Passive catheter tracking with a controllable susceptibility effect

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Introduction: Due to the rich anatomic information available, MRI is an attractive tool for guiding endovascular interventions. Susceptibility artifact–based tracking using paramagnetic markers [1] is a simple and economical approach, but has been met with limited enthusiasm partly because of the image degradation that results from such devices. Recently, a susceptibility-based tracking device which can be mechanically turned ON and OFF was proposed [2]. In this work, the layers of graphite and titanium (diamagnetic and paramagnetic, respectively) were re-computed for a three-layer design with widely available materials, and were scaled down to 3mm (9F) diameter and attached to a catheter to show feasibility. Real-time images showing the performance of the device in a phantom study are presented.

Materials and Methods: The dimensions of component layers are selected by first measuring the relative magnetic susceptibilities of the paramagnetic and diamagnetic materials using an Evans balance. The Evans balance readings (arbitrary units) were 1017 +/- 10 for titanium and -860 +/- 10 for graphite. These relative susceptibilities were then used in an optimization to design the component thicknesses that minimize the magnetic fields outside of the tracking device when the ends of the components are aligned. A magnetostatic simulation was implemented in Matlab, with the magnetic field surrounding the components computed for each iteration. The sum of the absolute values of the magnetic field offsets on a mesh adjacent to the tracking device was used as a cost function. Here, this mesh spanned a rectangle 4.1 millimeters across the axis of the cylinders, and 2 mm in front of the tip. The diameter of the outer paramagnetic layer was held fixed to the desired size (3mm), with optimization of the outer diameters of other components. The cost function was systematically computed using "fminsearch" and a global minimum was found. The final device design consisted of 1) a 1.1 mm ø titanium (6AL 4V ELI) wire in 2) a 0.65 mm wall thickness graphite (grade EC-17) shell and in 3) a 0.3 mm wall thickness titanium (6AL 4V ELI) shell giving an outer diameter of 3mm and length of 15mm (figure 1), and was fabricated using electrical discharge machining (EDM).

The device was held in the center of a doped-water bath (saline and copper sulfate), gluing one end of each of the titanium parts to an acrylic spacer and the graphite cylinder nested between the titanium cylinders is glued in the opposite end to a catheter (hemostasis introducer, FAST-CATH™ 8F, St. Jude Medical) (Figure 2). The graphite cylinder can then slide in and out relative to the titanium parts by pushing and pulling the catheter guidewire either by hand or with a dedicated axial motor that can be synchronized to the MRI scanner. All the imaging experiments were performed using a 1.5T MR scanner (GE Signa HDx, GE Healthcare, Waukesha, WI), with a 5 inch diameter receive-only surface coil. A fast gradient-recalled echo sequence was used to acquire 60 images of the same slice in continuous mode over 2 minutes with 1 second gap between images. During the 1 second gap the graphite cylinder was moved in or out of the titanium pieces to test the ON and OFF position of the susceptibility device. The parameters were TR/TE = 18/5 ms, $\alpha = 30^{\circ}$, bandwidth = 62.5 kHz, Nfreq = 256, Nphase = 64, averages = 1, FOV = 12 × 12 cm, and slice thickness = 1 mm. Images with positive contrast were also acquired with the same pulse sequence but with the slice rewinder gradient turned off, slice thickness = 20 mm and TR/TE = 8/4 ms.

Results and Discussion: Representative real-time images of the catheter setup are shown in figure 3. As shown in images A and E the image distortions are minimized when the device is in the OFF position (with the graphite cylinder completely inside the titanium parts). When the graphite cylinder was pulled out of the device the field perturbations around it are more noticeable (figure 3) causing a hypointense region (Figure 3 B, C and D) at both ends of the device. Figure 3 (E, F, G and H) shows the "positive contrast" image were only the adjacent water is bright (the "white marker" effect [3]). This facilitates locating the device in projection images which can be helpful *in vivo* to automatically track the device.

Conclusions: A passive tracking device with a susceptibility effect that can be enabled and disabled by sliding one of the components was designed, fabricated and demonstrated. The difference between the aligned and miss-aligned configurations was large in the acquired MR images, showing the feasibility of tracking the device by periodically moving the graphite layer. In future work, this design will be incorporated into a 9F catheter and demonstrated *in vivo*.

Acknowledgements: Funding from the Canadian Institutes of Health Research (CIHR PPP106789).

References:
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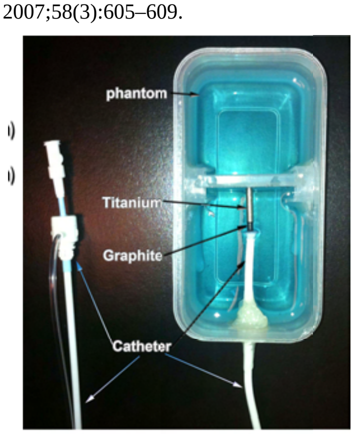

Figure 2: Catheter prototype setup

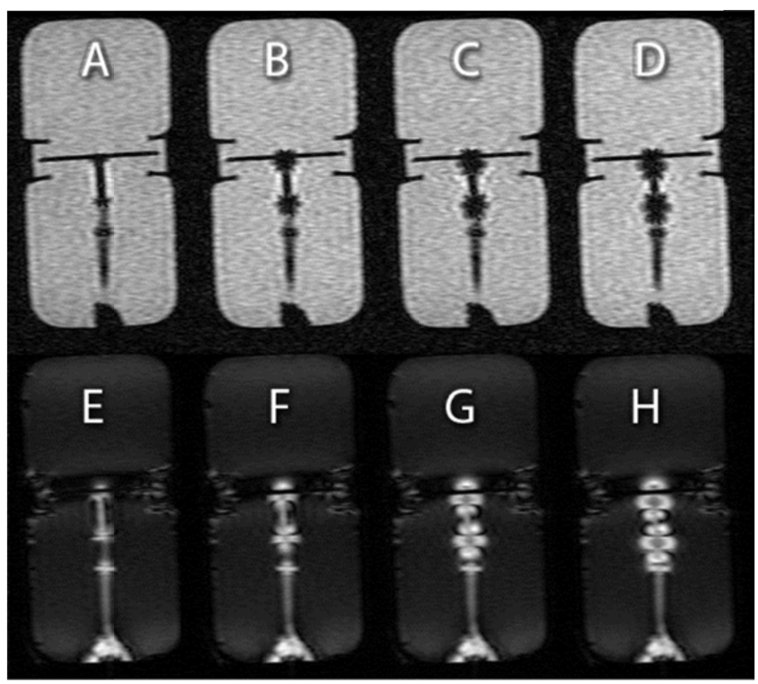

Figure 3: Real-time images of the catheter setup acquired at 1.5T. A and E are images with the graphite cylinder completely inside the titanium parts (OFF position), with negative and positive contrasts respectively. Equally B–F, C–G and D –H are images with the graphite cylinder 2 mm, 3mm and 4mm pulled outside the titanium parts.