Best surgical practices: a stepwise approach to the University of Pennsylvania deep brain stimulation protocol


Center for Functional and Restorative Neurosurgery, Pennsylvania Hospital, University of Pennsylvania, Philadelphia, Pennsylvania

Deep brain stimulation (DBS) is the treatment of choice for otherwise healthy patients with advanced Parkinson disease who are suffering from disabling dyskinesias and motor fluctuations related to dopaminergic therapy. As DBS is an elective procedure, it is essential to minimize the risk of morbidity. Further, precision in targeting deep brain structures is critical to optimize efficacy in controlling motor features. The authors have already established an operational checklist in an effort to minimize errors made during DBS surgery. Here, they set out to standardize a strict, step-by-step approach to the DBS surgery used at their institution, including preoperative evaluation, the day of surgery, and the postoperative course. They provide careful instruction on Leksell frame assembly and placement as well as the determination of indirect coordinates derived from MR images used to target deep brain structures. Detailed descriptions of the operative procedure are provided, outlining placement of the stereotactic arc as well as determination of the appropriate bur hole location, lead placement using electrophysiology, and placement of the internal pulse generator. The authors also include their approach to preventing postoperative morbidity. They believe that a strategic, step-by-step approach to DBS surgery combined with a standardized checklist will help to minimize operating room mistakes that can compromise targeting and increase the risk of complication.

(Key Words: • deep brain stimulation • dystonia • essential tremor • surgical technique)

Over the past 20 years, DBS has emerged as the most promising and safest surgical option in managing advanced PD, particularly in patients suffering from medically induced dyskinesia.2,4,8,11,15,18 Deep brain stimulation has also proven to be effective in other movement disorders, including refractory essential tremor and dystonia.7,8,12,18 More recently, DBS has shown efficacy in various neuropsychiatric disorders.10,13,16 It is an extremely attractive option for many patients given its reversibility and titratability. However, careful patient selection is crucial in optimizing the efficacy of this procedure. Moreover, the clinical efficacy of DBS depends largely on accurate targeting and implantation of the lead. In fact, subthalamic nucleus localization using MR imaging and a stereotactic head frame can have an accuracy of < 1 mm². The need for such precision demands rigid practice and surgical guidelines in lead placement. Indeed, we have incorporated the use of an intraoperative checklist to detect and remediate procedural errors.5 Further, efforts to reduce the incidence of morbidity, such as infection, are crucial for optimizing the overall outcome of this elective surgical procedure. In the present review, we outline in a step-by-step manner the details of the standard pre-, intra-, and postoperative courses used at our institution for all patients undergoing DBS. Our institution has documented a complication rate of 12.6% and a permanent sequelae rate of 4.6%, indicating a relatively low incidence of permanent complications.14 We believe that such a review can be helpful to all members of a functional neurosurgical team in both developing and/or self-evaluating their practice, particularly as we discover new diseases and targets requiring neuromodulation.

Abbreviations used in this paper: AC = anterior commissure; DBS = deep brain stimulation; IPG = internal pulse generator; LM = localizer marking; PC = posterior commissure; PD = Parkinson disease.
Preoperative Preparation

All candidates for DBS surgery are evaluated by a movement disorder specialist at our institution prior to being referred for surgery. In patients with PD, levodopa responsiveness; the presence of tremor, bradykinesia, and/or rigidity; frequent on-off fluctuations; and decreased functional on-times are characteristics of good candidacy. It is essential that careful selection and diagnostic criteria are met for the best surgical outcome, as patients with moderate to severe cognitive dysfunction and other parkinsonian syndromes have been shown to have unfavorable outcomes.3,9 Patients are considered appropriate candidates if they are in relatively good general health and have exhausted medical management. We do require all patients older than 50 years with medical comorbidities to obtain medical clearance from their respective doctors (that is, medical, cardiac, and pulmonary). Patients exhibiting cognitive deficits are required to undergo neuropsychiatric evaluation before being scheduled for surgery.

