Control of Intravascular Catheters Using a 3D Array of Active Steering Coils

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Introduction: One of the challenges of endovascular procedures is directing the catheter tip into small or complicated blood vessels. While standard procedures use x-ray image guidance [1], x-ray angiography is still to only projection views, and poses significant risk due to radiation exposure. For these reasons, several groups have developed alternative methods for catheter guidance based on interventional MRI (iMRI). iMRI has the advantage of imaging within a true 3D without ionizing radiation. As previously demonstrated, the strong magnetic field of MRI systems also provides a special environment that can be used to enable remote control of a catheter [2, 3]. Previous work used only axial coils, whose response depended on the initial angle between the main magnetic field and the catheter. In the present work we propose a 3D array of coils in order to generate not only stronger deflections, but also more complex ones as well. We also demonstrate methods for visualization of the catheter and/or surrounding areas.

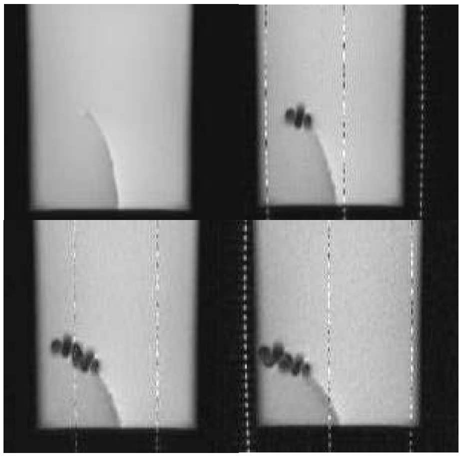

Fig1. a) No coil excited b) first axial coil excited (110mA) c) both axial coils excited (110mA/coil) d) three coils are excited (110mA/coil). Note the increasing deflection.

Material and Methods: Three coils, made of 42 gauge wire, were built over a 2.5 Fr microcatheter. Two of these were 70 turn axial coils separated by 1cm and a 15 turn square side coil that was 2x4 mm^2. Each of the coils was independently current controlled by a microprocessor which communicated directly with a host computer running Matlab. Image based data was obtained in a 1.5 T clinical MRI scanner (Espree, Siemens) using a knee coil. The catheter was placed in a water phantom containing 1% Gd-DTPA. The phantom was placed at the magnet isocenter with the catheter in the vertical direction (perpendicular to B0). Deflection angles were measured with respect to the initial inclination angle of the catheter using a real-time FLASH sequence.

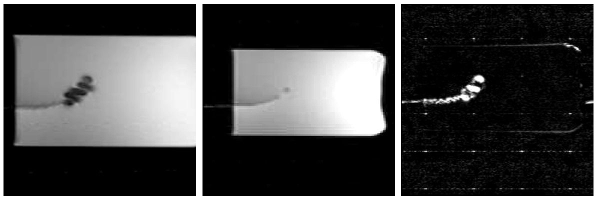

Fig 2 A) Image with coils active B) Imaging mode where the current was switched during acquisition. C) Bright signal mode acquired with unbalanced slice gradients.

Since significant susceptibility voids are present when the coils are active, two different approaches were used for imaging. In order to visualize surrounding tissue without interference from the catheter, the current was rapidly switched off during the TR. A FLASH sequence with 25 ° flip angle, 200mm FOV, 10mm slice thickness was used. The times are set in order to avoid catheter motion, while using the shortest possible readout windows to maintain the position of the catheter. In other instances, one may wish to visualize the catheter by itself. In these cases, a FLASH sequence without slice select rewinding gradients was used to provide a bright signal representation [4].

Results: As can be seen in Fig 1, large deflections were possible using the 3 coils together. The additional coils also allow the catheter to function regardless of the initial angle with respect to B0. Also seen in Fig 1 are the significant signal voids in the image due to susceptibility effects from the field generated by the coils. As shown in Fig 2, these can be avoided through implementing both imaging and catheter-only excitation modes. The susceptibility artifacts are avoided in Fig 2b allowing visualization of surrounding areas, while they are advantageously used for catheter visualization in Fig 2c. The motion of the catheter during the imaging experiment was minimal as long as the readout window was shorter than 2ms. Also, the deflection was sub-optimal for TR less than 15ms. Visualization of the catheter in a bright signal mode was straightforward and showed good results across a wide range of situations.

Discussion and Conclusion: This study has demonstrated that the use of an array of steering coils is a potential solution for remote control of catheters in an iMRI setting. In addition to the increased flexibility and range of motion provided by the array, two different imaging approaches where developed which allow better visualization of the catheter. We believe that these developments could lead to a range of new interventional devices for intravascular interventions.

References: 1. Chu, J.C., et al., J Appl Clin Med Phys, 2005. 6(3): p. 143-9. **2.**Roberts, T.P., et al., MRM, 2002. 48(6): p. 1091-5. **3.**Settecase, F., et al., Med Phys, 2007. 34(8): p. 3135-42. **4.**Draper, N.J., et al., J Magn Reson Imaging, 2006. 24(1):p. 160-7