Since its introduction in 1987 by Benabid et al., \(^7\) deep brain stimulation (DBS) has become a widely recognized technique for reversible modulation of brain function that is adjunctive to the medical management of movement disorders. Its proven efficacy in Parkinson disease (PD),\(^{7,15,33,38,56}\) has led to its worldwide application for a spectrum of hyperkinetic diseases, including essential tremor (ET),\(^{6,28,31,49}\) dystonia,\(^{13,34,65,66}\) cerebellar outflow tremor,\(^{9,10,26,57}\) Gilles de la Tourette syndrome,\(^{17,27,63}\) as well as a growing number of other medically intractable disorders, such as obsessive-compulsive disorder,\(^{16,23,24,43,46}\) major depressive disorder,\(^{40,44,45}\) and cluster headache.\(^{46}\) As this procedure becomes more commonplace, questions of intra- and postprocedural safety, including hardware complications, infection, and suboptimal results,\(^{48}\) will continue to arise during preoperative consultations and must be correctly addressed to prospective patients. In an effort to promote the relative safety of this procedure, we pre-

---

Clinical article

**ALBERT J. FENOY, M.D.,1 AND RICHARD K. SIMPSON JR., M.D., PH.D.2**

1Mischer Neuroscience Institute, Department of Neurosurgery, The University of Texas Health Science Center at Houston; and 2Methodist Neurological Institute, Department of Neurosurgery, Houston, Texas

*Object.* Deep brain stimulation (DBS) surgery is increasingly prominent in the treatment of various disorders refractory to medication. Despite the procedure’s efficacy, the community at large continues to be hesitant about presumed associated risks. The main object of this study was to assess the incidence of various surgical complications occurring both during and after DBS device implantation in a large population of patients with movement disorders in an effort to better quantify patient risk, define management plans, and develop methods for risk avoidance. A second aim was to corroborate the low procedural complication risk of DBS reported by others, which in light of the procedure’s efficacy is needed to promote its widespread acceptance.

*Methods.* All patients who had undergone new DBS device implantation surgery between 2002 and 2010 by a single surgeon were entered into a database after being verified by cross-referencing manufacturer implantation records. All surgical records and charts were reviewed to identify intraoperative, perioperative, and long-term surgical complications, including any characteristics predictive of an adverse event.

*Results.* Seven hundred twenty-eight patients received 1333 new DBS electrodes and 1218 new internal pulse generators (IPGs) in a total of 1356 stereotactic procedures for the treatment of movement disorders. Seventy-eight percent of the patients had staged lead and IPG implantations. Of the 728 patients, 452 suffered from medically refractory Parkinson disease; in the other patients, essential tremor (144), dystonia (64), mixed disease (30), and other hyperkinetic movement disorders (38) were diagnosed. Severe intraoperative adverse events included vasovagal response in 6 patients (0.8%), hypotension in 2 (0.3%), and seizure in 2 (0.3%). Postoperative imaging confirmed asymptomatic intracerebral hemorrhage (ICH) in 4 patients (0.5%), asymptomatic intraventricular hemorrhage in 25 (3.4%), symptomatic ICH in 8 (1.1%), and ischemic infarction in 3 (0.4%), associated with hemiparesis and/or decreased consciousness in 13 (1.7%). Long-term complications of DBS device implantation not requiring additional surgery included hardware discomfort in 8 patients (1.1%) and loss of desired effect in 10 (1.4%). Hardware-related complications requiring surgical revision included wound infections in 13 patients (1.7%), lead malposition and/or migration in 13 (1.7%), component fracture in 10 (1.4%), component malfunction in 4 (0.5%), and loss of effect in 19 (2.6%).

*Conclusions.* The authors confirmed that the overall risk of both procedure- and hardware-related adverse events is acceptably low. They offer advice on how to avoid the most common complications.

(http://thejns.org/doi/abs/10.3171/2013.10.JNS13225)

**KEY WORDS**

- deep brain stimulation
- complication
- movement disorder
- management
- prevention
- functional neurosurgery

---

Abbreviations used in this paper: DBS = deep brain stimulation; ET = essential tremor; GPI = globus pallidus internus; ICH = intracerebral hemorrhage; IPG = internal pulse generator; IVH = intraventricular hemorrhage; IVP = intraventricular pneumocephalus; MER = microelectrode recording; PD = Parkinson disease; STN = subthalamic nucleus; Vim = ventral intermediate nucleus of the thalamus.
sent a retrospective analysis of all adverse effects in 728 consecutive patients treated with DBS by 1 neurosurgeon (R.K.S.) between 2002 and 2010 along with a comparative analysis of the medical literature. Advice on complication avoidance is discussed as well.

