Multi-mode Probes for MR-guided Therapeutic Endovascular Interventions

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INTRODUCTION

A successful MR-guided minimally invasive endovascular procedure requires a) MR-guidance of therapeutic endovascular devices such as catheters and guidewires to the region of interest, b) high-resolution imaging of the target region and its surroundings in order to diagnose and assess disease, c) performing a therapeutic procedure/intervention, and d) evaluation of the outcome/efficacy of the therapeutic procedure. A number of *active* [**1-3**] and *passive* [**4-5**] methods have been developed and employed for the tracking and visualization of catheters and guidewires. Independent devices [**6**] have also been developed for high resolution endovascular imaging as the requirements for tracking and imaging devices are entirely different. An endovascular procedure using separate tracking and imaging probes will necessitate multiple insertions and extractions of catheters and guidewires, thereby increasing the risk of causing injury to the vasculature.

We present multi-mode or all-in-one intravascular MR probes that combine the functionalities of a tracking coil, a receive-only imaging coil, and an inductively coupled self-resonator (wireless marker) into one that may obviate multiple insertions and extractions and reduce risk of injury to the vasculature. The objective of this study was to develop and evaluate *in vitro* and *in vivo* performance of such multi-mode intravascular probes, which are also compatible with Gd-DTPA-based MR-visible coatings that can act as an internal signal source to improve tracking capability.

MATERIALS AND METHODS

A multimode MR intravascular probe consisting of a simple loop connected in series with a tightly wound solenoid was built and placed at the tip of a 6F catheter. The loop is 20 mm long and spans the diameter (2 mm) of the catheter. The 15-turn solenoid wound around the catheter and is 2 mm in length. The loop and the solenoid were constructed with a 36 AWG copper magnet wire. Small surface mountable tuning and matching capacitors were placed at the terminals of the multi-mode coil. The coil was matched and tuned at 64 MHz under loaded conditions. The resonant multi-mode coil was then connected to one end of a two port lumped element 50Ω transmission line π section placed at the proximal end of the catheter via a 50Ω 42 AWG micro-coaxial cable. The decoupling circuit was implemented across the series element of the π section. The separation of the decoupling circuit from the resonant coil enabled the coil to be used in both imaging and wireless marker modes. The other end of the transmission line section was connected to the single channel receiver port of a 1.5T GE Signa (Milwaukee, WI) MRI scanner.

Such a multi-mode probe attached onto a catheter was tested in a water-filled phantom consisting of a bottle with a diameter of 147 mm with two coaxially placed tubes of diameters 37 mm and 25 mm. The coil was tested in active tracking mode by applying a non-selective RF pulse and a readout gradient along a single axis. It was expected that the highly localized sensitivity of the solenoid component would yield a peak that would aid in tracking the tip of the catheter. The coil was then tested in imaging mode by using it as a single-channel receive only coil with the body as transmitter. 2D SSFP and GRE sequences were used to acquire images. Finally, the multi-mode coil/probe was tested in the wireless-marker mode by simply using the body coil in transmit/receive mode. 2D SSFP and GRE sequences with a low flip angle (5-10^o) were used to obtain body coil images.

RESULTS AND DISCUSSION

The multi-mode probe used for the *in vitro* experiments is shown in Figure 1a. In the tip-tracking mode, when a spatially non-selective RF pulse and a readout gradient along a single axis is applied, due to the localized spatial sensitivity of the coil, this gives rise to a sharp peak in the Fourier-transformed signal as seen in Figure 1b. The position of the peak corresponds to the location of the catheter tip along the axis, which can be superimposed as a small icon onto a roadmap. If this is repeated for the remaining two axes, the 3-dimensional position of the coil can be obtained. In the imaging mode employing the single loop part of the multi-mode probe, an axial image obtained using a 2D SSFP sequence is shown in Figure 1c. It has a radially circular imaging sensitivity which is important for vessel wall imaging and characterization of plaques in imaging mode. In the wireless-marker mode, the multi-mode probe acts as an inductively coupled self-resonator which magnifies the B_1 field generated by the body coil in the region of sensitivity of the multi-mode coil. The low flip angle used during the transmit cycle results in suppression of signal from the rest of the phantom while enhancing the signal in the vicinity of the multi-mode probe.

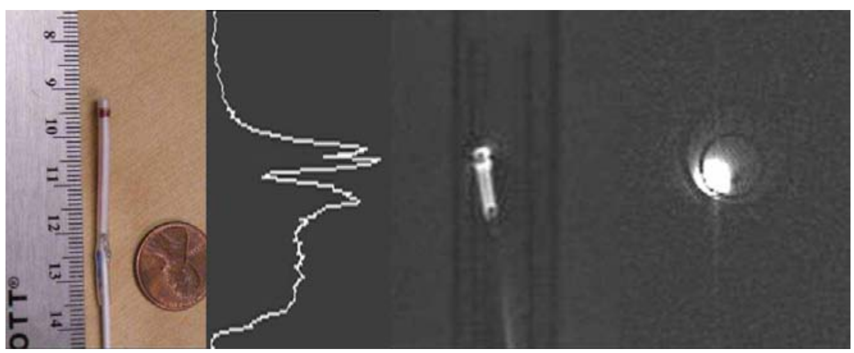

Figure 1: (a) Photograph of a multi-mode probe, (b) Peak due to the localized spatial sensitivity of the solenoid used in tip tracking, (c) Coronal Image obtained in wireless-marker mode, and (d) Axial image of a tube obtained in imaging mode.

CONCLUSIONS

Our initial results suggest that a multi-mode probe that can function in different modes (*i.e.*, tracking, imaging, and wireless-marker modes) is feasible. Further studies are underway to study and optimize the SAR effects of the current design.

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