MR Active Insertion Mandrel for Improved Delineation of Deep Brain Structures during MR Guided Electrode Insertion

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Introduction

The insertion of deep brain stimulation (DBS) electrodes into the brain is presently used to treat movement disorders and the application of DBS therapy has expanded to the treatment of epilepsy, Tourrette's syndrome, obsessive compulsive disorders and depression. In order for these electrodes to be effective they must be precisely positioned within a specific brain structure that varies with the clinical application. Surgical implantation of DBS electrodes is challenging and conventional stereotactic surgery methods alone lack the accuracy that is necessary for this application. We have developed an alternate approach for delivering DBS electrodes with intra-operative MR image guidance and this methodology has achieved very high targeting accuracy [1,2]. The approach utilizes a rigid mandrel within a peel-away sheath that is initially inserted to the target brain structure. If acceptable anatomic positioning is achieved, then the rigid mandrel is removed, leaving the peel-away sheath as a placeholder, and replaced by the actual DBS electrode, which is flexible. The peel-away sheath is then removed, leaving only the DBS electrode. We have utilized a rigid ceramic mandrel due in part to the low artifact level it produces on the images that document its anatomic positioning. The mandrel itself simply acts as a signal void and is a passive marker of position. In this research we explore the potential benefit that an MR active rigid insertion mandrel may have in characterizing its anatomical setting. We explore different RF coil designs that could be mounted on the tip of this mandrel and assess their relative SNR performance.

Methods

We explored three different RF coils designs that could be integrated onto the tip of an insertion mandrel, including: (1) dipole antenna, (2) opposed loop solenoids, and (3) flat loops. All coils were constructed such that they fit within a 1.4mm diameter cylinder, which is typical of insertion mandrels employed in DBS surgery. The dipole antenna's active region extended over the distal 30 mm of the device, while the flat loop was 25 mm in length, 1.35mm in diameter and included three overlapping turns. The opposed solenoid design contained two 20-turn solenoids that were 4mm in length, 1.35mm in diameter and included a central gap of 2mm. All coils were tuned to 63.9 MHz and imaged with T_1-weighted spin echo imaging on a 1.5T Siemens MR scanner (Siemens Avanto, Erlangen, Germany). Probes were placed in a saline filled phantom and oriented at 20^0 with respect to B_0, which is consistent with typical electrode orientations in supine patients. Imaging was performed parallel to and perpendicular to the axis of the mandrel and we evaluated the relative SNR and spatial sensitivity that could be achieved with each of these designs.

Results

All probes were successfully built within the required spatial constraints and tuned to 63.9 MHz. Both the flat loop and opposed solenoid designs produced substantially higher SNR than was achieved with the dipole antenna design (Figure 1). Accordingly, the dipole antennae design was considered inappropriate for this application and analysis of this design was discontinued. The flat loop coil exhibited a homogeneous appearance along the coil axis while the opposed solenoid produced its characteristic 3-lobed appearance along its axis. Perpendicular to the coil axis, the opposed solenoid achieved slightly higher peak SNR, but signal was inhomogeneous even in this plane. The flat loop coil achieved very homogeneous sensitivity in this image plane as well. Penetration of the flat loop coil was approximately 6 mm, which is more than four coil diameters. Analysis at the coil tip, which is relevant for looking into tissue that the probe has not yet penetrated, demonstrated a slight advantage to the opposed solenoid design. This forward looking ability, however, was limited to only 1.5-2mm with either coil design.

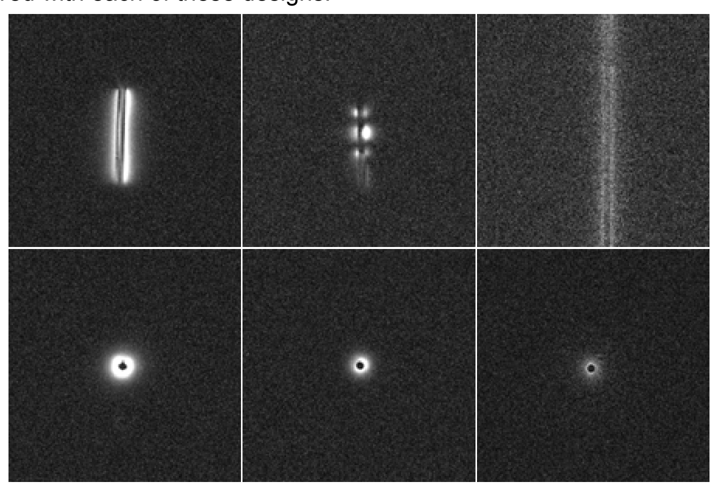

Figure 1: Images obtained from a saline water bath with the flat loop (left), opposed solenoid (middle) and dipole antenna (right) designs. Coil sensitivity is demonstrated along the probe (upper) and perpendicular to the probe (lower). Window and leveling are preserved between all scans.

Conclusions

It is practical to build MR coils onto the tip of insertion mandrels that have dimensions consistent with those used in DBS implantation procedures. The dipole antenna design produced unsatisfactory results while both the flat loop and opposed solenoid designs demonstrated substantial sensitivity external to the insertion mandrel. Penetration depths of up to four coil diameters were demonstrated with both the flat loop and opposed solenoid designs, although only the former achieved that relatively homogeneously along the full length of the coil axis. MR active insertion mandrels potentially offer the ability to image tissue in close proximity to the insertion mandrel at higher resolution than can be achieved with external coils.

References

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