Methods

All patients who had undergone new DBS implantation surgery between January 2002 and December 2010 were entered into a database. These patients were identified based on consecutive surgical reports from 1 primary surgeon (R.K.S.) operating at multiple campuses. Procedures were performed at Houston Methodist Hospital, St. Luke’s Episcopal Hospital, and Memorial Hermann Hospital. The database was cross-checked with the manufacturers’ records of hardware implantations performed at the participating institutions for data verification. The DBS devices were primarily Medtronic implants, with a few investigational device implants (Libra DBS system, St. Jude Medical Neuromodulation). Individual referring neurologists made all diagnoses, and R.K.S. corroborated DBS treatment candidacy, often in a multidisciplinary meeting.

Patients charts identified in the database were analyzed retrospectively for the occurrence of intraoperative, perioperative, and long-term adverse effects, as described in a similar but less inclusive study by the same surgeon. Institutional review board approval for this retrospective chart review was sought and granted at each institution. The perioperative period was defined as the first 2 weeks after implantation; and the long-term, as the period occurring after the first 2 postoperative weeks. Transient programming-related symptoms were excluded since these did not surface at postoperative visits to the neurosurgeon; therefore, only undesired sustained side effects that led to lead replacement were recorded. Internal pulse generator (IPG) replacement due to depletion was not considered a complication.

Surgical Procedure

Our standard surgical procedure for DBS has been described in detail elsewhere. Briefly, a stereotactic frame (Leksell, Elekta AB) is placed, and a patient undergoes volumetric imaging whereby indirect targeting can be completed based on reference to the anterior commissure–posterior commissure line. The trajectory is determined using StealthStation navigation (Medtronic Inc.) to avoid cortical vessels and, if possible, the lateral ventricle, usually choosing bur hole locations 4 cm lateral from the midline at the coronal suture. Occasionally, ventriculomegaly makes ventricular transgression unavoidable. Early in the series, lead implantation was often performed during the same time as placement of the lead extensions and IPG, but by 2004 the procedure largely became staged. Stage 2, which involved placement of the extensions and IPG, would occur 1–2 weeks after Stage 1, which was for lead implantation. Microelectrode recording (MER) was routinely performed for all targets except the ventral intermediate nucleus of the thalamus (Vim), for which the Leksell insertion kit (Elekta AB) was used instead of MER at Houston Methodist Hospital and St. Luke’s Episcopal Hospital. At all hospital locations, intraoperative test stimulation was performed to verify target accuracy and the lack of sustained side effects. Postoperative CT was routinely performed to verify the location of leads.

Statistical Analysis

All statistical analyses were performed using standard statistical software (SPSS Statistics, version 17.0, SPSS Inc.). Risk factors for the occurrence of adverse effects, such as patient age, diagnosis, date of surgery, and institution, were analyzed with multivariate logistic regression.

The Student t-test with equal variances was used to compare age at implantation between patients with adverse effects and those without. Evaluation of differences between patients with adverse events depending on implant target and hardware type was performed using the Fisher exact test.

Results

Demographic Data

Seven hundred twenty-eight patients received 1333 new DBS leads and 1218 new IPGs in a total of 1356 stereotactic procedures. In this same population, 32 lead revisions and/or replacements and 637 IPG replacement procedures were performed during the study period. Of the newly implanted leads, 1312 were manufactured by Medtronic (model 3387) and 21 by St. Jude Medical Neuromodulation (Libra). Of the newly implanted pulse generators, 1116 were Soletra, 56 were Kinetra, 14 were Activa PC, and 11 were Activa RC, with 21 Libra from St. Jude Medical. Five hundred ninety-two of the 637 IPG replacements were Soletra, with a few in each of the other categories.

