# MRI Compatible Robotic System with Haptic Feedback for RF ablation/Biopsy under continuous MRI.

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**Introduction**: Although RF ablation (RFA) has achieved wide success in recent years, the conventional procedure still exhibits many shortcomings. A clinical study for RFA of liver tumors reports a full necrosis rate of 95.1% of the treated tumors [1], while initial studies for RFA of breast cancer report that in order to reach high success rates a volume much bigger than the tumor must be ablated, unnecessarily damaging healthy tissue [2]. Meanwhile, reported short-term disease-free survival rates for those treated with RFA for liver cancer vary from around 80% [1, 3] to 54.6% [4]. Potential reasons for the somewhat limited success of RFA stem from human error in probe placement, movement of the chest and abdomen through the normal respiratory cycle during probe placement, and unpredictable shape and volume of ablated tissue [2], [5]. Similar arguments can be made regarding false negatives for image-guided biopsy procedures. Automating this process could potentially improve many of the shortcomings in the standard RFA procedure. Here we present initial results from the design and operation of a prototype MRI-compatible 1-DOF robot for automated RFA/biopsy probe advancement with haptic feedback, along with a series of experiments proving MRI-compatibility and functionality of the device. Automation of probe placement under continuous MRI guidance can be very effective as one can take advantage of the exquisite contrast provided by MR of the soft-tissue and its ability to monitor temperature changes during RF ablation procedures.

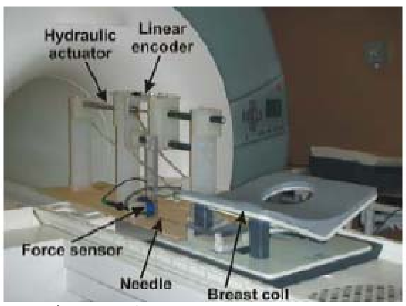

Figure 1a

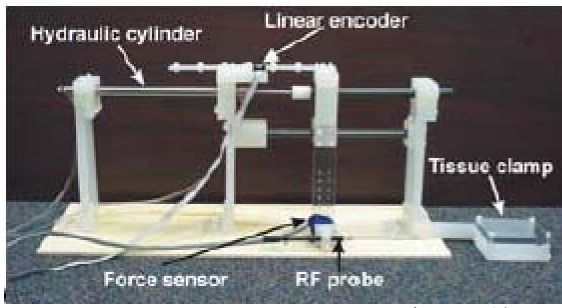

Figure 1b

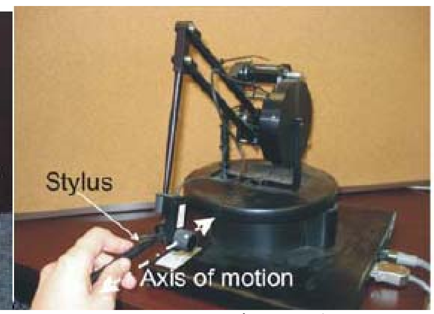

Figure 1c

**Materials & Methods**: We have designed, developed, and implemented a one degree-of-freedom robot to guide an RF probe inside the MRI scanner, while at the same time recording the forces exerted by the probe on the force sensor during probe insertion and withdrawal. Figure 1a shows the configuration of the 1-DOF robotic system within the MR system. A detailed picture of the robotic system is provided in figure 1b. Figure 1c shows a photograph of the PHANToM haptic device in operation providing force feedback to the operator. To ensure MRI-compatibility, electrohydraulics was chosen as a means of actuation, and polypropylene was chosen as the main material for the structure of the device. With the exception of the optical encoder and the force sensor, all electronics and computer equipment are located in the MR control room to minimize noise, while the cables and hydraulic lines run into the scanning room through a wave guide, which attenuates the RF noise. The RFA probe position or a biopsy needle position is directly controlled in real-time by the position and velocity of the PHANToM stylus motion, while data from the force sensor is relayed back to the stylus to generate real-time haptic feedback. Since the primary force sensing takes place along the x-axis of the force sensor (which is the z-axis of the bore of the magnet), we displayed the x-component of the force through the PHANToM. Force data from the sensor and velocity readings from the PHANToM stylus were filtered online with a 5$^{th}$ order Butterworth low-pass filter to transmit smooth velocity commands to the controller and to display force feedback to the user. This enabled the user to directly insert the RF probe into a tissue sample from outside the scanning room, while at the same time feeling the forces exerted onto the force sensor by the RF probe. The device was placed on the far end table of the magnet and experiments were performed on a breast phantom with this teleoperated robotic haptic feedback system to see if we could detect the presence of an inclusion. A dynamic MR scan (3D-GRE with temporal resolution of 1 sec) was performed to track the path of the probe through the tissue and tumor (inclusion within the phantom mimicking tumor). Force feedback from the probe was correlated with the position of the probe within the phantom from the MR images.

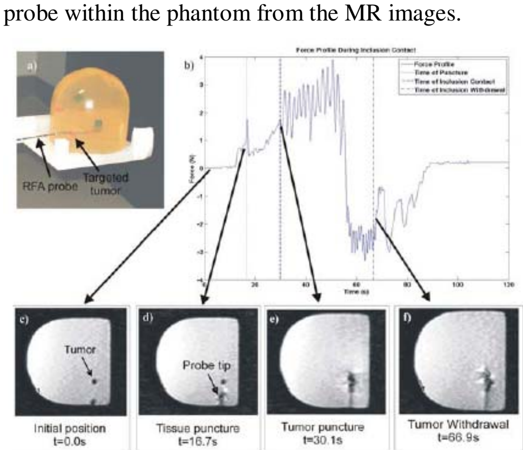

Figure 2

**Results**: Figure 2 shows the photograph of the breast phantom with inclusions mimicking tumor. MR images from the dynamic scan are shown at select time points to demonstrate the path of the probe as it encounters the inclusion and traverses back. Corresponding force profile is also provided in this figure. Based on these observations, we concluded that the user can in fact detect the presence of an inclusion through both visual and haptic feedback.

**Conclusions:** We have successfully developed a 1-DOF haptic feedback robotic system compatible in the high-field of 3T MRI system. This device will be used and studied to help us better understand the issues related to automated probe guidance leading to a more complex multi-DOF robotic system. The work presented in this paper is the first step toward the development of a robotic system with multiple degrees of freedom for RFA/biopsy of tumors under continuous MR imaging.

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