Check for updates

Received: September 22, 2020 Revised: November 19, 2020 Accepted: December 21, 2020

(onlinelibrary.wiley.com) DOI: 10.1111/ner.13360

Surgical and Hardware Complications of Deep Brain Stimulation—A Single Surgeon Experience of 519 Cases Over 20 Years

Paresh K. Doshi, MCh; Neha Rai, MS; Deepak Das, MCh

ABSTRACT

Objective: Deep brain stimulation (DBS) surgery has its own set of risks and complications. This study from a single center and a single surgeon analyzes various risk factors for complications and tries to establish if there is a learning curve effect in minimizing the complications.

Materials and Methods: A retrospective analysis of 519 patients (1024 leads) who underwent DBS surgery and 232 patients who underwent implantable pulse generator replacement (IPG), by a single surgeon, between the years 1999 and 2019 was performed. Perioperative and hardware related complications were evaluated.

Results: The follow-up period ranged from six months to 20 years. Surgery-related complications occurred in 46 (8.9%) cases which included confusion in 31 (5.98%), intracerebral hemorrhage in 7 (1.3%), vasovagal attack in 3 (0.58%), respiratory distress in 2 (0.38%), postoperative aggressiveness in 1 (0.19%), and blepharospasm in 2 (0.38%) patients. Complications related to the DBS hardware were found in 35 cases, including erosion and infection in 22 (2.95%), inaccurate lead placement or migration in 6 (0.6%) lead fracture/extension wire failure in 2 (0.26%), IPG malfunction in 2 (0.26%), and hardware discomfort in 3 (0.4%) cases. In three patients, one lead was repositioned. In cases of infection, 87% of patients had either partial or complete removal of hardware. There was no mortality. The complications were analyzed for every 100 DBS procedures. There was a significant drop in the percentage of complications in from 23% in the first 100 cases to 7% in the last 100 cases ($p < 0.0001$).

Conclusion: Confusion remains the most frequent operative and perioperative complication. Erosion and infection of the surgical site represents the most frequent hardware complication. DBS surgery is safe and the complication rates are acceptably low. The complication rate also decreases with cumulative years of experience, demonstrating a learning curve effect.

Keywords: Complications, confusion, deep brain stimulation surgery, hardware complications, hemorrhage, infection

Conflict of Interest: The authors reported no conflict of interest.

INTRODUCTION

Deep brain stimulation (DBS) surgery was introduced by Benabid et al. in 1987 (1). Over the years, the therapy has expanded and its indications now include movement disorders, psychiatric disorders, pain, epilepsy, and so on (2). Though perceived to be safe and reversible, it has its own set of complications. There is no consensus on which factors are responsible for these complications and after how many surgeries the complication rate reduces substantially. We plan to answer these questions in this paper. The study analyzing the experience of a single surgeon and a single-center eliminates other variables like varying levels of expertise, techniques, equipment, etc., which have a strong influence on complication rates. Univariate and multivariate analysis has been performed to identify factors increasing the risk of complication and to evaluate the impact of experience in their reduction. It is for the first time that we have been able to document the number of surgeries that are required to significantly reduce the complication rate. This has wide and far-reaching implications. It would help in identifying the centers of excellence and training. DBS indications are rapidly evolving and it is important that the newer indications be first explored by centers of excellence, again this number can be helpful in identifying such centers.

MATERIALS AND METHODS

A retrospective study was conducted, at Jaslok Hospital and Research Center, to determine the surgical and hardware-related complications in DBS surgery and correlating the risk factors associated with such complications. A retrospective study was designed as we wanted to evaluate factors over a larger sample

Address correspondence to: Paresh K. Doshi, MCh, Department of Neurosurgery, Jaslok Hospital and Research Centre, 15, Dr G Deshmukh Marg, Mumbai, Maharastra 400026, India. Email: pareshkd@gmail.com

Department of Neurosurgery, Jaslok Hospital and Research Centre, Mumbai, Maharastra, India

Source(s) of financial support: No financial support was required for this project.

Table 1. Diagnoses of All Patients and Targets of Implantation.

Types of diseases	Types of target	No. of cases bilateral	No. of cases unilateral	Surgery abandoned	No. of leads
PD	STN	432	3	2	867
PD	GPi	20			40
Primary and secondary dystonia	GPi	16	3		35
Myoclonic dystonia	GPi	2			4
Choreoathetosis	GPi	3			6
Neuroacanthocytosis	GPi	2			4
NBIA	GPi	4			8
Tourette syndrome	GPi	2			4
PSP	PPN	10			20
OCD	Nucleus accumbens	2			4
OCD, autism	Nucleus accumbens	1			2
PVS	CMPf nucleus	2			4
Depression	Subgenual cingulate gyrus	3			6
ET	VIM	6	1	1	13
Multiple sclerosis tremors	VIM	1			2
Poststroke tremor	VIM		1		1
Cerebellar outflow tremor	VIM and CZI	1			2
SCA12	CZI	1			2
	Total	**508**	**8**	**3**	1024