Four hundred fifty-two patients suffered from PD, 144 from ET, and 64 from dystonia. Table 1 shows details regarding patient diagnoses and targets of implantation. Patients ages ranged from 11 to 92 years (average 60.8 ± 14.5 years). Thirteen patients were under the age of 18 years at time of DBS implantation. Only 6% of the patients were left handed, and 65.5% were male. The minimum follow-up was 6 months in all but 5% of the patients. The mean neurosurgical follow-up was 1.9 ± 2.2 years (range 14–2982 days); this number excludes subsequent programming sessions with the referring neurologist. Note that referrals back to neurosurgery were made up to 12.1 years from the initial implant for IPG exchanges, hardware-related issues, and loss of system efficacy, including patients who required surgical revision in the study period but had undergone initial implantation by R.K.S. prior to 2002. Thus, we estimate that most if not all surgery-related long-term complications were captured in this process.

Adverse Events or Complications

Adverse events were subdivided based on when they occurred relative to implantation: intraoperative, perioperative (± 2 weeks after implantation), or long-term postoperative (after 2 weeks from implantation). Table 2 provides a summary of event frequency in these 3 categories.
Intraoperative Events. The most common overt intraoperative complication was a vasovagal response, which occurred in 6 patients (0.8%), precipitating syncope in 4 patients and causing the procedure to be aborted on 4 occasions. One such episode caused only very transient hemiplegia but did not postpone the case; postoperative CT showed putaminal and intraventricular hemorrhage (IVH). One episode leading to an aborted procedure was later found to be correlated with a postoperative CT finding of air in the cavernous sinus. One intracerebral hemorrhage (ICH) and 1 subcortical infarction produced intraoperative symptoms of hemiparesis, occurring immediately after the first lead insertion, requiring postponement of the remainder of the case.

The most severe complication was hemorrhage: symptomatic ICH developed in 8 patients (1.1%) and manifested as postoperative hemiparesis in 7 and early somnolence in 4. Asymptomatic ICH was identified on postoperative CT in 4 patients (0.5%). More common was the incidental reporting of small IVH layering in either the atrium or the occipital horn of the lateral ventricle in 28 patients (3.8%); only 3 of these patients (11% of those with IVH, 0.4% of the series total) had transient postoperative confusion.

Two patients (0.3%) had a tonic-clonic seizure just prior to MER, with negative emergent imaging findings, causing the procedure to be aborted. Isolated intraoperative issues included 1 case of arrhythmia (0.1%), 2 of transient confusion (0.3%), and 5 of anxiety (0.7%), which was remedied with a small propofol infusion that wore off prior to MER.

Perioperative Events. Perioperative events, which occurred ≤ 2 weeks after surgery, were witnessed during either the hospitalization after Stage 1 or a return to the operating room for Stage 2 of the procedure. Most patients complained of headache (31 patients [4.2%]), which was transient. Confusion either with (4 patients [0.5%]) or without (7 patients [1.0%]) agitation was the next most common symptom, and again was transient; 10 such incidences were associated with subthalamic nucleus (STN) trajectories. Transient hallucinations occurred in 3 patients (0.4%).

Several serious adverse events occurred as well, most within a few hours after the procedure. Thirteen patients (1.7%) had postoperative hemiplegia with or without decreased consciousness, 8 of whom had ICH identified on postoperative CT. One patient had evidence of cortical infarction (0.1%), 2 (0.3%) had subcortical infarctions, and still 2 others (0.3%) had “ill-defined hypodensities” around the electrode tip on postoperative CT, believed to be edema, causing only transient hemiparesis.

Further serious adverse events included seizure in 3 patients (0.4%) on postoperative Day 1 or 2 (with negative CT findings) and respiratory distress in 3 patients (0.4%), 2 of whom required reintubation due to pulmonary edema (1 patient) and aspiration pneumonia requiring subsequent tracheostomy (1 patient).

Long-Term Events. Long-term adverse events were defined as those events that occurred more than 2 weeks after surgery (Table 2). Given this study’s surgical perspective, only adverse events that were presented back to the neurosurgery clinic are listed; thus, transient programming-induced ill effects are excluded. These events can be categorized into wound, hardware, or satisfaction-related complications.

Wound Complications. Among wound complications, infection was the most common, occurring in a total of 23 cases (3.1%), 10 (1.4%) of which were self-limited and 13 (1.7%) of which required a return to surgery for debridement and/or device removal (Table 2). Erosions and dehiscence occurred in 2 patients (0.3%) each, requiring surgical debridement only.

Hardware Complications. All hardware-related complications required a reoperation. Lead malposition (9 cases [1.2%]) or migration (4 cases [0.5%]), were the most common hardware complications, leading to revision at an average of 1.3 years after initial implantation (range 0.25–6 years).

