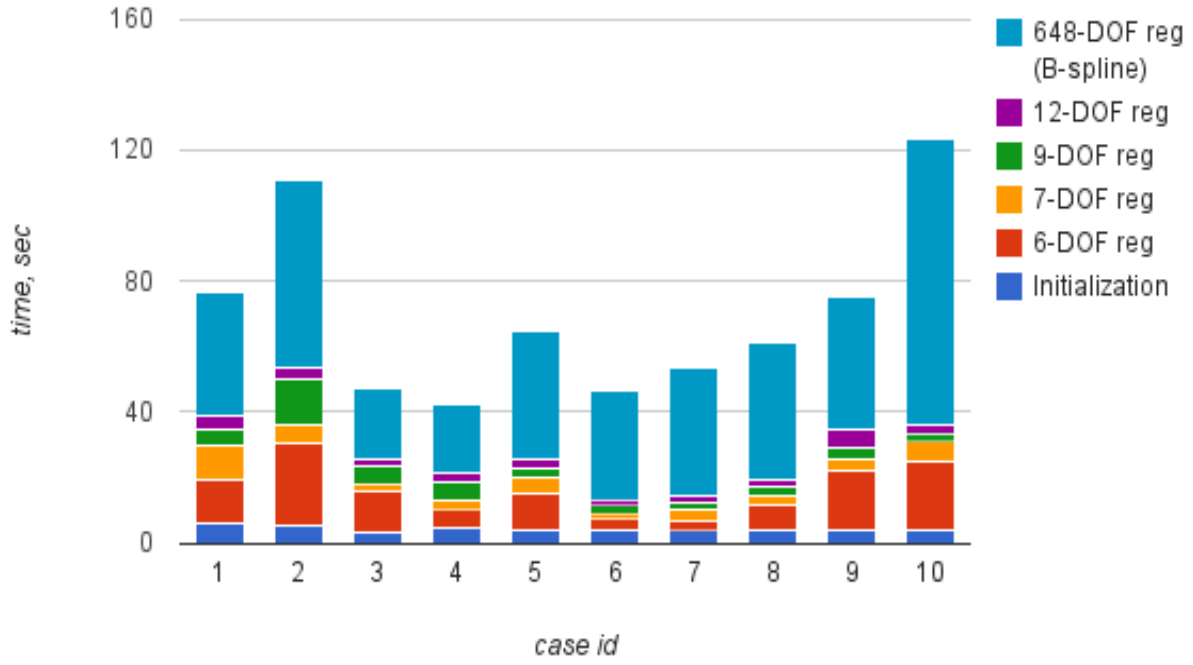


[1] *Surgical Planning Laboratory, Boston, MA, http://slicer.org*
[2] *Kitware Inc., Clifton Park, NY*
[3] *Johnson H. et al. 2007. Mutual Information Registration, Insight Journal*

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)