Patients and their families are seen in the neurosurgery clinic to confirm candidacy and discuss the risks and benefits of surgery as well as the anticipated outcomes and recovery period. At this time, a history is taken, a physical examination is performed, the patient is educated, and the overall preparation for surgery, including self-image preservation and postdischarge plans, is undertaken. Patients undergo routine preadmission testing including an electrolyte panel, complete blood count, coagulation studies, blood type and screen, urine analysis, electrocardiography, and chest radiography. Results are reviewed and faxed to any clearing physicians. Patients are given Bactoshield CHG 4% and chlorhexidine gluconate 4% (both Steris Corp.) with instructions to wash from head to waist twice the night before surgery and not to apply any cosmetic or hygiene products following this wash. All blood-thinning agents, including aspirin, clopidogrel, warfarin, and nonsteroidal anti-inflammatory drugs, are withheld for 1 week prior to surgery. Although instructed to hold all movement disorder medications (that is, carbidopa-levodopa, propranolol, baclofen, and so forth) on the morning of surgery, patients may take pertinent medications such as antihypertensives.

Day of Surgery

Frame Assembly

At our institution, we use the Leksell MicroStereotactic System Model G Frame (Elekta), which is fixed with the angled face plate directed superiorly as depicted in Fig. 1. The short posts are fixed into the posterior corners of the frame so that 1 cm is exposed inferiorly below the frame (Fig. 2). Place the long posts into the anterior slots, positioned so that 4 cm is exposed below the frame. Insert the disposable plastic screw hole inserts in all 4 screw hole sites. Attach the ear bar adapters to the sides of the frame with the angled portion directed anteriorly. The anterior edge of the ear bar adapters should be positioned 125 mm anterior to the posterior-most aspect of the frame. Insert ear bars through the middle ear bar insertion points. Do not lock the ear bars in place. Antibiotic ointment such as that used at our institution (Bacitracin Zinc and Polymyxin B sulfate ointment, E Fougera & Co.) should be available for placement on the pins.

Frame Placement

Once the patient enters the room on a stretcher, place cotton balls soaked in lidocaine gel into his or her ears. Keep the patient on the stretcher in an upright position at nearly 90°. If the patient has long hair, apply a lubricated gel such as Medichoice Bacteriostatic lubricating gel (Owens & Minor) to the anticipated posterior screw sites to facilitate placement. Alcohol should be applied to the patient’s forehead.

Remove cotton balls from the patient’s ears. Place the frame around the patient’s head while an assistant holds the head straight and in a firm position. Place ear bars into the external auditory canal in the unlocked position for easy adjustability. A slight turn of the pins in opposite directions will lock the frame in position. The frame should be positioned precisely midline. We refrain from using the nose as a midline surface landmark but instead use the zygomatic arches and lateral canthi. Inject 2.5 ml
of lidocaine 1% subcutaneously into the anticipated insertion points of the 4 screws. Screw length should be determined based on the distance of the posts’ screw holes from the scalp. Hand-tighten the screws in a diagonally oriented fashion (that is, tighten adjacent screws) to prevent altering the frame position. Tighten with the appropriate screwdriver until adequate bone purchase is achieved. Again, tighten the screws in a diagonal fashion to prevent frame slippage. Recheck the position of the frame and obtain confirmation of its midline position from another member of the functional team.

Place the Leksell Frame MR Imaging Localizer onto the frame itself. Ensure that the localizer’s metal clip attachments are secured to the frame as seen in Fig. 3. Lay the patient supine for Foley catheter insertion, and prepare the patient for transport to MR imaging. Ensure that adequate oxygen is available during travel as well as the frame kit for any necessary adjustments and lidocaine for scalp pain related to screw placement.

**Magnetic Resonance Imaging**

On arriving in MR imaging, sit the patient upright and place the Leksell frame MR imaging adapter around the posterior aspect of the frame. Ensure that it is locked in place on the proper frame attachments. Lay the patient supine and flat and transfer him or her to the MR imaging table, ensuring insertion of the adapter into the appropriate slot on the table. Place a bolster under the patient’s legs for comfort. It is important that such measures are taken to prevent any motion during scanning. For MR imaging at our institution we use a 1.5-T magnet (Signa, General Electric). We use 1.3-mm slices on axial T1-weighted images to localize the AC and PC to perform indirect targeting of the planned neural target. To enhance our accuracy we perform direct targeting of the planned neural target by using 2.5-mm slices of axial T2-weighted images. These slices can provide excellent definition of subcortical structures for direct visualization.