---

Table 1: Diagnosis in 728 patients referred for DBS (2002–2010), with stimulation target*

<table>
<thead>
<tr>
<th>Disease</th>
<th>STN No. of Patients</th>
<th>Vim No. of Patients</th>
<th>GPi No. of Patients</th>
<th>PPN No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilat</td>
<td>Bilat</td>
<td>Unilat</td>
<td>Bilat</td>
</tr>
<tr>
<td>PD</td>
<td>452</td>
<td>72</td>
<td>318</td>
<td></td>
</tr>
<tr>
<td>ET</td>
<td>144</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dystonia</td>
<td>64</td>
<td></td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>PD/ET</td>
<td>30</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PT or MS tremor</td>
<td>24</td>
<td></td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>GTS</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>9</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>total no. patients</td>
<td>728</td>
<td>75</td>
<td>322</td>
<td>95</td>
</tr>
<tr>
<td>total no. leads§</td>
<td>1333</td>
<td>84</td>
<td>644</td>
<td>115</td>
</tr>
</tbody>
</table>

* GTS = Gilles de la Tourette syndrome; MS = multiple sclerosis; PPN = pedunculopontine nucleus; PT = posttraumatic.
† One side the STN and the other side the Vim in the same patient.
‡ Right pedunculopontine nucleus lead added to 2 patients each with bilateral GPi implants (not included in patient total).
§ Only original leads.
Management and avoidance of complications in DBS

**TABLE 2: Summary of adverse effects after DBS device implantation in 728 patients**

<table>
<thead>
<tr>
<th>Event</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>intraop</td>
<td></td>
</tr>
<tr>
<td>asymptomatic IVH</td>
<td>25 (3.4)</td>
</tr>
<tr>
<td>symptomatic ICH</td>
<td>8 (1.1)</td>
</tr>
<tr>
<td>asymptomatic ICH</td>
<td>4 (0.5)</td>
</tr>
<tr>
<td>acute perilesional edema</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>cortical/subcortical ischemic infarction</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>vasovagal response</td>
<td>6 (0.8)</td>
</tr>
<tr>
<td>hypotension</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>confusion</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>anxiety</td>
<td>5 (0.7)</td>
</tr>
<tr>
<td>seizure</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>arrhythmia</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>aborted procedure</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>periop (≤2 wks)</td>
<td></td>
</tr>
<tr>
<td>headache</td>
<td>31 (4.2)</td>
</tr>
<tr>
<td>hemiparesis w/ or w/o decreased LOC</td>
<td>13 (1.7)</td>
</tr>
<tr>
<td>confusion</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>confusion/agitation</td>
<td>4 (0.5)</td>
</tr>
<tr>
<td>respiratory distress</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>seizure</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>hallucinations</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>somnolence</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>fall</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>long-term postop (&gt;2 wks)</td>
<td></td>
</tr>
<tr>
<td>wound complications</td>
<td></td>
</tr>
<tr>
<td>wound infection–self limited</td>
<td>10 (1.4)</td>
</tr>
<tr>
<td>wound infections</td>
<td></td>
</tr>
<tr>
<td>requiring system removal</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>requiring lead removal only</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>requiring IPG/extension removal only</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>requiring debridement only</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>skin erosion–device removal</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>wound dehiscence–debridement only</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>hardware complications</td>
<td></td>
</tr>
<tr>
<td>lead fracture–lead revision</td>
<td>7 (1.0)</td>
</tr>
<tr>
<td>lead malposition–lead revision</td>
<td>9 (1.2)</td>
</tr>
<tr>
<td>lead migration–lead redirection w/o removal</td>
<td>4 (0.5)</td>
</tr>
<tr>
<td>lead malfunction/high impedance–lead revision</td>
<td>2 (0.3)</td>
</tr>
<tr>
<td>flipped IPG–revision</td>
<td>4 (0.5)</td>
</tr>
<tr>
<td>malpositioned/uncomfortable IPG–revision</td>
<td>4 (0.5)</td>
</tr>
<tr>
<td>IPG malfunction/high impedance–replace</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>lead extension malfunction/high impedance–replace</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>lead extension fracture–replace</td>
<td>3 (0.4)</td>
</tr>
<tr>
<td>satisfaction-related complications</td>
<td></td>
</tr>
<tr>
<td>loss of system efficacy over time–lead revision</td>
<td>19 (2.6)</td>
</tr>
<tr>
<td>decreased efficacy over time–no revision desired</td>
<td>10 (1.4)</td>
</tr>
</tbody>
</table>

* LOC = level of consciousness.