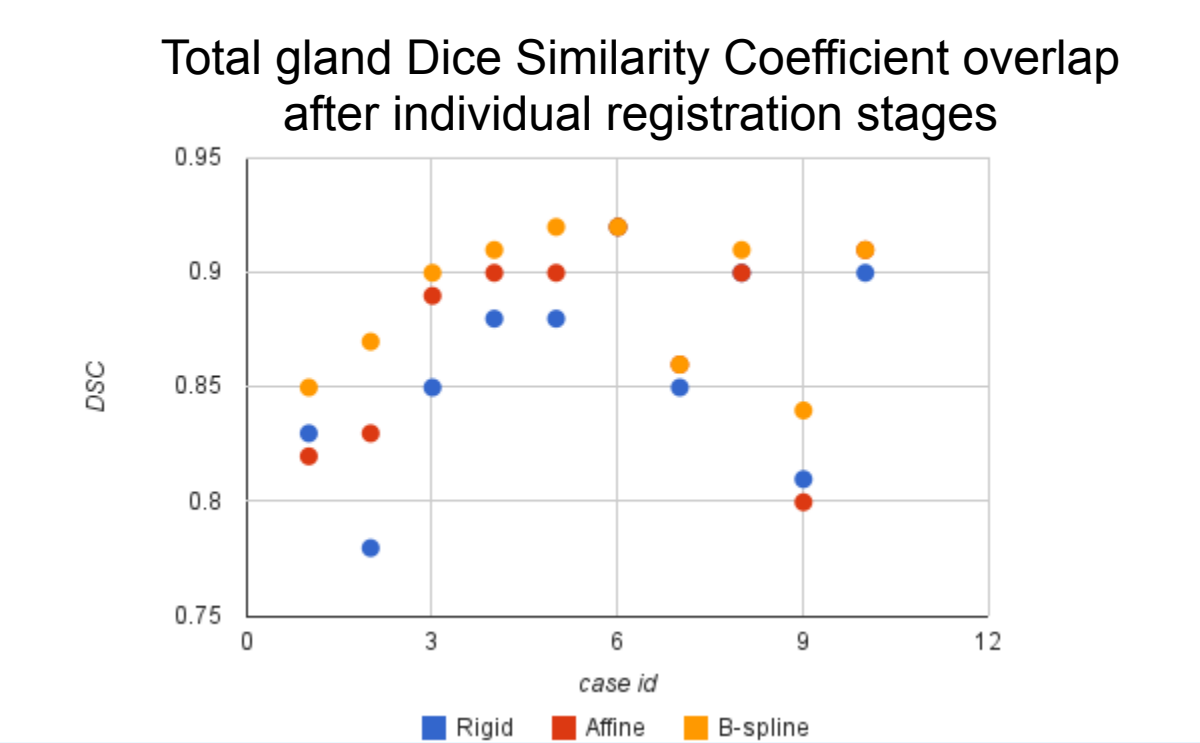
Computation time for the individual registration stages (seconds)



Cumulative computation for all the registration stages is within 2 minutes

Results: Accuracy

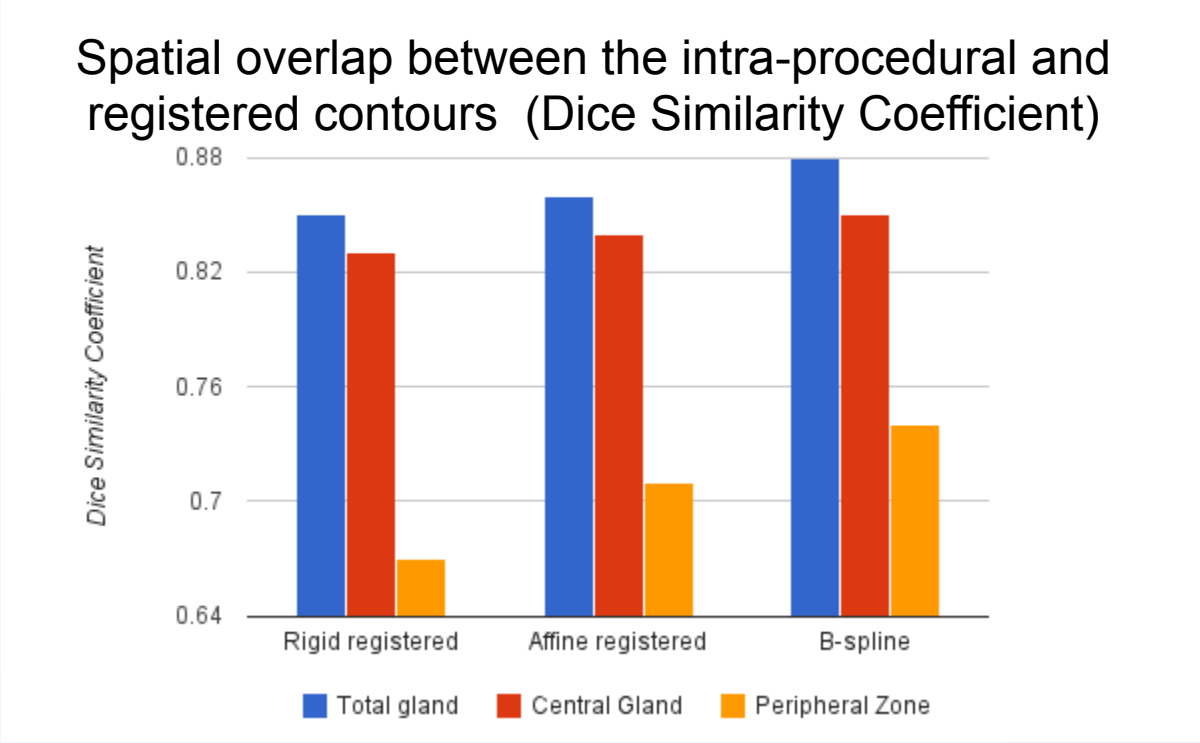
- Total Gland, Central & Peripheral zone contoured by an expert (15 years of experience in prostate MRI)
- Quality of overlap assessed with Dice Similarity Coefficient (DSC) – measure between 0 and 1



