A System for Prostate Image Guided Interventions in a 3T MRI Scanner

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Introduction:

Earlier, we developed a system that enables image-guided prostrate needle interventions in a conventional 1.5T MR scanner, whose feasibility was successfully demonstrated in canine studies [1]. This APT-MR system (Access to Prostate Tissue under MRI-guidance) was consequently redesigned for patient studies. The system provides transrectal needle access to the prostate while a patient is imaged inside of a ‘closed’ 1.5T scanner and showed a successful solution to combine tissue biopsy and fiducial marker placement with MR imaging in clinical trials [2]. A novel remotely actuated manipulator that was designed for use in a standard high-field MRI was developed for this purpose too [3]. The purpose of this work is to investigate the upgrade of the APT-MRI to work with a 3T Philips Intera MR system. The modified 3T APT-MRI system provides a potential for improved signal and imaging characterization of prostatic tissues during the interventional procedure which previously has not been possible.

Figure 1: Hardware parts of the device. A. Picture of the APT-MR system showing the different components of the manipulator, the needle tip, needle guide, sheath, positioning stage, insertion stage, flexible actuation shafts, and mount. B The cylindrical needle guide contains MR-tracking microcoils and a needle channel. C. The positioning stage houses the mechanism that converts rotation of the two control rods into rotation and translation of the needle guide, which fits inside the endorectal sheath. D. The
stationary endorectal sheath, with an integrated 20 mm diameter single-turn imaging coil. The 6 channel interface box that connects all of the coils to the 3T Philips Intera scanner.

**Materials/Methods:**
As shown in Figure 1 the 3T APT-MR system is composed of a mechanical system that enables transrectal insertion of a biopsy needle, an endorectal imaging coil, 3 small tracking coils for locating the device, and software that gives real-time feedback to the operator. In the process of the migration to a 3T system, we first proved the 3T compatibility of the mechanical system. Later, the tracking coils and a single-loop endorectal coil were constructed and tuned to 128MHz. To improve the visibility of the surrounding structures a large double looped phased array coil was constructed. All coils operate as receivers and were actively decoupled from the body coil to ensure patient safety and high image quality. To interface the 6 coils of the system to the scanner, a box was built (Figure 1E) that contained both an RF board and a digital board. While the RF board serves as a low-noise preamplifier, the digital board functions as a coil identifier to the scanner and handles the decoupling control signals to switch the pin diodes used for decoupling. Surface and endorectal imaging coils were tested with phantom and volunteer experiments. The combined intrinsic SNR over the prostate region ranged between 96 and 28 μL^{-1}sec^{-1/2}. Images were free from decoupling artifacts. Highly differentiable signals were received from the tracking coils with more than 35dB isolation. The RF board pre-amplifies the signals on each channel by 24dB with a measured noise figure below 1dB. The board provides a switching current up to 100mA/channel at a delay of 25 μSec to ensure proper decoupling. Pulse sequences were modified to enable accurate fast device tracking. Image display software was modified to enable tissue targeting.

**Results**
After confirming both the electrical and mechanical safety of the device, it was approved by the Safety Subcommittee of the NMR center, and IRB-NCI for human research. In the process of verifying the system's functionality 5 diagnostic procedures have been conducted in patients where MR images have been acquired by the combination of the endorectal and the surface coils. Next, four successful fiducial marker placements procedures have been performed in patients using the 3T APT-MRI system. Finally, 2 successful clinical biopsy procedures were performed. Figure 2 shows an example of images obtained during one of the biopsy procedures, where a target is selected on an anatomical image and then the needle is guided to its target through the mechanical manipulator with the aid of the tracking mechanism. The needle’s position is then verified as can be seen on both the axial and sagittal images.
Figure 2: Targeting and needle visualization images. **A:** A target (red dot) is selected on axial TSE T2 weighted image. **B:** The needle tip void is visualized in an axial TSE Proton Density image. It can be seen that the desired target matches the actual position of the needle. **C:** The needle void is visualized on a sagittal TSE Proton Density image where the estimated needle path (red and purple dots) matches the actual path.

Conclusions
We have constructed an APT-MRI system in order to conduct needle interventions for prostate cancer diagnosis and therapy under 3T MR image guidance. The system's performance has been verified in 6 clinical procedures. Further work is being conducted to optimize imaging coil and pulse sequence performance for better visualization. Clinical studies will continue to accrue in an effort to better define the targeting accuracy, tolerability, and clinical value of this device.

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References

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