Lead fractures (7 cases [1.0%]) and lead extension fractures (3 cases [0.4%]) were also common hardware complications, followed by component malfunction (4 cases [0.5%]) as identified by high impedance in the system, resulting in lead revision (2 cases [0.3%]), lead extension or IPG revision (1 case each [0.1%]) occurring at an average of 4.4 years after the initial operation (range 0.5–8.7 years). Four patients (0.5%) had an IPG that flipped or an uncomfortable or malpositioned IPG, all requiring repositioning.

Satisfaction and System Effectiveness. During the follow-up, stimulation-induced side effects that limited effective use of the DBS device to treat the underlying disorder included dysarthria, diplopia, paresthesia, and nausea in 7 patients (1.0%), none of whom wanted a revision. All patients with malpositioned DBS leads requiring revision (9 cases [1.2%]) eventually suffered from such stimulation-induced side effects, limiting utility of the system. Eight patients complained of discomfort around the lead extensions in the cervical area (1.1%). Pocket hematoma developed in 3 patients (0.4%) after pulse generator implantation, although it subsequently resolved in each case.

Nineteen patients (2.6%) ultimately lost efficacy of 1 or both of their leads over the duration of the study and underwent lead revision. Eighteen of them had either ET or PD tremor that worsened such that initial motor control derived from stimulation was lost despite repeat programming, with lead revision at an average of 4.8 years after initial implantation. One patient with secondary parkinsonism and dystonia had bilateral STN leads revised after 5 years because of limited initial effects. Ten other patients (1.4%) with tremor noted loss of system efficacy over time but did not desire lead revision.

Five patients (0.7%) ultimately wished for complete removal of their system because the system was ineffective (2 patients), symptoms had resolved (1 patient with MS tremor), serial brain MRI studies were needed (1 patient with comorbid tremor and Rasmussen’s encephalopathy), and severe dementia had developed (1 patient).

If the total number of hardware complications (n = 29), infections (n = 13), and erosions (n = 2) requiring reoperation are combined, then the total number of long-term device-related complications requiring repeat surgery was 44 (6%). Over the 9 years of this study, 1365
leads were placed, amounting to 12,285 electrode-years; thus, the device-related complication rate was calculated as 0.3% per electrode-year.

Patient age and sex, implant type, or implant location showed no statistical predilection for an adverse event. Complications did not occur any more often at a specific time in the 9-year study period. However, 7 of 8 observed symptomatic ICHs and 3 of 4 asymptomatic ICHs were attributable to lead placement targeting the STN, which is interesting. Note that no ICH occurred upon targeting the globus pallidus internus (GPi).

**Discussion**

Although it is known that DBS is a relatively safe and effective procedure, actual rates of complications in the literature vary because of the differences in their definition, the relative lack of large series, and the difficulty in making comparisons across studies. Through our large series’ compilation of adverse effects, we corroborated the overall low complication rate attributed to DBS surgery. Through our volume of cases, we hoped to emphasize the relative safety of the procedure to both the physician and patient communities so that more patients can benefit from its tremendous efficacy.

This series features one of the largest populations with movement disorders that has received DBS hardware from 1 primary surgeon; thus, data concerning actual risks to patient safety can be clearly interpreted. The most common side effects due to implantation in the immediate postoperative period (headache or confusion), fortunately, were transient. The most serious complication resulting from DBS device implantation is a systematic vascular accident due to lead insertion, which was uncommon in our series for both ICH (1.1%) and infarction (0.4%).

Our observed rate of DBS-related ICH was considerably lower than that reported in the literature (1.0%–25.0%).1,4,8,12,15,25,31,33,35,36,39,41,42,47,50,55,64,66,69,70 Cortical or subcortical ischemic infarction related to DBS is very rarely reported in the literature, occurring in about 1 patient per series (0.3%–0.9%).61,64 This finding could be due to the fact that ICH is not readily identifiable on routine postoperative CT imaging and that most are asymptomatic. The very low incidence of either hemorrhagic or ischemic stroke, despite a large number of procedures, could be attributable to greater surgical experience.

