Guidewire Tip Design with Selectively Enabled Magnetic Field Perturbation

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Introduction: The placement of interventional devices such as guidewires and stents using magnetic resonance (MR) guidance is a promising and evolving field with great clinical potential. In MR imaging, the marker used for tracking is a material with a sufficiently large magnetic susceptibility relative to tissue, such as a stainless steel needle-tipped catheters (1), which create a hypointense region in the surrounding tissue. However, despite being easy to locate in MR images and relatively cheap and safe, the resulting black hole in the image obscures precisely the region that must be seen – the tissue at the tip of the device. Thus, the location of the tip can be easily measured, but the nature of the tissue that the device is being moved through is obscured. A device is presented which can create a susceptibility marker that can be mechanically turned on and off.

Materials and Methods: Magnitude and phase images were measured for grade 6AL 4V ELI titanium wire (Small Parts, Miramar, FL) and grade EC-17, cold isostatically pressed graphite rods (GraphiteStore.com, Buffalo Grove, IL), each 0.125" ø × ~0.125" L, in a water bath using a 1.5T MR scanner (GE Signa HDx, GE Healthcare, Waukesha, WI), a 3" ø receive-only surface coil, and gradient-recalled echo sequences with TE(s)/scan = 1, TE = 10, 15, 20, 25 ms, TR = 100 ms, $\alpha = 90°$, bandwidth = 31.25 kHz, $N_{freq} = 256$, $N_{phase} = 256$, averages = 4, FOV = 12 × 12 cm, and slice thickness = 3 mm. The *prelude* tool in FSL (Analysis Group, FMRIB, University of Oxford) was used to compute unwrapped phase-difference images and volume magnetic susceptibility was estimated for each sample by fitting points on the images to the dipole field of a spherical sample.

Magnetostatic field simulations using coaxial cylindrical shells surrounding a cylindrical rod all of the same length, using various combinations of the above materials were performed using MATLAB (The MathWorks, Natick, MA). A combination was found where the magnetic field around the device was minimally perturbed when all the pieces were nested with their ends aligned and where the field was greatly perturbed when the core was extended from the shells. This combination consisted of 1) a 0.125" ø titanium wire in 2) a 0.0675" wall thickness graphite shell in 3) PTFE tape (~0.0225" thick), and in 4) a 0.035" wall thickness titanium shell (grade CP2), giving an outer diameter of 0.375" and length of 2". The device was held in the centre of a water-filled conical tube by an acrylic spacer (Fig. 1). Coronal gradient-recalled images of the device parallel to the magnetic field were made using the above hardware and TE(s)/scan = 1, TE = 5 ms, TR = 50 ms, $\alpha = 30°$, bandwidth = 31.25 kHz, $N_{freq} = 256$, $N_{phase} = 256$, averages = 1, FOV = 20 × 20 cm, and slice thickness = 5 mm with the ends of the core and shells aligned and with the core extended from the shells by 0.25". Similarly, axial images of the water immediately ahead of the shells with slice thickness = 2 mm were made in both configurations.

Results: The volume magnetic susceptibility for the titanium was measured to be $2.1\times10^{-4} \pm 7\times10^{-5}$ and for the polycrystalline graphite, $-2.0\times10^{-4} \pm 9\times10^{-5}$, comparable to those found in literature (2). Hypointensity in an image of the water ahead of the device was only evident when the core of the device was extended from the shells (Fig. 2 and 3).

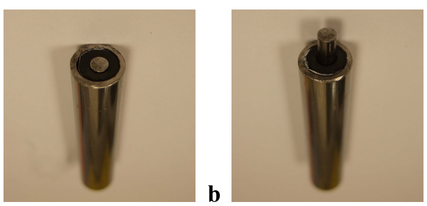

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Fig. 1: Photographs of the device (2" length) inside a water-filled conical tube with a) the ends of the core and shells aligned and b) the core extended from the shells.

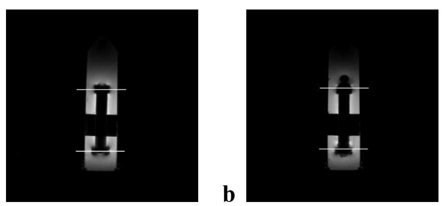

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Fig. 2: Coronal images of the device with a) the ends of the core and shells aligned showing minimal hypointensity ahead of the device and b) the core extended from the shells showing hypointensity (ends of shells marked by lines).

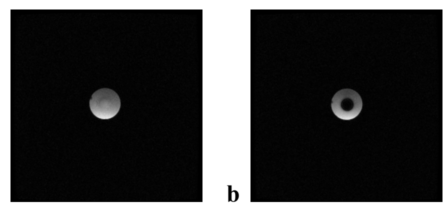

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Fig. 3: Axial images the water ahead of the device with a) the ends of the core and shells aligned showing no hypointense regions and b) the core extended from the shells showing hypointensity.

Discussion: A hypointense region at the tip of the device was caused by the magnetic susceptibility difference between the titanium core of the device and water, and could be turned on and off as the core was extended and retracted, respectively, as expected. When the core was not extended, the magnetic field perturbation was not perfectly cancelled around the sides of the device as evidenced by additional hypointense regions. This is likely due to error in the rough magnetic susceptibility measurements used here. When the slice-select gradient amplitude was modified such that the on-resonance spins were not rephrased (creating the "white marker" effect; Ref. 3), a positive contrast image showing only the extended device core was made (Fig. 4). This demonstrates the ease of locating the device in projection images. Future work includes optimization of the design, miniaturization of the device, and in vivo studies.

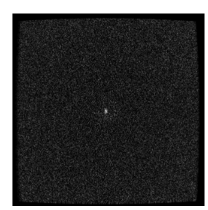

Fig. 4: Axial positive contrast image of the water ahead of the device with the core extended from the shells showing the "white marker" effect.

Conclusion: A scale model of a guidewire design with selectively enabled magnetic field perturbation was prototyped. A hypointense region ahead of the device, only when the perturbation was enabled, was predicted and found.

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References: 1. Dharmakumar et al. Phys Med Biol 2008;53:N249–N257. 2. Schenck. Med Phys 1996;23(6):815–850. 3. Seppenwoolde et al. Magn Reson Med 2007;58(3):605–609.