Steering and Tracking of Magnetic Catheters Using MRI Systems

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Purpose: MRI gradient coils can apply a force on magnets along any direction in space. The goal of this project is to use an MRI system to track and steer magnetic catheters or unthetered devices.

Materials and Methods: Navigation and steering was achieved by inducing displacement forces from the three orthogonal slice selection and signal encoding gradient coils of a 1.5 T Avanto Unit. Software was developed to perform automatic tracking, propulsion at a sufficient rate to allow navigation along preplanned paths in the circulatory system. Experiment 1: 2 mm cubic NeFeB magnets (M=106 A/m) were fastened at the tip of a 5f catheter. A custom built gradient coil was used to apply gradients from 40 to 400 mT/m on the cubic magnet. The deflection angle of the catheter was measured. Experiment 2: The magnetic tip has to be removable if good quality image acquisition is required. In order to address this problem, balloon catheters were inflated using liquid magnets (Fe3O4 ferrofluid) similar in nature to SPIO contrast agents. Experiment 3: A wireless magnetic sphere (1.5 mm) was released inside the carotid artery of a living swine at a velocity varying between 10 to 13 cm/s while tracking it 24 times per second.

Results: Experiment 1: Deflections of 2.8º, 6.8º and 10.2º were achieved with a free catheter length of 5 cm, a 400 mT/m gradient and 1, 2 and 4 magnets respectively. Deflections of 7.7º, 11.9º, 14.6º were obtained with a free catheter length of 10 cm. At 40 mT/m (typical gradient amplitude for clinical systems), 1.15º and 2.58º were obtained with 4 magnets and 5 cm and 10 cm free catheter length respectively. Experiment 2: the ferrofluid filled balloon catheters were deflected using the imaging gradients of a standard Siemens Avanto 1.5T system. Experiment 3: During the in-vivo experimentation, the magnetic sphere was successfully stabilized, tracked and navigated into the carotid artery in cranial and caudal directions with an excursion of 4 cm along 11 waypoints. These roundtrips were repeated 11 times during 60 seconds.

Conclusions: These results show the feasibility of using clinical MRI scanner to perform catheter steering and tracking of ferromagnetic particles during interventional procedures.