It is interesting to note that 1 capsular ischemic stroke (50%), both cases of acute perilesional edema (100%), and 10 (83%) of 12 ICHs were attributable to electrode placement targeting the STN. This finding does not seem to be wholly corroborated by the literature. Starr and Sillay61 reported that 4 of 8 symptomatic ICHs on postoperative imaging occurred when targeting the STN; 3 were subcortical (2 capsular, 1 thalamic). In our present series, we found that 7 of 8 symptomatic ICHs occurred when targeting the STN, and 4 of them were subcortical (1 putaminal, 3 thalamic). A possible explanation for our higher incidence is that the STN was targeted most frequently (53% of patients with implants). There are no viable anatomical arguments as to why the subthalamic area is more vulnerable to infarction than other subcortical areas. Although delayed ischemic infarction following pallidotomy has been described,3,37 its occurrence could be the result of stereotactic methodology rather than an inherent feature of DBS.

Of further interest is our finding that only 3 (11%) of the 28 observed IVHs were associated with transient postoperative confusion, and the patients in all 3 of these symptomatic cases had electrodes placed in the STN. Of this series’ 28 incidences of IVH, 9 (32%) had occurred because of targeting the Vim and 19 (68%) because of targeting the STN. Twenty-five small IVHs in the occipital horn and/or atrium were incidental findings on postoperative CT and were considered to represent asymptomatic passage of either the microelectrode or the stimulating lead through the ventricle. This is probably an underestimate of the total number of ventricular wall penetrations. Elias et al.18 reported that 113 (46%) of 248 trajectories in their series violated the ventricle, with only 5 (4.4%) resulting in asymptomatic IVH. Gologorsky et al.21 noted 16 ventricular wall transgressions on postoperative MRI of 145 consecutive leads placed in the STN, with only 1 having associated IVH. The patients in 8 of these cases experienced postoperative confusion, and the authors identified a significantly greater risk (p < 0.001) of neurological compromise in such ventricular wall passes. In the present study, 3 (16%) of 19 STN trajectories causing IVH were associated with confusion, whereas 10 of the 11 patients with postoperative confusion and/or agitation had STN trajectories. Given the series total of 397 patients with STN targets, we calculated a 2.4% risk of postoperative confusion. We noted 728 consecutive leads placed in the STN; as we do not have postoperative MRI studies for every patient, it was impossible to determine total transventricular transgressions. However, postoperative CT evaluation could easily demonstrate IVH or intraventricular pneumocephalus (IVP), which would give quick proof of ventricular penetration. In this series, we observed IVP in 141 patients; 98 instances occurred in patients with a targeted STN, 38 in patients with a targeted Vim, and 5 in patients with a targeted GPi. Therefore, we calculated that at least 25% of the patients with STN trajectories in this series had penetration of the lateral ventricle; each of the 10 patients with STN targets and postoperative confusion also had IVP (9.8%). What we can infer from our study and others18,21 is that evading transventricular passage is desirable when planning trajectories to avoid IVH and/or IVP and possible transient confusion, especially when targeting the STN. Patients and families should be appropriately counseled. However, if a ventricular trajectory is unavoidable, our experience indicates that such passage causing IVP and/or IVH produces only transient confusion if anything.

Most asymptomatic hemorrhages detailed in the literature reflect a subcortical or cortical finding on CT.12,61,64 Starr and Sillay observed that asymptomatic subcortical blood on routine postoperative MRI in 15 patients (4%) was located at the microelectrode terminus and thus was believed to be due to MER.61 We found 4 cases of asymptomatic ICH, but only 1 was near the actual electrode tract; the others were cortical. We noted 2 patients (0.3%) with intraoperative seizures, which was similar to the reported occurrence of 0.3%–2.3% of patients in large DBS series.9,12,61,64,66 Postoperative seizures have been report-
ed to range from 0.9% to 9.1%, although we noted 3 cases (0.4%).

Vasovagal responses were the most common, overt intraoperative adverse effects (6 patients) and are well known to us and others. They are heralded by an episode of coughing soon after bur holes are made and are commonly followed by a “swoon” in blood pressure. These responses are overt manifestations of transvenous air embolism, which are especially frequent in DBS surgery because the patients are in a seated position, with the head above the heart, and are awake, spontaneously breathing and generating negative venous pressures. The surgeon must anticipate the occurrence of air embolism and wax the bone edges well and copiously flood the field with saline to prevent possible venous air embolism. Similarly, the anesthesiologist must recognize it and quickly correct the blood pressure to prevent prolonged hypotension, which would increase the risk for ischemic infarction. Intravenous lidocaine and modest doses of propofol have proven effective, in our experience, to suppress the coughing, which in itself raises intracranial pressure and increases the risk of hemorrhage. So long as the coughing subsides, hypotension is averted, and the patient remains neurologically intact, the procedure can continue.

