Hierarchical Image Registration for Improved Sampling during 3T MRI-guided Transperineal Targeted Prostate Biopsy

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Introduction

Prostate cancer (PCa) is one of the most common cancer types in men in the USA. Diagnosis and staging of PCa relies on the histological analysis of biopsied prostate tissue samples. Joint use of multi-parametric MRI (mpMRI) (T2, DWI, DCE) results in improved detection of prostate cancer, while the use of MRI for biopsy guidance leads to superior accuracy of needle targeting. A challenge in the use of diagnostic scans for targeting during the MR-guided biopsy is that the prostate gland deforms due to the differences in the patient position (supine vs lithotomy) and the image acquisition (endo-rectal coil vs surface coils). The objective of this work is to develop a highly automatic method for registration of the diagnostic MRI with the intra-procedural configuration of the gland during transperineal MR-guided targeted biopsy procedure. Our goal is to demonstrate the feasibility of using application-specific registration technology within the constraints of the clinical protocol, which limits registration time to be under 5 minutes, and to quantify the accuracy of the registration.

Materials and Methods

Image acquisition Eight patients were enrolled in a prospective clinical study approved by the institutional review board. In 6 of the patients, diagnostic MRI was acquired in a GE 3T MR scanner using an endorectal coil (ERC) with the patient in the supine position, and included T1w, T2w, DWI, DCE sequences. In the other 2 cases (cases 1 and 7) the ERC was not used due to clinical indications. One patient had prior history of radiation threatment (case 2). Suspicious foci were identified based on the diagnostic mpMRI. Intra-procedural T2w MRI was obtained in a closed bore Siemens Verio 3T MRI scanner using surface coils with the patient in the lithotomy position. Image registration was performed between the diagnostic axial FRFSE T2w MRI (voxel size 0.3x0.3x3 mm) and the intra-procedural axial TSE T2w MRI (voxel size 0.4x0.4x3 mm).

Image Registration First, a rough estimate of the prostate gland boundary is prepared for the diagnostic and intra-procedural T2w MRI by a non-clinical operator using the 3D Slicer software [1]. All of the subsequent steps are performed automatically using the software modules developed in 3D Slicer. The scans are corrected for intensity inhomogeneity [2] to account for the strong bias artifact in the diagnostic scan due to the ERC. The registration workflow is derived from the BRAINSFit tool, originally developed for brain MRI [3]. Geometric centers of the segmented gland are automatically aligned, followed by a sparse regular sampling of the rigid transformation parameter space to obtain the initial transformations. Starting from this initialization, we minimize the value of the Mutual Information (MI) similarity metric between the regions corresponding to the prostate gland in the inhomogeneity-corrected volumes. The registration is accomplished in a hierarchical fashion by gradually increasing the flexibility of the transformation model from rigid to affine, to B-spline with the coarse grid of 3x3x3 knots.

Evaluation Protocol The accuracy of alignment after rigid, affine and B-spline registration was quantified using the Dice Similarity Coefficient (DSC) between the contours of the peripheral zone and central gland (PZ and CG), and the total prostate gland (TG) in the intra-procedural T2w MRI and the registered diagnostic T2w MRI. 95% Hausdorff distance (95% HD) [4] was computed to quantify the surface misalignment for the segmented structures.

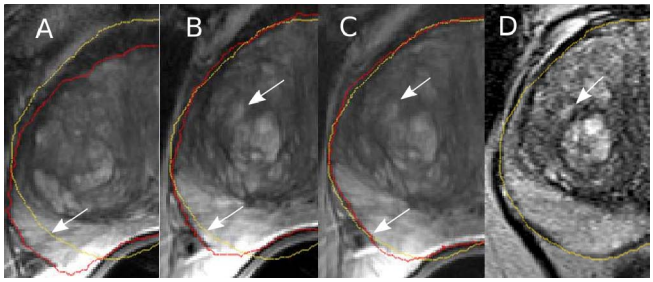

Figure 1: Diagnostic T2w MRI after rigid (A), affine (B) and B-spline (C) registration steps warped to the intra-procedural T2w MRI (D) for Case 5. Fused contour of the prostate gland in the diagnostic MRI (red), and the contour of the gland in the intra-procedural MRI (yellow) are shown in the overlay. Note the gradual improvement in alignment of the prostate capsule boundary, PZ/CG interface and the central gland BPH nodule.

