Transrectal MRI-guided prostate biopsy: evaluation of a novel robotic technique

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Introduction: Patients with a rising prostate specific antigen (PSA) and repeated negative transrectal ultrasound (TRUS)-guided biopsy sessions are a common clinical problem. With a detection rate of 59% - after two or more negative transrectal ultrasound (TRUS)-guided biopsy sessions - magnetic resonance image (MRI)-guided biopsies will play an important role in these patients[1]. Needle positioning, is influenced by motion of the patient and prostate, as well as tissue deformation during biopsy[2-4]. Consequently, the needle does not always reach the targeted region. Needle guide positioning is a precise work and often a time consuming process since the patient has to be slid in and out the from the scanner bore multiple times to manually adjust needle guide direction. During needle guide manipulation the target may have moved. For these reasons an in-house pneumatically actuated MR-compatible robotic technique was developed where needle guide direction can be controlled from inside the control room[5]. The robotic technique demonstrated promising results regarding precision of needle positioning and short manipulation time in a phantom study[5]. The purpose of this study was to evaluate the accuracy and speed of a novel pneumatically controlled magnetic field compatible manipulator as an aid to perform magnetic resonance image (MRI)-guided biopsies on patients with cancer suspicious lesions in the prostate.

Method: A pneumatic controlled manipulator (figure 1) with 5 degrees of freedom constructed of plastic to achieve magnetic field compatibility was developed in-house to guide biopsies under real-time imaging[5]. Real-time image sequence parameters: TR/TE/FA=894/2.3/60, resolution 1.6 x 1.6 x 5.0 mm, readout gradient strength= 7.53 mT/m, 3 slices in different planes (sagittal, coronal, axial plane), 0.9 s/slice). The targeting and biopsy accuracy of the new robotic technique and the existing commercially available manual device (Invivo, Schwerin, Germany) to sample a predefined target were measured. In total, 13 biopsy procedures (8 procedures using the robotic technique) were performed on a 3T whole body closed bore MR system. A target displacement vector was determined for each needle position by evaluating the shift of anatomical landmarks around the cancer suspicious lesion. These landmarks were manually selected from 3D volumetric spin echo sequences (TR/TE/FA=1000/102/100, resolution 1.0 x 1.0 x 1.0 mm, readout gradient strength=7.22 mT/m, acquisition time 2:36 minutes) made before needle guide manipulation and after needle insertion. This in order to determine distance and direction of target displacement. The time needed for both procedures was recorded to evaluate manipulation and procedure time. Two-tailed student t-tests were performed to determine differences between groups. Significant differences were considered at $p < .05$.

Results: Both the robotic and manual techniques demonstrated comparable results regarding mean targeting error (5.7 vs 5.8 mm, respectively) and mean target displacement (6.6 vs 6.0 mm, respectively). The mean biopsy error was larger (6.5 vs 4.4 mm) when using the robotic technique, however not significant. The mean angle between needle trajectory and target displacement direction was similar for both the robotic and manual techniques and was 36.7° (range 4.0 – 82.2°) and 37.6° (range 7.7 – 73.3°), respectively. These results suggest that most target displacement was seen in the direction of the needle trajectory. The mean procedure time was 76 minutes using the robotic technique and 61 minutes with the manual technique. Mean manipulation time to move from target to target was 6 minutes with the robotic technique and 8 minutes with the manual technique. Manipulation time and procedure time were not significant different when comparing the robotic and manual techniques.

Discussion: Currently, the robotic technique for transrectal real-time MR-guided prostate biopsies did not outperform the manual technique. Furthermore, this study provided insight into reasons for target motion during a biopsy procedure. Our results suggest that most target displacement is caused by needle insertion. There is room for improvement. For example, the size (especially height) of the robotic technique should be reduced to improve workflow. When the position of the patient and robotic technique was not performed correctly the whole setup did not fit into the scanner bore or movement of the needle guide was impaired. Image registration during the biopsy procedure may help to improve the biopsy error. Target displacement may be reduced by using other techniques for needle insertion, such as rotating needles and a tapping device[6,7].

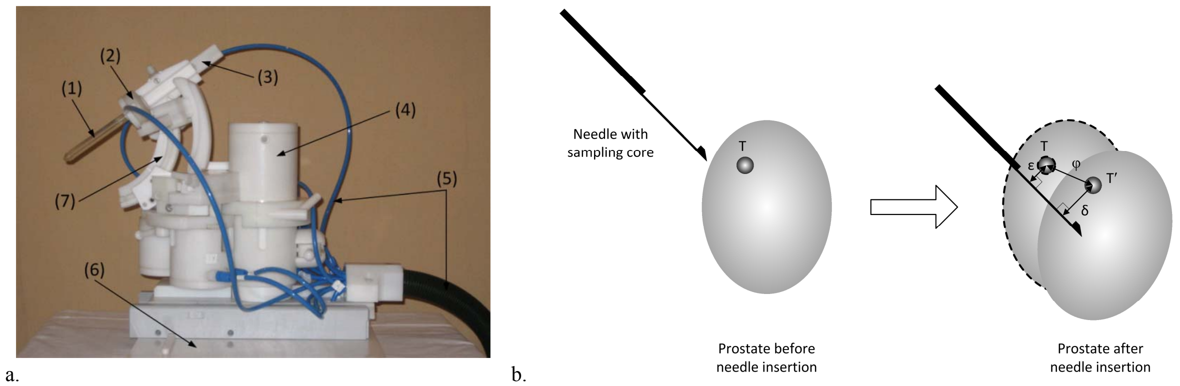

Figure 1: (a.) The robotic technique is shown with (1) the needle guide, (2) safety mechanism with the suction cup, (3) tapping mechanism to introduce the needle guide, (4) pneumatic motor, (5) tubings to the motors, (6) ground plate for installation on the MR table, (7) angulation rail to move the needle guide in the coronal plane. (b.) Representation of the needle inside the prostate illustrating targeting error (ε), target displacement (φ) and biopsy error (δ). The targeting error, defined as the normal distance from needle to the original target coordinate (T), is shown. Target displacement, defined as the distance between original target (T) and transformed target (T′), is represented by φ. Furthermore, the biopsy error (δ) is shown which is defined as the normal distance between transformed target (T′) and needle.

References

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