The risk of infectious complications has been reported to range from 0% to 15% in various studies, although we noted 3 (1.2%) of 728 patients required a return to surgery. (Details of the presentation and management of such wound infections are detailed in Tables 2 and 3 in Fenoy and Simpson.) Thus, 1.24% represents a more reasonable rate for comparison across studies examining postoperative infection requiring reoperation and is indeed lower than, if not the lowest, of those in most studies. Wound complication avoidance seemed best correlated to a consistent surgical team with strict enforcement of sterility, a relatively quick procedure, and use of prophylactic antibiotics.

There is sufficient discussion in the literature about redirecting malpositioned DBS leads, and our study seems to corroborate this strategy. There were 9 (1.2%) malpositioned leads with a mean latency of 1.6 years before revision, and the leads were moved a mean distance of 5.6 mm, which is similar to the distances in other series. Four leads were placed too deep and were simply elevated 0.5–1 mm without using a new lead or MER, at an average of 0.4 year after insertion. The poor positioning was determined based on lead asymmetry on postoperative CT and the lack of any effect, and thus was detected earlier. Since ending this study, we have adopted the use of multiple trajectories during MER to optimize lead placement, which we have found particularly useful when targeting the STN. Like other groups, we most often choose the center trajectory, however, electrophysiological comparison during MER allows the best choice for lead placement. We do not have an increased risk of hemorrhage with this technique, and lead misplacement has been less than 1% with it, which has led to good clinical outcomes.

As others have observed, loss of system efficacy occurs over time in progressive disease, most noticeably in ET and parkinsonian tremor, even when good control is obtained without side effects. We observed this phenomenon in 19 patients in this series. Given the long study period of 9 years, we can reliably estimate that most patients who became dissatisfied with the effectiveness of their DBS system did return to the implant surgeon (R.K.S.) for revision.

Limitations of this study include the fact that we focused only on complications of the DBS surgery itself to better characterize various procedural risks and their avoidance and that we did not concentrate on the efficacy of the DBS system for individual patient motor function, for example, by using motor disease scales, but instead looked at the series of patients as a whole. However, as evidenced by patients returning for revision more than 10 years from the initial implant (before 2002), we did have long-term follow-up data on patients who became dissatisfied with the loss of system effectiveness over time.

It is possible that we underestimated the number of complications sustained over the 9-year study period. We only included in the study those patients who had returned to the neurosurgery clinic for reevaluation and did not analyze quantification of the efficacy of stimulation or the effects or side effects of programming. Nonetheless, we believe that all complications that may have been presented back to the neurologist—that is, those that may have been significant, sustained, and/or surgery related—would have been referred back to the implanting surgeon for evaluation. Some patients were indeed lost to follow-up (approximately 15% of the 728), and we could not control for this aspect; therefore, some long-term complications may be incompletely identified. Note that because this study represents a large series treated by 1 primary implanting neurosurgeon, interoperator error is avoided, and the true procedural risk can be better quantified.

Conclusions

In this large series of consecutive DBS implantation procedures for patients with a variety of movement disorders, we concluded that the risk of intraoperative adverse events is low and that complications related to the implanted hardware are also acceptably low. In fact, long-term complications are low relative to the high rate of procedural efficacy. Intraventricular trajectories should be avoided if possible, given the increased risk of subsequent transient confusion, but are not associated with a significant risk of long-term sequelae.

Disclosure

Dr. Fenoy is a consultant for, and has received clinical or research support for the described study from, Medtronic.

Author contributions to the study and manuscript preparation include the following: Conception and design: Fenoy. Acquisition of data: both authors. Analysis and interpretation of data: Fenoy. Drafting the article: Fenoy. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Fenoy.
References
Management and avoidance of complications in DBS


Manuscript submitted June 11, 2013. Accepted October 7, 2013. Please include this information when citing this paper: published online November 15, 2013; DOI: 10.3171/2013.10.JNS131225. Address correspondence to: Albert J. Fenoy, M.D., Mischer Neuroscience Institute, Department of Neurosurgery, University of Texas Health Science Center at Houston, 6400 Fannin St., Ste. 2800, Houston, TX 77030. email: albert.j.fenoy@uth.tmc.edu.

J Neurosurg / Volume 120 / January 2014