**Coordinates and Measurements**

Some general concepts about the coordinate and measurement system are outlined as follows. 1) The X coordinate corresponds to the mediolateral axis, the Y coordinate to the anteroposterior axis, and the Z coordinate to the superoinferior axis. 2) The X, Y, and Z coordinates at the patient’s rightward-most, posterior-most, and superior-most points are represented by 0, 0, and 0. 3) For reference in the discussion below, the LM seen on MR imaging in the axial plane will be labeled LM1–9 (Fig. 4). 4) The distance between LM1 and LM3 is 120 mm, as is the distance between LM7 and LM9. 5) The superoinferior lines LM1 and LM3, and LM7 and LM9 are connected by diagonal contrast lines. On any given MR imaging slice, the diagonal contrast lines create LM2 and LM8, which sit between LM1 and LM3 and between LM9 and LM7, respectively. Thus, on any given image slice, an isosceles triangle can be drawn connecting LM2 to LM1 (or LM3) and LM8 to LM7 (or LM9; Fig. 3). The dimensions of this triangle, which sits in the Y and Z plane, allow a calculation for the Z position of the image slice in question. 6) Indirect targeting using the coordinate system (X, Y, and Z) in relation to the midcommissural point (see below) or the PC are as follows: a) subthalamic nucleus, 11–13 mm, –2 mm, and 5 mm; b) ventrointermediate nucleus, 14 mm, quarter of the AC-PC distance measured from the PC, and 0 mm; c) globus pallidus internus, 21–23 mm, 2 mm, 5 mm. 7) The declination is determined by the slope of the arc in the anteroposterior plane, and the azimuth is the angle of approach in the mediolateral axis. 8) Register the MR imaging to a sagittal cut in which the AC and PC are both easily visible, placing the MR imaging slices in the plane of both the AC and PC. 9) Measure the AC-PC line. The midpoint of the AC-PC line is the midcommissural point. Using the measure stick function on the axial cut, insert a line connecting LM1 to LM7 and LM3 to LM9 (Fig. 4). The intersection of these lines is the precise center of the Leksell frame. Given their...
distances in millimeters from the 0 coordinate on the Leksell frame, the center X, Y, and Z coordinates are 100, 100, and 100. We recommend superimposing a grid over the center of the intersecting lines to assist with measurements. 10) Determine the X, Y, and Z coordinates of the AC and PC in relation to the Leksell frame. Again, the 0, 0, and 0 coordinate is the point most rightward, posterior, and superior. 11) For the X coordinate of the AC, measure the lateral distance from the AC to the anteroposterior plane of the midpoint. If the X coordinate of the AC or PC is more than 4 mm from the plane of the midpoint, the Leksell frame should be repositioned with new screw sites and a new MR sequence. Once the lateral distance of the AC from the midpoint is determined, subtract this number from 100 if the AC is to the right of the midline or add this number to 100 if the AC is to the left of the midline; this determines the X coordinate of the AC. The same can be done for the PC. 12) For the Y coordinate, measure the distance from the AC to the mediolateral plane of the midpoint. Add this number to 100 if the AC is more anterior to the axis center or subtract from 100 if the AC is more posterior to the axis center. The same can be done for the PC. 13) Determine the Z coordinate of the AC and PC. As mentioned above, LM2 and LM8 are part of an isosceles triangle that helps derive Z coordinates. By measuring the distance between LM2 (or LM8) and LM1 (or LM9) for the particular axial slice containing the AC and PC, an indirect measure of the Z coordinate is made because of the isosceles triangle depicted in Fig. 3. A 40-mm correction is used to determine the length of Z. In the axial view the distance from the superior-most post to the inferior-most post is exactly 120 mm. So the distance from the center of the frame to each post is 60 mm. Given that we want the center coordinate to be 100 (and not 60), we add 40 mm to the distance from LM1 to LM2 and from LM8 to LM9.

Target Coordinates: Indirect and Direct

Based on the aforementioned methods, determine the indirect target coordinates. If possible, obtain direct measurements of the targets based on anatomical visualization of the target’s center on T2-weighted axial images.

Transfer the patient onto the stretcher from the MR imaging table. Remove the frame adapter and return to the operating room.

Operating Room Setup

Transfer the patient to the operating table, ensuring that the most superior aspect of his or her shoulders is flush with the head of the table. Hold the frame during the transfer. Position the head of the patient at the foot of the operating table to allow for use of fluoroscopy during DBS. If the neurosurgical and anesthesia team agree on the use of general anesthesia, induction can ensue. We prefer general anesthesia in patients with severe dystonia and in any patient at high risk for obstructing an airway, as determined by the attending anesthesiologist. Of note, we have successfully performed microelectrode recordings despite general anesthesia using desflurane gas (unpublished data).