	Total Gland	Central Gland	Peripheral Zone	Time, sec
1	0.82 / 0.81 / 0.85	0.73 / 0.73 / 0.78	0.72 / 0.79 / 0.82	**195**
2	0.79 / 0.82 / 0.87	0.77 / 0.80 / 0.85	0.60 / 0.65 / 0.75	**94**
3	0.85 / 0.88 / 0.89	0.66 / 0.73 / 0.76	0.85 / 0.88 / 0.89	**55**
4	0.88 / 0.90 / 0.90	0.90 / 0.91 / 0.90	0.63 / 0.67 / 0.69	**63**
5	0.88 / 0.90 / 0.91	0.89 / 0.92 / 0.91	0.66 / 0.72 / 0.79	**92**
6	0.92 / 0.90 / 0.90	0.90 / 0.90 / 0.89	0.72 / 0.69 / 0.57	**104**
7	0.84 / 0.85 / 0.85	0.79 / 0.80 / 0.81	0.73 / 0.73 / 0.72	**65**
8	0.89 / 0.89 / 0.90	0.87 / 0.86 / 0.87	0.73 / 0.75 / 0.76	**41**

Table 1: DSC between the structures in the intra-procedural and registered diagnostic MRI (rigid / affine / B-spline registration steps), and the registration execution time.

Results

Image registration was successfully accomplished in each of the 8 cases within time compatible with the clinical protocol. The average registration computation time was 2 min. For the purposes of registration, contouring of the prostate in each of the cases was completed by a computer scientist with 3 hours of prior training in radiologic appearance of the prostate in MRI. The average time required for the preparation of these approximate manual contourings of the prostate was within 2 min in each of the cases. For the evaluation of registration, accurate TG, PZ and CG contours were prepared by an abdominal radiologist with over 10 years of experience, which required on average 10 min per case. Contouring was done using the 3D Slicer software [1]. Transformations produced by the registration were applied to the multiparametric diagnostic images and to the planned biopsy targets identified before the procedure. The quality of the registration was examined visually by the interventional radiologist and found to be acceptable. Quantitative assessment showed that in most cases the accuracy of alignment of TG, CG and PZ segmented by the expert improved between the rigid and affine, and between affine and b-spline registration steps. In the cases where no ERC was used (1 and 7), the improvement was less prominent. No improvement due to deformable registration was observed in Case 6, where the difference in the shape of the gland was not significant due to the presence of rectal filling during the biopsy procedure. On average, registration resulted in 0.88 DSC and 4.4 mm 95% HD for the total gland contour after registration.

Discussion and Conclusions

We presented a novel approach to the registration of diagnostic T2w MRI with the intra-procedural MRI for improved targeting during MR-guided transperineal PCa biopsy, and its preliminary evaluation on 8 cases. Our approach allows to register the images within the constraints of the clinical workflow, and facilitates fusion of the diagnostic data for improved PCa targeting. The advantages of the developed methodology over the surface-based registration methods is in its ability to leverage the intensity information throughout the whole prostate gland, which enables improved alignment of the features corresponding to the internal structures, as demonstrated in Fig.1. Unlike the previously developed intensity-based approaches to recover similar prostate deformations [4], we significantly reduced the involvement of the operator: once the approximate contours of the prostate gland are identified, our method is fully automatic and does not require further interaction. Additionally, we improved the robustness of the registration procedure by incorporating inhomogeneity correction and automatic initialization into the registration process.

Acknowledgments

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