Proof of principle of an MR-compatible robot for MRI-guided interventions using a unique tapping device

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Introduction Since MRI offers superior soft tissue contrast in diagnostic and treatment procedures, MR-compatible robotic systems allowing real on-line MRI-guidance would be extremely valuable with these procedures. We built an MR-compatible robot to be used for MRI-guided interventions as brachytherapy and biopsy. Because of its unique way of needle insertion (tapping rather than pushing) tissue deformation will be minimized *[1,2]*, making it also suitable for sites where tissue deformation due to needle insertion is problematic, like breast or prostate. In this study we demonstrate the proof of principle of this robot in patients. Four fiducial gold markers were placed transperineally into the prostate of a patient with a stage T3 prostate cancer.

Methods and materials In this study, which was approved by the institutional review board, we deliver fiducial gold markers inside prostates of patients that are eligible for external beam radiotherapy treatment (EBRT). The markers will be used for the position verification of the prostate during EBRT. Since the marker placement criteria are soft (the target volume is the whole prostate) this application is ideal to test robotic MRI-guided needle insertion and marker placement.
The first patient included in this study is a patient with: tumor stage T3, age 76 years, body mass 84 kg, length 1.76 m, BMI 27 kg/m^2, prostate volume 75 cc.

Procedure The patient got local anaesthesia and was placed in supine position on the MR table with legs spread within the MR bore. The needle was pushed manually just beneath the patient's skin through an insertion point defined by the radiation oncologist and then automatically tapped towards the desired position by the robot using a controller unit outside the scanning room. During this procedure several 3D balanced Steady State Free Precession (bSSFP) scans were acquired to check whether the prostate was freely accessible following the needle trajectory and to define the target position. Scan parameters were: repetition time (TR)=6.4 ms, echo time (TE)=3.2 ms, acquisition time (T_{acq})=261 s, flip angle=50°, read-out bandwidth (BW_{read})=781.3 Hz/voxel, field of view (FOV)=340x271x100 mm^3, acquisition voxel=1.3x1.0x2.0 mm^3, overcontiguous slices=yes, number of samples averages (NSA)=6. Furthermore, we generated fast 2D MR scans of two orthogonal planes during tapping, to track the needle trajectory and depth on-line. Scan parameters were: TR=5.7 ms, TE=2.8 ms, T_{acq}=5.2 s, flip angle=45°, BW_{read}=256.6 Hz/voxel, FOV=300x300 mm^2, acquisition voxel=1.3x1.3x10.0 mm^3, number of slices=2 , NSA=2. At the target position the radiation oncologist manually placed a gold marker through the needle. Two parallel needle trajectories were used to place four markers.

Robot The MR-compatible robot is made of polymers and non-ferromagnetic materials as copper, titanium and aluminium (Figure 1a). It can be placed between patient's legs inside a 1.5T closed bore MR scanner. It contains a tapping device to tap the needle with an adjustable stepsize of a few millimeters towards the desired location. In the time period in between the steps, fast images were acquired (see above) to monitor the needle and target position. The tapping device can manually be translated and rotated resulting in six degrees of freedom [3]. Tapping itself is controlled from outside the scanning room.

Results The robot could tap the needle towards the desired position under MRI-guidance with the use of the fast 2D scans. In both the 2D and 3D scans, it was possible to discriminate the target volume (prostate), critical structures as rectum and pubic arch, and fiducials as the needle and the markers (see Figure 1b-e). All markers were delivered inside the prostate and the procedure time was 1.5 hours.

Discussion Since the susceptibility artefact caused by the needle is confined to the tip of the structure, the needle tip can be better distinguished than the needle shaft. The real needle tip is approximately 5 mm proximal from the outer edge of the artefact using the bSSFP sequences of this study at 1.5 T, as we know from simulations *[4]* and previous experiments. In Figure 1c-e, a prostate deformation up to 7 mm was measured, which suggests to further increase the needle insertion speed. In the nearby future, we aim to speed up the manual procedure steps as well as the imaging acquisitions, allowing the acquisition of more (3D) MR images to investigate the marker placement accuracy under in-vivo conditions.

Conclusion This study reveals that it is possible to automatically insert a needle under MRI-guidance towards a target position in the prostate using our robot. This opens the door for MRI-guided interventions as biopsy and brachytherapy in tissue, where deformation might be problematic.

References:

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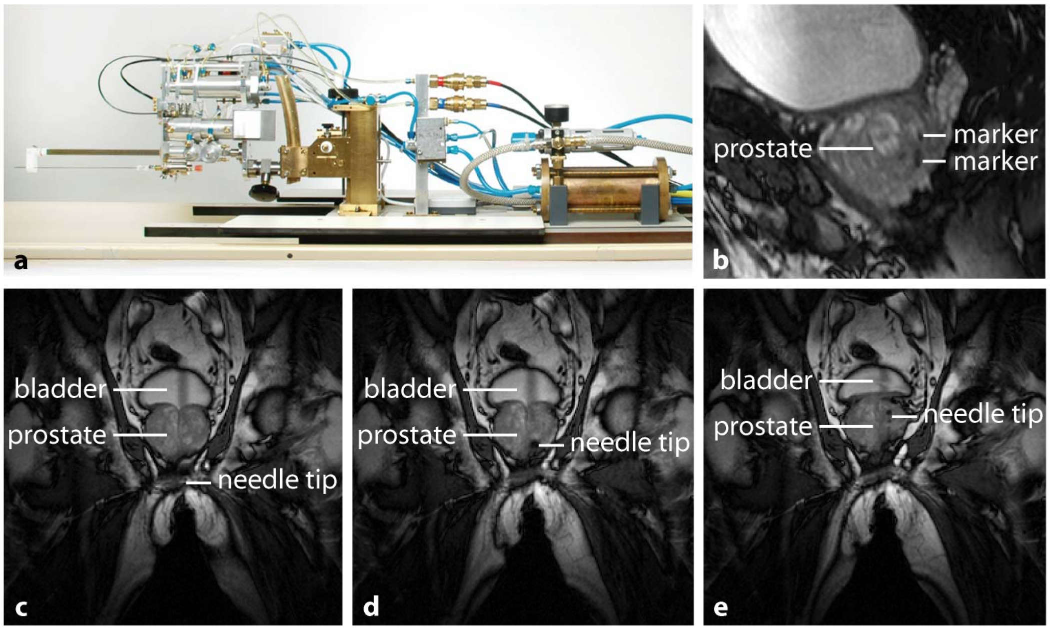

Fig.1 (a) The robot, (b) 3D bSSFP image at the end of the procedure, (c,d,e) Coronal plane in which needle is situated at three different time points.