Guidewireless Endovascular Catheter Steering for Interventional MRI

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Introduction:

Endovascular procedures done under fluoroscopic guidance often require the use of metal guidewires for steering catheters along their desired paths. The use of metal guidewires in interventional MRI is rendered problematic due to RF resonant heating of conductive metals in the MR environment, and by susceptibility artifacts (1). The magnetic field present in an MR scanner provides a unique environment for development of novel diagnostic and interventional instruments. Using 1.5 F catheters in a 2 T scanner, Roberts et al. (2) demonstrated that current applied to a solenoid wound at the tip of a catheter can be used to steer a catheter tip through simulated vessel branch points. The magnetic moment (M) created in a solenoid, is given by the equation,

$$M = niA,$$

where n, is the number of turns in the solenoid, i, is the current applied, and A, is the cross-sectional area of the solenoid. The magnetic moment experiences a torque which pulls the distal catheter tip into alignment or anti-alignment with the main magnetic field, given by the equation,

$$\tau = MB\sin\theta,$$

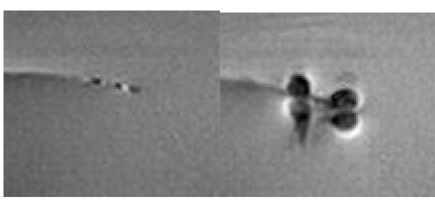
where M is the magnetic moment, B is the magnitude of the main magnetic field, and θ is the angle between M and B. The amount of torque necessary to cause a given deflection is proportional to the "stiffness" of the catheter (related to its Young's modulus). The forces generated by this method offer a potential alternative to metal guidewires for steering endovascular catheters in interventional MRI. The purpose of this study was to test the applicability of the theory to larger diameter, stiffer 5 F PCTA catheters commonly in use today for endovascular procedures such as angioplasty and stenting. In addition, we were interested in determining the amount of current necessary to cause considerable deflection, the effect of varying the amount of turns in the solenoid and catheter type (or stiffness) on deflection angles obtained, and in observing the artifact produced. Optimization of these parameters is important for minimizing the current requirements, which in turn would reduce unwanted heating effects (from power dissipation), and decrease image artifact.

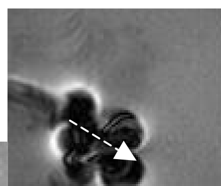
Methods:

A solenoid of 38 AWG magnet wire was wound onto the distal tips of two 5 Fr PCTA catheters of varying stiffness (Cook Pursuit and Cordis Opta lp). Heat shrink tubing was used to secure the distal tips. The number of turns in the solenoid was varied from 50-150 turns. The catheters were suspended in a 2 L glass beaker filled with water at a 90 degree angle to the direction of the main magnetic field. Scanning was done in a 1.5 T scanner (GE Medical Systems, Milwaukee, WI). MR images were acquired using a FIESTA sequence for real-time imaging in the sagittal plane. An 8-channel RF coil was used. Current was varied between 0 and 1.2 A. Deflection angles were measured using gridlines on the user interface for the MR scanner.

Results:

With no current applied, the catheter was barely visible and remained stationary (Fig. 1). The catheter tip deflection angle increased linearly with the amount of current applied (Figs. 1 and 2). Increasing the number of turns in the solenoid from 100 to 150 had minimal effect on the deflection/unit of current applied. Decreasing the number of turns to 50, in addition to using a stiffer catheter (Cordis Opta lp), resulted in a smaller tip deflection per unit of applied current (Fig. 2), although it is difficult to separate their relative effects with this data. The artifact in the vicinity of the solenoid (Fig 1) also increased in proportion to the current applied.





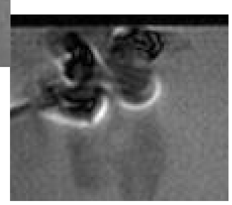


Figure 1. FIESTA 128x128 (TR 2.7/TE 0.9) sagittal plane. Cook Pursuit Catheter with 150 turns. Current varied stepwise from 0 A, 225 mA, 1250 mA, and -1250 mA. As applied current increased, deflection angle increased (arrows). Reversing polarity of the current caused a deflection equal in magnitude and opposite in direction. Note that the artifact around the solenoid also increased in proportion to the current applied.

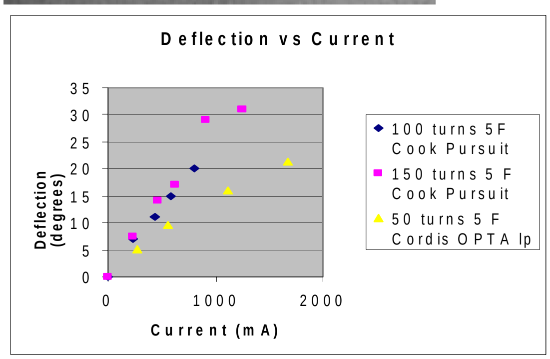


Figure 2. Graph of Catheter tip deflection vs. Current. Deflection minimally affected by increasing number of turns in the solenoid. Deflection increasing with current applied and with decreasing catheter stiffness.

Discussion:

In this study we demonstrated that 5 F catheters can be deflected considerably using the main magnetic field, without a guidewire. Our results would indicate that increasing the number of turns the solenoid and using more flexible catheters are important considerations for trying to maximize the deflection angle per unit of current applied. The relative importance of these two parameters, however, deserves further investigation. Reducing the current requirement is desirable in order to reduce the local field inhomogeneity artifact produced by the solenoid and the potential heating effects from power dissipation. Further increases in tip deflection angle per unit of current applied can also be expected by introducing a paramagnetic material within the core of the solenoid (although this would increase the artifact produced). In contrast to the continuous presence of the susceptibility artifact produced by metal guidewires, the artifact produced by the magnetic moment in the solenoid is only present while current is being applied. Furthermore, the effects of current application on image quality can be minimized by interleaving current application and image acquisition. While these results demonstrate the potential of this method of catheter steering as an alternative to guidewires for a variety of catheter sizes, further optimization of the parameters studied and quantification of heating effects is necessary.

References:

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2. Roberts TP, Hassenzahl WV, Hetts SW, Arenson RL. Remote control of catheter tip deflection: an opportunity for interventional MRI. Magn Reson Med. 2002 Dec;48(6):1091-5.