Once the patient is lying on the operating table, place the frame adapter on the Leksell frame with the turn knob directed superiorly (Fig. 5). Ask for assistance to hold the frame while placing the adapter. The frame adapter should then be attached with firm tightening of all screws. Reinject all screw sites with 2.5 ml of Marcaine.

StimPilot System

At our center, we remeasure the coordinates of the AC and PC as well as the planned target by using StimPilot (Medtronic, Inc.). The StimPilot system measures in fractions of millimeters and thus is very helpful in making precise calculations. When differences arise in the calculations of coordinates between MR imaging and the StimPilot, weighted averages are taken based on clinical judgment.

Patient Prep and Drape

The patient’s head should be prepared using the normal sterile technique. At our institution, we do not shave a patient’s head prior to prepping. We use Steris Bactoshield CHG 4% and chlorhexidine gluconate 4%. We wash with 2% chlorhexidine gluconate/7% isopropyl alcohol solution. In fact, we have demonstrated improved rates of infection at our own center by using a chlorhexidine wash without increased rates of complication with this prep (unpublished data).

Put on lead and thyroid shield and scrub. Set up an intravenous pole on either side of the patient’s head. Using long folded drapes, cover the patient’s body in the caudal to cranial direction but do not cover the patient’s head. Place a drape around the head. An up-going drape should be placed to exclude the anesthesia station from the surgical field. Place an Ioban drape (3M Health Care) on the patient’s head, extending it from the anterior-most portion of the Leksell frame and over the patient’s head. As depicted in Fig. 5, place an isolation drape (3M Health Care) along the top of the intravenous poles in front of the patient. Place a Neurodrape (3M Health Care) under the patient’s head. Securely attach suction tubing to the bottom of the Neurodrape, and place a Floor Dry directly under the patient’s head.

Procedural Setup

Determine the location of the coronal suture. We make the incision approximately 2 cm anterior to the coronal suture extending about 2 cm posteriorly. At our institution, we use a correction factor of 1.5 mm added to the left X and 1.0 mm added to the right X.

Set the 2 coordinates on the arc adapters to the frame and set the Y. Set the X coordinates on the stereotactic arc prior to placing it in position. On the right side, adjust the X coordinate and tighten. The stereotactic arc should be able to loosely pivot in the anteroposterior direction, allowing the surgeon to adjust the declination. Circular plate inserts with the circular (left) and square (right) targets should be placed on the arc attachments to assist in determining the target’s center point by using fluoroscopy (Fig. 6).

Fluoroscopic Analysis

Position the C-arm with a sterile cover around the
patient’s head as seen in Fig. 6. Continuously take fluoroscopic images until the circular and square targets are centered and the approximate trajectory estimated by a metallic instrument is in the 11 o’clock position on the fluoroscopic image.

Apply the microdrive to the arc at the proper azimuth as determined by the StimPilot (Fig. 7). Insert a probe through the microdrive’s center to mark the entry site and approximate bur hole position. We routinely start on the right side when performing bilateral DBS. Mark where the tip of the probe comes in contact with the scalp and draw your planned incision. Once this step is complete, adjust the arc so that the left-sided coordinates are correct and mark the scalp appropriately. Remember to adjust the X coordinates first, as historically this step is often forgotten.

**Surgical Procedure**

**Bur Hole Placement**

Pivot the stereotactic arc with the attached microdrive inferiorly, away from the incision site, and inject lidocaine. It is preferable to be liberal with the local anesthetic agent, particularly if the patient is awake. Using a number 10 blade, make the planned incision. We regularly make the first incision on the right side. Using a narrow peristeal elevator, create a plane under the periosteum for easy passage of the DBS leads to the contralateral side for connection to the extension wiring later in the case. Of note, the IPG will be placed on the right side if you are using the Kinetra system (Soletra, however, is bilateral). Use a mastoid retractor to expose the underlying calvaria. Visualize the coronal suture and ensure that your planned bur hole is directly on the suture or slightly anterior to it. Adjust the arc so that you can insert a metal probe through the microdrive’s center track. Mark where the probe touches the calvaria and place your bur hole using the Midas drill (Medtronic, Inc.). Use a curette to remove remaining bone over the dura and quickly apply bone wax to any bleeding edges to prevent an air embolism. If the case is unilateral, continue working on the appropriate side; if bilateral, however, move to the left side before puncturing the dura to avoid any unnecessary loss of CSF. Once the dura is exposed on the left, coagulate the dura in a cruciate fashion using a bipolar cautery. With an 11 blade, incise the dura carefully avoiding any visible vasculature. Use the bipolar cautery device to cauterize the...
Electrophysiological Study

