A Novel MRI Compatible Manipulator for Prostate Interventions

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Introduction: MRI provides excellent soft-tissue contrast and promises to improve image-guided prostate interventions, presently performed with ultrasound [1,2]. MRI-guided transperineal prostate biopsy has been demonstrated inside an open MRI scanner [3]. Transrectal prostate biopsy has been demonstrated inside a high-field MR scanner utilizing passive fiducial tracking [4]. In contrast to these approaches, we have developed a remotely actuated manipulator, employing active fiducial tracking [5], that operates inside a conventional 1.5T MRI scanner, which results in a higher SNR than most open configuration scanners, and provides transrectal access to the prostate. The manipulator provides precise image-guided targeting of a needle with millimeter accuracy for therapeutic procedures and biopsy of the prostate. A targeting system displays MR images, overlays the proposed needle path, and provides a graphical user interface for the physician. We have recently reported the use of a first-generation prototype of this manipulator [2]. Here, we describe the design and construction of a second-generation device for use in clinical trials.

Methods: The manipulator consists of a needle guide, rectal sheath, positioning stage, insertion stage, flexible shafts, and mount (Figure 1). The patient is positioned prone in the scanner. The manipulator is positioned with the needle guide and sheath adjacent to the prostate in the rectum of the patient. The sheath, which contains an endorectal imaging coil, is kept stationary during the procedure while the needle guide rotates and translates within the sheath. The needle exits the needle guide through a window in the sheath. The manipulator can employ two different approaches to the prostate: a curved needle approach (Figure 2A) for fiducial marker placements and other therapeutic procedures; and a straight needle approach (Figure 2B) for biopsy. While the curved needle channel allows for unobstructed coverage of the prostate, even with high exit angles, the straight approach was necessary for biopsy procedures (because the 14-gauge spring-loaded biopsy gun could not function normally when curved). For better coverage of the prostate, the biopsy needle guide contains two needle channels: a channel with a 30-degree exit angle for proximal parts of the prostate; and a channel with a 20-degree exit angle for the distal parts.

The positioning stage converts rotation of two flexible shafts into translation and rotation of the needle guide, allowing for remote actuation from outside the scanner bore. Needle insertion depth is controlled by using a variable offset stop. The mount consists of a slide and rail assembly for motion along the main axis of the scanner bore and an arm with two integrated ball joints for adjusting the horizontal and vertical position and orientation of the device. The manipulator is mainly comprised of plastics, such as ultem and nylon. The flexible shafts are made of phosphor bronze and the ball joints and slide and rail are made of aluminum.

Three tracking micro-coils [5], integrated inside the manipulator, encode the position of the device. We developed a custom visualization and targeting program that displays MR images and reads the tracking coil positions. The program overlays a schematic view of the device, including the needle trajectory, onto the volumetric images. After selecting a target position, the program calculates the inverse kinematics and displays the necessary rotation and translation to reach the target. These values are displayed on a screen next to the scanner and are updated every second while the physician moves the needle guide to the target trajectory. The tracking sequence is stopped once the needle trajectory is aligned with the target, the insertion depth is set, and the needle is advanced.

Results and Discussion: The manipulator was successfully used in a series of 8 clinical procedures. Five fiducial marker placement procedures and three biopsy procedures were performed with no adverse patient outcomes [6]. The average needle placement error for 36 needle placements was 1.9 mm. Further clinical trials are in progress.

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References: [1] Yu KK. Radiol Clin North Am 2000;38:59. [2] Susil RC. Radiology 2003;228:886. [3] Hata N. Radiology 2001, 220:263. [4] Beyersdorff D. RSNA 2002;629. [5] Dumoulin CL. Magn Reson Med, 1993;29:411. [6] Susil RC. in submission for ISMRM 2004.

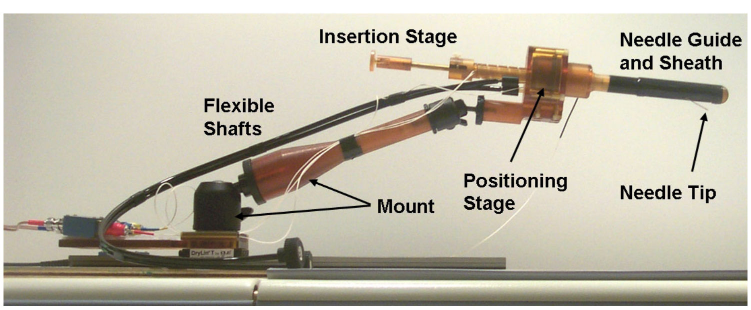

Figure 1: The manipulator consists of a needle guide, endorectal sheath, positioning stage, insertion stage, flexible actuation shafts, and mount.

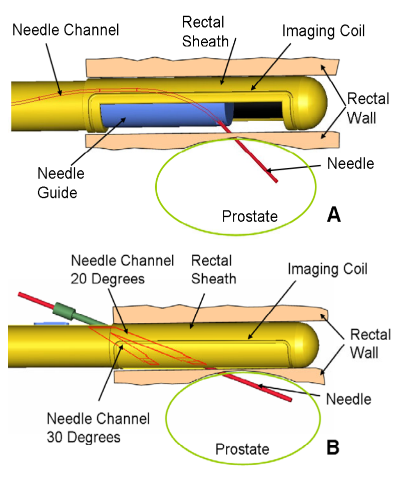

Figure 2: Computer-aided design (CAD) drawing of needle guide and sheath. **Panel A:** Needle guide and sheath with curved needle channel. The needle is guided inside the curved needle channel and advanced through a window in the sheath into the prostate. **Panel B:** Needle guide and sheath with straight needle channel. A 20-degree channel is used for distal parts of the prostate and a 30-degree channel for proximal parts of the prostate.