Image-Guided Deep Brain Stimulation

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KEYWORDS

• Deep brain stimulation • Functional neurosurgery • Movement disorders • Stereotactic surgery • Target localization • Intraoperative imaging • Magnetic resonance imaging • Computed tomography

KEY POINTS

- The clinical efficacy of deep brain stimulation (DBS) is highly dependent on accurate lead placement; traditional stereotactic techniques have an average accuracy of 2 to 3 mm.
- Intraoperative computed tomography can be used during DBS surgery with minimal disruption, and provides an effective means to confirm lead placement with a high degree of accuracy; however, it cannot visualize DBS targets directly and thus depends on fusion with preoperative magnetic resonance imaging (MRI).
- Intraoperative MRI allows DBS surgery to be done under general anesthesia using real-time anatomic targeting and can account for intraoperative brain shift, but usually requires significant changes in implantation techniques.
- The merits of purely anatomic targeting versus physiologic targeting are still under debate.

INTRODUCTION

Deep brain stimulation (DBS) has been advantageous to patients with medically intractable movement disorders and severe psychiatric illness.[1–3] The efficacy of DBS depends on the accurate placement of the leads at the targeted locations.[4–6] Knowledge of the anatomic position of the DBS electrode in the brain is essential in quality control, selection of the stimulation parameters, and ultimately for the success of the therapy. Various types of imaging modalities have been used for intraoperative targeting. Both computed tomography (CT) and magnetic resonance imaging (MRI) have been successfully integrated into the workflow of DBS surgery by a variety of groups. Several examples of these techniques and a discussion of their relative merits are discussed herein.

INTRAOPERATIVE CT-GUIDED DBS

There are 2 types of intraoperative CT available: fan-beam CT (FBCT), which is the same technology used for diagnostic imaging in radiology suites, and flat-panel cone-beam CT (CBCT), which typically is portable and increasingly common in the operating room (OR) environment. A small portable FBCT device (Ceretom; NeuroLogica Corp, Danvers, MA) is commercially available, and its utility in DBS surgery has recently been reported.[7,8] Its small bore makes it difficult to use during the procedure itself,

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but it can be used to obtain the registration scan and to check final lead position before leaving the OR. In Richmond, the authors have studied the utility of a commercially available CBCT (O-arm; Medtronic Inc, Minneapolis, MN), which has a field of view large enough to image the whole head and a ring aperture large enough to be used repetitively throughout the procedure to check microelectrode tracks during physiologic recording. However, it has inferior soft-tissue resolution. The results of the authors' experience using the O-arm are presented, as well as others' experience with the Ceretom, as examples of well-studied CT-guided DBS.

O-Arm–Guided DBS with Physiologic Testing

Procedure overview

The philosophy of the Richmond program is to maximize any information that improves targeting while improving patient comfort during the surgery. Thus the authors' procedure combines anatomic imaging and physiologic testing. Intraoperative imaging with the O-arm allows for correction of the average 2-mm targeting error seen with frame and frameless stereotaxy.[9–12] Physiologic testing provides adjustment for interpatient variability in physiology and symptomatology. Both microelectrode recording (MER) and intraoperative Unified Parkinson's Disease Rating Scale (UPDRS) testing are useful in this regard. A determined effort is made to assure that the awake portion of the procedure is as comfortable as possible for the patient. Use of the frameless device provides comfortable head and neck support, and allows the patient to adjust head and body position during the surgery. The patient is sedated for infiltration of local anesthetic and drilling. Attachment of the anterior cervical portion of the head rest provides safety during arousal from sedation and can be removed once the patient is awake. The incorporation of the O-arm into the procedure provides the opportunity to incorporate the fiducials within the sedated portion of the procedure and to obtain the registration scan in situ, which further improves patient comfort. O-arm images can be obtained in standard mode to minimize the radiation dose (0.6 mSv), or in enhanced mode to enhance soft-tissue contrast (2.2 mSv), which has radiation dosing similar to that of a regular CT scan (~2–4 mSv) (**Fig. 1**).[10] The authors have determined that enhanced-mode imaging provides slightly better accuracy for fiducial localization than nonenhanced images (0.61 vs 0.70, $P = .04$); therefore, the enhanced mode is used for the registration scan standard mode is used for subsequent scans. MRI and CT images are obtained preoperatively, and the target is selected on the volumetric T1-weighted and T2-weighted images. The burr-hole entry site is chosen to optimize the maximum number of contacts within the

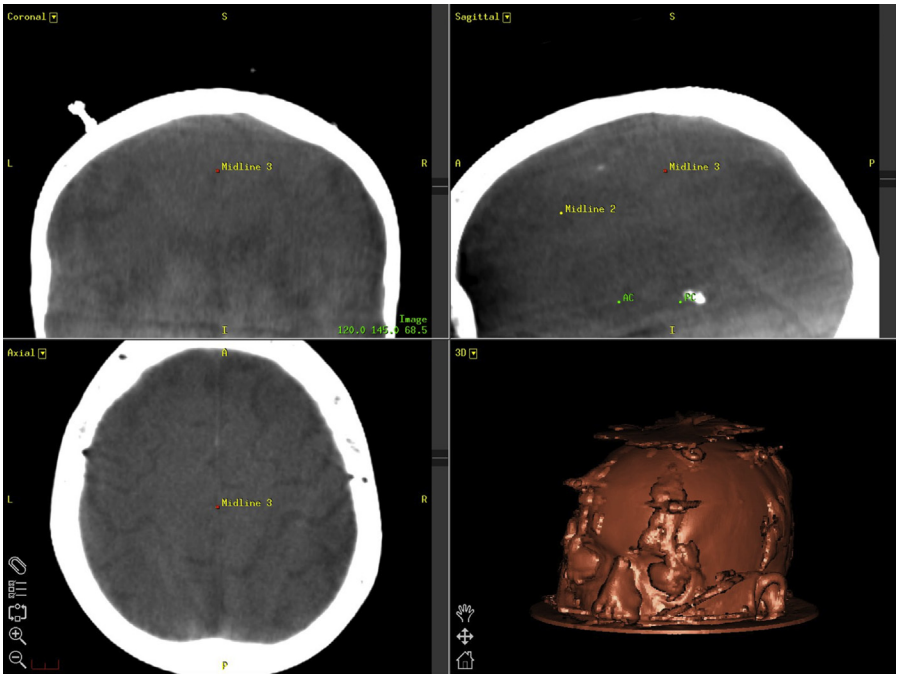

Fig. 1. Example of image obtained by the O-arm in enhanced mode, which increases the soft-tissue contrast thus providing sulcal anatomy and increased accuracy for intraoperative localization of fiducial markers.