Mean DSC for the total gland after registration is 0.89

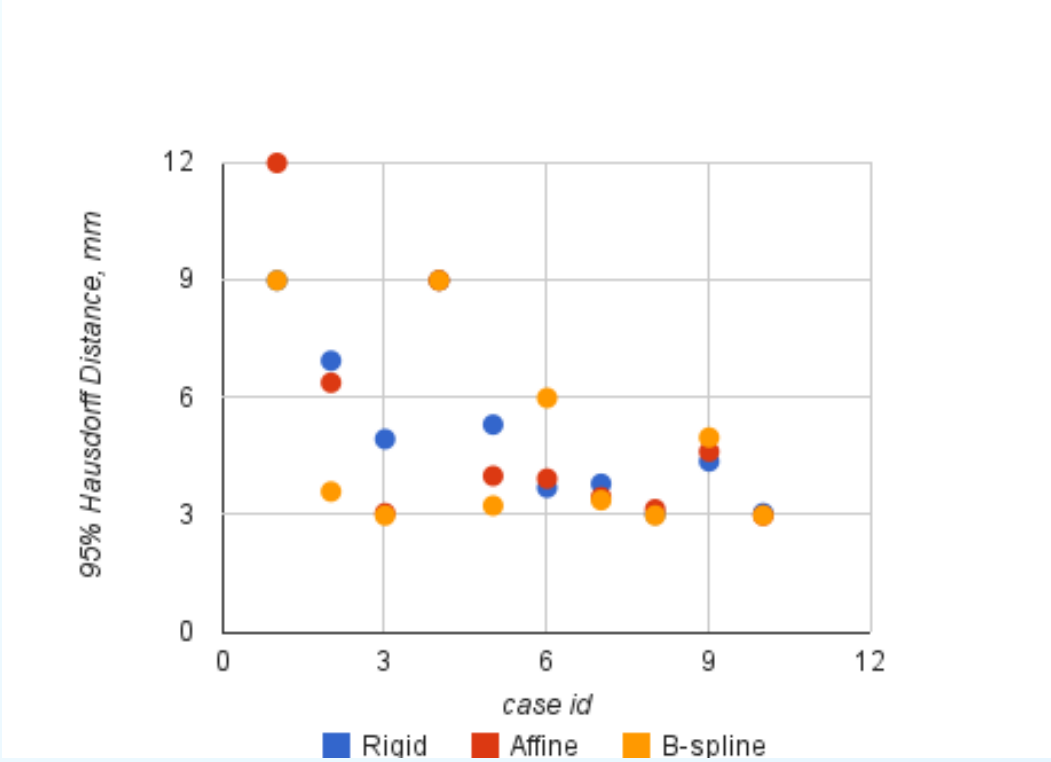
Results: Accuracy

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



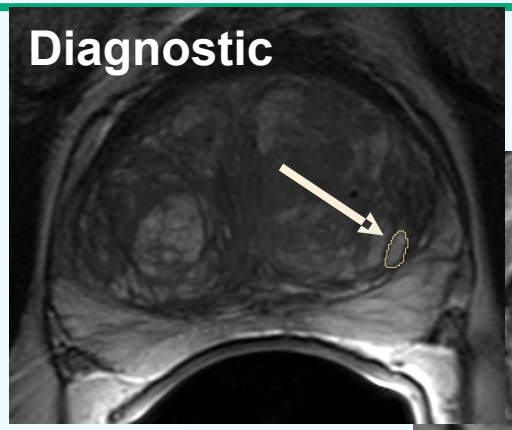
Results: Accuracy

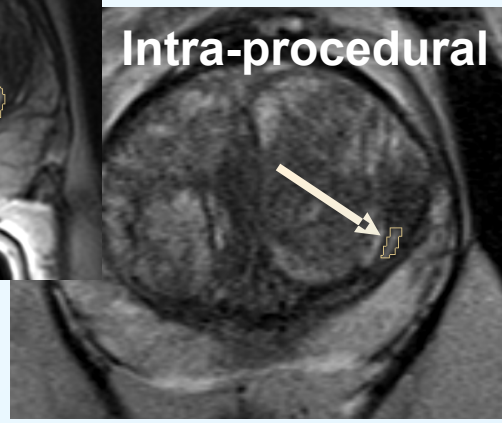
- Hausdorff Distance (HD): maximum point-wise distance between the two sets of points sampled over the surfaces
- 95% HD measured



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

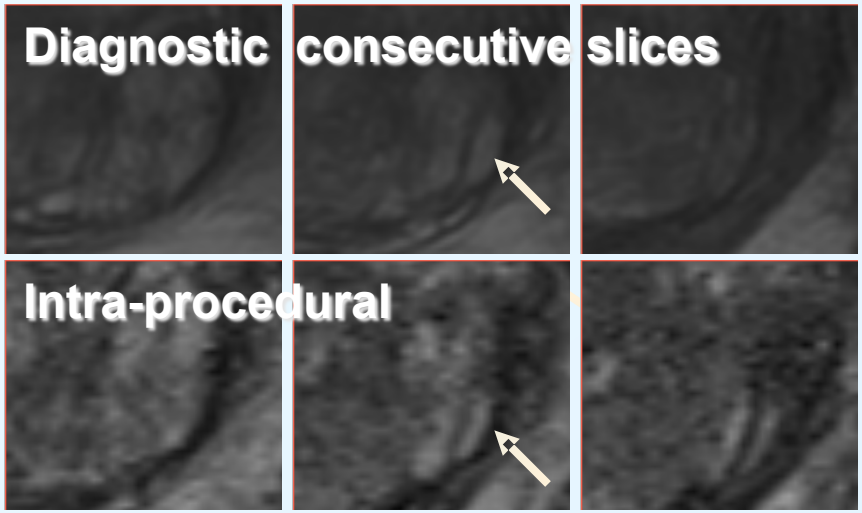
Landmark Accuracy Assessment





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

Transformation	Mean error (mm)	Maximum error (mm)
Rigid	1.7	4.6
Affine	1.5	2.9
B-spline	1.3	2.2



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)*
[2] *Bharatha et al. (2001) Evaluation of three-dimensional finite element-based […] Medical physics 28(12)*

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

Acknowledgments

- Imaging: Yi Tang, Bob Mulkern
- 3D Slicer: Steve Pieper, Nicole Aucoin
- N4ITK: Nick Tustison
- Registration: Hans Johnson
- Coordination: Louise Greenberg
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