Insert the guide cannula and stylet through the center trajectory of the microdrive. Once satisfied with the planned trajectory, microelectrode recordings should commence. It is important to ensure that the microelectrode lead does not abut the dural edges, as any such migrational force can compromise targeting. The ground electrode attaches to the guide cannula, while the recording electrode attaches to the distal tip of the microelectrode. Turn off all the lights, suction device, electronic operating table, Bovie, and any other unnecessary forms of electromagnetic interference. Using the microdrive, slowly guide the microelectrode to the target depth. Take intermittent fluoroscopic images at 10, 5, and 2 mm above the target to confirm proper advancement and trajectory of the microelectrode. Since the physiology team is non-sterile, they can assist the surgical team by performing sensorimotor tests when the microelectrode is approaching the target. If recordings are inadequate, a second trajectory can be attempted. The holes on the microdrive correspond to tracks 2 mm anterior, posterior, medial, or lateral to the original center hole.

Lead Implantation

Once the target is confirmed electrophysiologically and clinically, remove the guide cannula and microelectrode. Place the external guide piece onto the microdrive and insert the quadripolar macroelectrode (Medtronic, Inc.) into the microdrive (Fig. 7). Confirm placement at the target by using fluoroscopy. Begin macrostimulation of symptom release to further confirm placement and test for adverse effects. Remove the guide cannula and DBS lead stylet. Repeat fluoroscopy to ensure the lead is still in the desired position. Place the bur hole cap to lock down the DBS lead and repeat fluoroscopy to ensure the lead has not changed position. If performing bilateral DBS, reposition the arc to the proper coordinates, adjusting the X coordinates as well as the azimuth and declination, and repeat the procedure on the contralateral side.

Closing Procedure

Remove the stereotactic arc with the attached microdrive. Irrigate the surgical wounds with povidone-iodine and sterile saline. If the case is bilateral, place a Kelly underneath the scalp from the right incision to the left and pull a guide tube through to facilitate tunneling of the left DBS leads to the right side. Most of the IPGs that we place at our institution are Kinetras (that is, unilateral and on the right side). Remove the guide tube and bury both DBS wires underneath the scalp in a circular fashion around the right bur hole. Place three 2-0 Vicryl sutures in the galea on the left side and close with staples. On the right side, simply place 1 Vicryl suture and staple the wound. This side will need to be reopened when implanting the IPG.

Remove all drapes and the C-arm from the field. Proceed with washing the patient’s head with warm water, 3% hydrogen peroxide (Medichoice, Owens & Minor), and baby wash (Johnson & Johnson Consumer Companies, Inc.). Disassemble the stereotactic arc. Remove the Leksell frame. Ask an assistant to hold the patient’s head while the anterior screws are removed using the appropriate Leksell screwdriver. As the posterior screws are removed, the assistant will need to provide full support to the patient’s head. Unlock the frame adapter, and swing the frame down and away from the patient’s head. Replace the head of the bed.

Placement of the IPG

Placement of the IPG can be done with the patient under general anesthesia. The IPG should be placed approximately 4 finger-breadths inferior to the clavicle (Fig. 8) in a subcutaneous pocket. Shave the patient’s chest as necessary. You will also need to shave the posterior-auricular region. Prep and drape the field in a normal sterile fashion from the right scalp incision (if bilateral or for right-sided surgery) to the posterior-auricular region as well as to the neck and right chest wall. Place an Ioban drape over the surgical field.

Open an extension kit for DBS (7482A-51, Medtronic, Inc.; Fig. 8). Using scissors, cut through the Ioban drape at the site of the right-sided scalp incision and remove the staples. Using a number 10 blade, cut along the chest incision and bluntly create a subcutaneous pocket. Place a radiopaque sponge in the pocket while the DBS extension wires are tunneled for hemostasis. Using uterine packing forceps, burrow subcutaneously from the DBS incision site to the posterior-auricular site in a manner similar to that for a standard ventriculoperitoneal shunt technique. Use a 15 blade to incise at the tips of the forceps posterior to the ear. Using the tunneling tool from the kit, tunnel subcutaneously from this skip incision down to the inci-
sition in the chest wall. Remove the tunneler’s stylet and insert the extension wire. Pull the tunneler with the extension through to the skip incision. Repeat with another tunneler to bring the wire from the skip incision to the scalp incision. This tunneling process must be repeated for bilateral procedures.

