Catheter Steering in MRI using Longitudinal Current Loops

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INTRODUCTION

Electrical mapping and RF ablation of the heart are two electrophysiology (EP) applications that require precise maneuvering of a catheter within the cavity of the heart. Stereotaxis provides a solution to this with its Magnetic Navigation System (MNS) [1]. However, the imaging modality used with the MNS is x-ray fluoroscopy, which emits ionizing radiation and only acquires 2D projections. MR on the other hand can provide high soft-tissue contrast and the ability to visualize 3D anatomy, making it better suited for EP. We propose a new technique for steering a catheter that exploits the strong magnetic field of an MR scanner. It involves a single wire loop around the inner and outer wall of the catheter longitudinally along its axis (Fig. 1A). A current applied to this wire will generate a magnetic field which will interact with the scanner's field, resulting in a Lorentz force. Due to the geometry of the design, the forces from the inner and outer wire portions are opposite and unbalanced, resulting in a deflection in the transverse plane (i.e. axial, perpendicular to the magnetic field). This deflection can be used as a mechanism for steering.

MATERIALS AND METHODS

To explore the basic concept of steering experimentally and theoretically, we manufactured a steering catheter by inserting a 38 AWG insulated copper magnet wire inside a 15 cm long portion of a 5F angioplasty catheter (Imager II, Cordis) and looping the wire back along the outside (Fig. 1A). The catheter was then secured as a cantilever in the bore of a 1.5 T MR scanner (Twinspeed HDX, GE Healthcare), pointing perpendicular to the sagittal plane. Currents up to 700 mA DC, at 100 mA intervals, were applied to produce deflections which were then compared to predictions from theory. Based on these results, a second design was examined. This was constructed using 9.5 cm of a 3F multifunctional probing catheter (Boston Scientific). To achieve larger deflections for less current, the wire was looped three times through the catheter instead of once – equivalent to looping three separate wires and applying the same current to each. The catheter was secured as a cantilever pointing vertically downward into an ex-vivo canine heart. A 256×256 image was acquired using an SPGR sequence (TE=6ms, TR=50ms, FOV=16cm, FA=30 deg, slice thickness=5mm, NEX=1) while 20 mA of current was applied to characterize both deflection and susceptibility artefacts in images associated with the applied current.

RESULTS AND DISCUSSION

Deflections of the catheter agree well with the theoretical predictions, except for a slight offset of the tip's position which is most likely due to gravity (Fig. 1B). A digital photo of the 5F catheter being deflected in the bore of the scanner is shown in Fig. 1C. In this figure we see that there must be enough unobstructed volume around the catheter for the outer wire to separate from the main catheter in order to cause deflection; this space is readily available in the left ventricle. Fig. 1D shows an example of the catheter being deflected against the septum of an ex-vivo canine heart. Susceptibility artifacts due to the applied current can be observed in the MR image; however the anatomy can still be depicted clearly. Although these artifacts can be minimized by using more flexible catheters (and hence less current) and using pulse sequences with shorter echo times, they can also be exploited for passive device visualization.

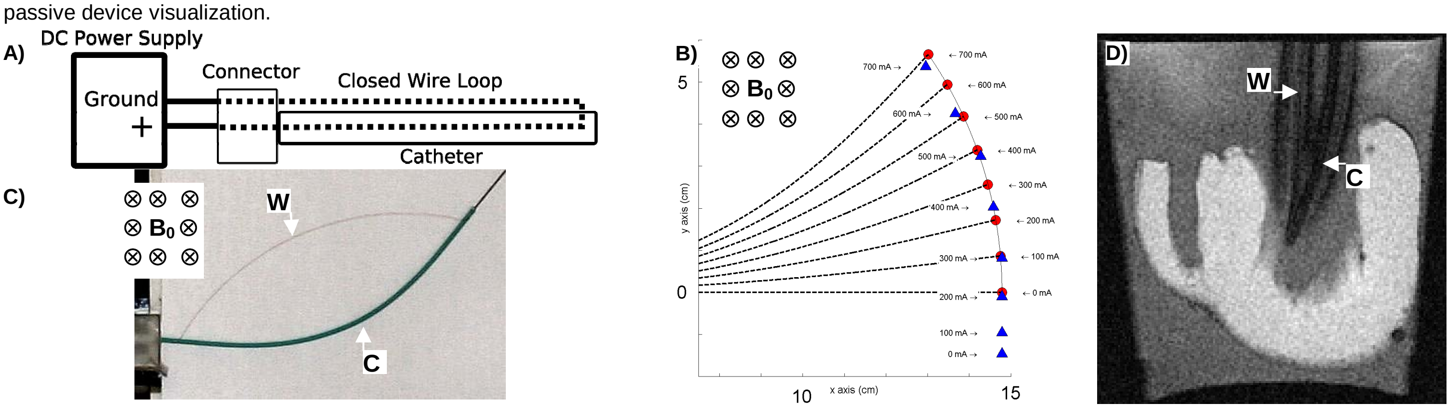

Figure 1. W = wire, C = catheter. **A**) Steering catheter with wire loop. Current is supplied to the inner wire segment while the outer wire segment is grounded. **B**) Quantitative measurements (triangle) of the catheter's tip positions are taken and plotted against an analytic expression for the shape of the catheter (dashed lines, circles) for currents up to 700 mA. The magnetic (B_0) field points into the page. **C**) A photo of the 5F catheter deflected with 700 mA inside the magnet. **D**) Demonstration of the catheter inside an ex-vivo heart. Catheter is deflected with 20 mA so that its tip touches the septum.

One advantage to using this technique over mechanically-steered catheters is that it offers the potential for better contact between the catheter tip and the septum during the entire heart cycle for more effective ablations. As the heart moves, the catheter will preferentially bend before the static frictional force holding the catheter tip to the septum is overcome. Another advantage is that the technique requires less current (20 to 50 mA) for large catheter deflections when compared to recently published current-controlled catheter steering techniques (100 to 200 mA) [2]. Heating effects could not be felt along the wire or catheter at currents below 500 mA. Due to the geometry of our design, deflections are restricted to the transverse plane. However, a solenoid-based steering technique can provide small deflections in the coronal plane. Since these two steering techniques have complementary (orthogonal) deflection planes, a hybrid catheter that utilizes both steering methods would achieve better functionality.

CONCLUSION

We have developed a new steering method for an intracardiac catheter by applying electric currents to a wire loop connected to the catheter inside the strong magnetic field of an MR system. Resulting deflections can be predicted with reasonable accuracy. This method, combined with complementary approaches yielding orthogonal deflections and some MR guidance capabilities such as in [3], could contribute to an integrated system for electrophysiology interventions exploiting MR.

REFERENCES

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