Interventional MRI–Guided Deep Brain Stimulation Lead Implantation

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KEYWORDS

• Deep brain stimulation • Intraoperative MRI • Interventional MRI • Parkinson disease
• Subthalamic nucleus • Globus pallidus • Movement disorders

KEY POINTS

- Current knowledge of the functional anatomy of the subthalamic nucleus and globus pallidus, discovered through microelectrode recording and postoperative imaging, justifies purely anatomic targeting for deep brain stimulation (DBS).
- Interventional MRI (iMRI)-DBS is more anatomically accurate than traditional awake procedures and has similar clinical outcomes, without increased risk or increased operative times.
- iMRI lead implantation allows patients to receive DBS therapy who otherwise cannot tolerate, or would not agree to undergo, an awake procedure.

INTRODUCTION

Improvements in brain imaging have allowed for the development of techniques to place deep brain stimulation (DBS) electrodes using MRI guidance. This approach uses high-resolution imaging to both guide trajectory planning and confirm electrode placement for DBS targets. This anatomic verification approach is in contrast to traditional functional verification approaches that use imaging for preoperative planning but rely on microelectrode recording (MER) and symptom testing with intraoperative stimulation to confirmation appropriate placement. In anatomic verification approaches, MRI has been used in 2 different ways. One method has been the use of intraoperative MRI to confirm placement of DBS electrodes before completion of the operation.[1,2] In contrast, an interventional MRI (iMRI) approach uses near real-time acquisition of images to prospectively guide trajectory planning before electrode placement.

Anatomic verification approaches such as iMRI are most useful for DBS targets that are visible on standard clinical imaging. Currently, there are 3 commonly used targets for DBS placement in movement disorders, 2 for Parkinson disease (PD) and 1 for essential tremor (ET). The target for ET is the ventral intermediate (VIM) nucleus of the thalamus. However, the VIM is not commonly implanted in iMRI because the target itself is not easily distinguishable from adjacent nuclei in the thalamus using readily available MRI sequences. Although customized imaging protocols combined with tractography may eventually be validated for direct anatomic targeting,[3] most surgeons still prefer to perform VIM implantation in the operating room where the expected clinical effect can be confirmed before securing the electrode. In contrast, the DBS targets for PD, the subthalamic nucleus (STN) and pars interna of the globus pallidus (GPi), are easily visible on MRI. Thus, in most centers, iMRI is used for electrode

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implantation in the STN and GPi. This article describes considerations for iMRI-DBS implantation in these targets, including patient selection, technique of electrode placement, expected outcomes, and potential complications.

PROSPECTIVE STEREOTAXY AND THE DEVELOPMENT OF INTERVENTIONAL MRI FOR DEEP BRAIN STIMULATION

The benefit of iMRI versus other anatomic verification approaches lies in that it allows the surgeon to correct for inaccuracy in trajectory planning before electrode placement. Intraoperative MRI for anatomic verification can detect imprecision that requires adjustment of the trajectory postplacement.[1] In contrast, iMRI with prospective stereotaxy almost always results in a single brain penetration for electrode placement. One reason for this difference is the subtle brain shift that can occur between the preoperative MRI scans used for trajectory planning and the actual location of the DBS target at the time of electrode placement. When the dura is opened and cerebrospinal fluid egress occurs, the brain can shift and, because DBS targets are small nuclei located deep within the brain, this can introduce error in electrode placement. Human error in precisely setting the coordinates on a stereotactic frame is another common source of inaccuracy. Indeed, MER in the early days of DBS surgery was a necessity, to functionally verify that electrode trajectories were implanted in the expected anatomic target.

Functional verification of electrode location with MER led to precision in electrode placement. Imaging electrode locations after guided placement by MER has demonstrated that the sensorimotor STN lies in the dorsolateral portion of the nucleus[4,5]; a similar finding has been demonstrated for the GPi.[6] Thus, the functional maps obtained from MERs have allowed researchers to derive precise anatomic coordinates for DBS electrode placement,[7] which are used for iMRI procedures.

Prospective stereotaxy is the use of real-time imaging to guide alignment of a DBS electrode trajectory to achieve a given target before implantation.[8] Using this approach, studies of iMRI in DBS have demonstrated accurate electrode targeting[7,9] that produces reductions in motor symptoms and medication dosage[10,11] (PS Lee, MD, PhD, and RM Richardson, MD, PhD, unpublished data, 2017) comparable with results from functional verification approaches with MER.[12,13]

In the late 2000s, a prospective stereotaxy iMRI approach for DBS lead implantation was developed at the University of California, San Francisco (UCSF). This technique uses MRI to determine whether a skull-mounted trajectory guide is aligned to a given target within the brain.[14] This first-generation platform was developed by adapting an MRI-compatible, commercially available skull-mounted stereotactic system (Nexframe MR, Medtronic, Minneapolis, MN, USA) for DBS electrode implantation into the STN for PD patients.[7] Based on this experience, a dedicated iMRI platform was developed, the ClearPoint system (MRI Interventions, Inc, Irvine, CA, USA).[15] The ClearPoint system has a specially designed trajectory guide (SMARTFrame) and integrated planning software. This system also can be used for several other similar stereotactic procedures in iMRI, such as the placement of cannulas for drug infusion.[16–18]

PATIENT SELECTION CRITERIA FOR INTERVENTIONAL MRI–DEEP BRAIN STIMULATION PROCEDURES

Generally speaking, iMRI DBS placement is appropriate for all patients who are candidates for awake DBS procedures. However, in most institutions the lack of availability of MRI scanner time limits iMRI to patients who strongly prefer to be asleep or who cannot tolerate an awake procedure. The criteria for defining these patients vary across institutions, though some have attempted to formalize criteria. For instance, Azmi and colleagues[19] list criteria focused mainly on patient comfort and body habitus. There are some patients for whom it is less safe to perform a traditional procedure under sedation due to the lack of airway control. This includes patients with severe torticollis or those with other anatomic considerations that increase the likelihood of airway obstruction with sedation. Performing the procedure under general anesthesia in iMRI also allows for greater patient comfort. First, patients are not required to hold medications to be symptomatic for intraoperative testing. In addition, patients are poor candidates for awake procedures if they have significant anxiety about the procedure that will compromise their ability to cooperate when their participation is required. Finally, patients who have communication difficulties, such as those who have severe dysarthria, hearing problems, or who are not fluent native-language speakers are poor candidates for awake procedures.

In the authors' program, some patients are directed primarily toward iMRI surgery, with significant anxiety being the most common indication, followed by physical discomfort secondary to symptoms of advanced disease. For the remaining patients, iMRI and awake procedures are both offered and patients are allowed to choose their