The white extension wire connector must be attached to the left DBS lead by using the kit’s screwdriver, while the clear connector must be attached to the right lead. At our institution we use the Kinetra Dual-Program Neurostimulator for Deep Brain Stimulation for bilateral implantations for PD or the Soletra Deep Brain Neurostimulator for unilateral cases (Medtronic, Inc. for both). Use the torque wrench to tighten the extension wire connectors to the IPG and insert the left wire anterior to the right wire. Using a bayonet, coil the DBS lead and extension wires underneath the scalp. Irrigate with povidone-iodine and sterile saline and close with Vicryl sutures and staples. Insert the battery into the subcutaneous pocket after profuse irrigation. Close the battery pocket with 2-0 Vicryl and 4-0 Biosyn sutures. Close the skip incision with 3-0 Nylon sutures. Remove the drapes and wash the patient’s head again before applying bandages. Extubate the patient and transfer them to the hospital bed and then to the recovery room.

Postoperative Care

All movement disorder-related drugs can be restarted in the recovery unit. Once the patient has recovered, obtain a same-day postoperative MR image to confirm lead placement and to rule out intracranial hematoma. Take the patient to the intensive care unit for 24 hours for monitoring.

Intravenous antibiotics (cefa zolin or vancomycin for penicillin-allergic patients) are initiated 30 minutes prior to incision and continued every 8 hours postoperatively for 24 hours. Oral antibiotics include cephalixin or Bac trin in patients with a penicillin allergy or with a history of a methicillin-resistant *Staphylococcus aureus* infection. Deep vein thrombosis prophylaxis is initiated in the preoperative holding area before surgery with 5000 U heparin (subcutaneously) and every 8 hours after surgery until discharge. Evidence from our institution has documented no increased rate of intracranial hemorrhage with the use of perioperative subcutaneous heparin. Patients also wear antithrombotic stockings as well as sequential compression devices throughout their hospitalization according to our standard protocol for prophylaxis against venous thromboembolism. Patients are placed on 81 mg aspirin daily (initiated on postoperative Day 1) for 7 days.

We encourage patients to mobilize out of bed the morning after their surgery once the Foley catheter and arterial lines are discontinued. Frontal scalp dressings are removed on postoperative Day 1. Physical therapy consultation is initiated on postoperative Day 1 as well and is continued throughout a patient’s hospitalization. Patients receive occupational therapy and speech therapy on an as-needed basis. On the general surgical floor, vital signs are checked every 4 hours. The neurosurgery team removes the postauricular and anterior chest wall dressings on postoperative Day 2. Patient and family education regarding disposition and recovery is provided throughout the hospitalization. Patients are discharged to home or a rehabilitation center based on recommendations by the neurosurgery team and physical therapy. The average hospital stay for our patients is 3 days. The need for in-patient rehabilitation is generally based on prior level of function. Rehabilitation services include physical, occupational, speech, and cognitive therapies. The typical rehabilitation course is 5–7 days.

Patients return to the neurosurgery office 10 days after surgery for suture and staple removal as well as initial device programming. Patients then return for their 1-month follow-up visit and further programming. They are then seen on an as-needed basis for additional programming of the device typically in collaboration with their movement disorder specialist who aims to wean dopaminergic therapy.

Conclusions

The applications of DBS surgery are rapidly expanding, making it imperative that optimal surgical techniques are used. Here, we provide our institution’s standardized stepwise approach to DBS surgery. Considering the more than 600 DBS procedures completed at our center and a reported complication rate of 12.8%, the procedure outlined above is designed to maximize efficacy and minimize...
As more data emerge to further guide the DBS surgical approach, greater accuracy in lead implantation, higher efficacy rates, and fewer complications will be achieved.

Disclosure

Drs. Jaggi and Baltuch are consultants for Medtronic, Inc.

Author contributions to the study and manuscript preparation include the following. Conception and design: Baltuch, Kramer, Halpern. Acquisition of data: Kramer. Analysis and interpretation of data: Kramer, Halpern. Drafting the article: Kramer, Buonacore, McGill. Critically revising the article: Baltuch, Kramer, Halpern, Hurtig, Jaggi. Reviewed final version of the manuscript and approved it for submission: Baltuch, Hurtig, Jaggi.

References