Accuracy analysis in MRI-guided robotic prostate biopsy

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Purpose

Prostate cancer is the most prominent form of cancer for men in developed countries [1]. Needle biopsy is often needed for a definitive diagnosis. The current standard prostate biopsy procedures use 2D transrectal ultrasound (TRUS) guidance. However, cancers have been routinely missed using this approach (detection rate 20-40%), resulting in a large number of repeat biopsy cases [2]. The superior soft tissue imaging quality of magnetic resonance imaging (MRI) provides an alternative for biopsy guidance. Due to confined physical space in the scanner and the length of the procedure, robotic assistance is often required. The Access to Prostate Tissue under MRI (APT-MRI) system [3] has been used at the U.S. National Cancer Institute for over six years. In addition to patient motion, the prostate itself can deform and dislocate upon needle insertion. The current system does not take into consideration of these factors, yet the biopsies still need to be sufficiently accurate to hit the intended target in order not to miss the suspected cancerous tissue. This paper reports a retrospective quantitative evaluation of the biopsy accuracy for the APT-MRI robotic biopsy system.

Methods

Sets of 2D transverse volumetric image slices of the prostate pre and post needle insertion were used for biopsy accuracy evaluation. The images were first pre-processed to decrease intensity non-uniformity in homogeneous tissue using N4ITK (Nick's N3 Insight Toolkit) implementation for MRI bias field correction. Next, a three-stage volume-to-volume registration procedure was developed using ITK to capture prostate motion during biopsy. The procedure starts with a rigid registration of the entire image volume to compensate for prostate motion in coherence with the biopsy device and patient. Next, another rigid step was performed using only the prostate as region of interest to correct for residual decoupled prostate motion. Finally, a B-spline deformable registration (grid size 5x5x5) was used to fine-tune the alignment and to adjust for tissue deformation. Due to large differences in our images, mutual information was chosen as the similarity metric.

The registrations were validated by performing image overlays and evaluating the prostate contour alignment between the resulting volumes and its corresponding fixed volume. If the results were off by more than 2 mm, manual registrations were performed. Using the registration results, target displacement (distance between planned and actual biopsy target), needle placement error (distance from planned biopsy target to needle trajectory), and biopsy error (distance from actual biopsy target to needle trajectory) were calculated as biopsy accuracy assessment (Fig. 1).

Results

A total of 90 biopsies from 24 patients were studied. The accuracy of the registration procedure was verified in order to provide a bound on biopsy accuracy evaluation. The registration results from all 90 biopsies were validated using the previously discussed image overlay approach. After manual adjustments, all registrations were accurate to within 2 mm. A signed rank test has shown that the results from rigid and deformable registrations were significantly different ($p \approx 0$). However, rigid registrations recovered the majority (88%) of the transformations. The mean target displacement, needle placement error, and clinical biopsy error were 5.2 mm (range: 0.9-18 mm, standard deviation: 3.5 mm), 2.5 mm (range: 0.1-10.7 mm, standard deviation: 1.6 mm), and 4.3 mm (range: 0.2-12 mm, standard deviation: 2.9 mm), respectively.

Conclusion

We performed a retrospective accuracy analysis of an MRI-guided robotic prostate biopsy system by using a three-stage registration procedure to capture prostate motion during biopsy. The targeting accuracy of the APT-MRI system is considered acceptable, since its needle placement error (mean: 2.5 mm, standard deviation: 1.6 mm) is less than the radius a clinically significant tumor (volume: 0.5 cm^3, sphere radius: 5 mm). This implies that the robotic device was accurate enough to place the needle at the intended biopsy target assuming no prostate movement. However, the prostate did dislocate and deform during the procedure (mean displacement: 5.2 mm), and this resulted in a mean biopsy error of 4.3 mm. Furthermore, 28% of the biopsies have an error greater than 5 mm, and this error is higher for cases with large patient motion. These results suggest that intra-procedual prostate motion may cause substantial biopsy errors, which should not be ignored. Further research on prostate motion and deformation upon needle insertion should be conducted, in order to facilitate the development of motion compensation techniques to be incorporated into the clinical protocol.

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References

[1] American Cancer Society (2012) Cancer facts and figures. http://www.cancer.org/acs/groups/content/@epidemiologysurveilance/documents/document/acspc-031941.pdf. Accessed 9 Jan 2013

[2] Welch H, Fisher E, Gottlieb D, Barry M (2007) Detection of prostate cancer via biopsy in the medicare–SEER population during the PSA era. J Nat Cancer Inst. 99(18):1395

[3] Krieger A, Susil R, Menard C, Coleman J, Fichtinger G, Atalar E, Whitcomb L (2005) Design of novel MRI compatible manipulator for image guided prostate interventions. IEEE Trans Biomed Eng 52(2):306-331

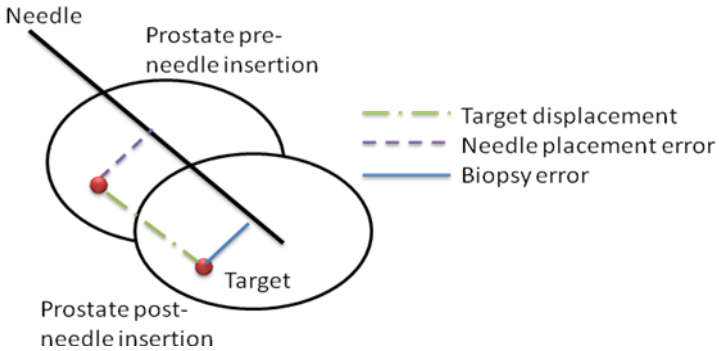

Fig. 1 Illustration of the prostate dislocation during needle insertion and the parameters used in biopsy accuracy analysis