CMP Nucl, centromedian parafascicular (CMPf) complex nucleus; CP, cerebral palsy; CZI, caudal zona incerta; GPi, globus pallidus pars interna; HIE, hypoxic ischemic encephalopathy; NA, nucleus accumbens; PKAN2, pantothenate kinase-associated neurodegeneration 2; PPN, pedunculopontine nucleus; SGCG, subgenual cingulate gyrus; STN, subthalamic nucleus; VIM, ventral intermediate nucleus of thalamus.

size and time frame. Moreover, retrospective study was possible as the clinical data of the patients who underwent DBS surgery were documented in their respective medical records (patient files). Approval from institutional review board of Jaslok Hospital and Research Centre was taken before the start of the study.

Patients who underwent DBS surgery at Jaslok Hospital and Research Center, Mumbai, India over the past 20 years, from year 1999 to 2019, were included in this study. Patients with movement disorders were evaluated by a multidisciplinary team of movement disorder specialist neurologist, neurosurgeon, psychologist, and patient counselor. When needed additional help from Psychiatrist and urologist was also sought. For other indications, appropriate multidisciplinary teams were involved. Most of the members of these team had not changed during these period, enabling them to develop a collective expertise. All cases confirmed to the prevalent consensus guidelines for selection for that disease. The study includes patients who underwent DBS surgery and had a six-month follow-up. Five hundred and nineteen patients who fulfilled the inclusion criteria were included in the study. All patients undergoing implantable pulse generator (IPG) replacements were also included in this study. The operational definition of perioperative period is first 30 days including the day of surgery and follow-up period is the period subsequent to the perioperative period. The clinical outcomes of these patients were along the line of the published literature and have also been reported by the author (3–7).

The medical records of all these 519 patients, who fulfilled the inclusion criteria, were reviewed. The clinical notes, discharge summary, and follow-up notes were reviewed manually to identify the complications.

Surgical Procedure

The detailed surgical procedure has been described previously (3). We will describe some salient points that may have some bearing on the complications. All the surgeries were performed in two stages, stage 1: simultaneous bilateral implantation of electrodes (except in unilateral cases) under local anesthesia and stage 2: implantation of IPG on day 2 under general anesthesia. Complete head shaving was mandatory for every patient. A stereotactic frame with a detachable front piece, for emergency airway access, was used for the surgery. The scalp incision involved a C-shaped flap to avoid the suture line crossing the burr hole. Dura was not opened and only pierced by the microelectrode recording (MER) canula. All movement disorders patients underwent MER recording and the number of passes ranged from two to five with the most common being three passes per side. Trajectories were planned through a precoronal burr hole, avoiding the F1-F2 sulcus and at least 2 mm away from the lateral border of the ventricle. For the Medtronic system, we used the regular plastic burr hole cap to anchor the DBS lead, whereas for other systems, we used the burr hole fixation device supplied by the manufacturer. Each patient underwent a postoperative computerized tomography (CT) scan to look for any hemorrhage and identify the lead position. The postoperative CT scan was fused with the planning sequences to correctly identify the lead position. IPG implantation was done in the left infraclavicular region by a horizontal incision, ensuring a minimum of 2 cm size of subcutaneous pad of fat. Intravenous antibiotics, cefuroxime, and netilmicin were given intraoperatively and for two doses after surgery. Thereafter, oral cefixime was administered until suture removal. Patients were kept in hospital until suture removal and during this time DBS was programmed. The DBS devices implanted were primarily of Medtronic, followed by Boston Scientific and few from St. Jude Medical Neuromodulation. Programming-related symptoms were excluded.

Statistical Methods

The data were analyzed using SPSS software. The variables were categorical, unpaired, and dichotomous. Hence, the

Table 2. Comparison of Different Complications Among Different Studies.

Studies	No. of patients (leads)	Confusion (total) (% of patients)	Vasovagal attack (total) (% of patients)	Intracerebral + intraventricular hemorrhage (total) (% of patients) (% of leads)	Erosion and infection (total) (% of patients) (% of total procedure)	Inaccurate lead placement/ migration (total) (% of patients) (% of leads)[§]	Extension wire failure/lead fracture (total) (% of patients) (% of leads)	Malfunction of IPG (total) (% of patients) (% of IPGs)	IPG discomfort /flipped IPG (total) (% of IPGs)
Fenoy and Simpson (9)	728 (1365[*])	14 (1.9%)	6 (0.8%)	37 (5%) (2.71%)	29 (3.9%)	13 (1.7%) (0.95%)	13 (0.95%) (1.7%)	1 (0.13%) (0.05%)	8 (0.43%)
Carvallo et al. (10)	512 (856)	NS	NS	NS	10 (1.9%)	19 (3.7%) (2.21%)	13 (2.5%) (1.5%)	NS	NS
Sorar et al. (11)	181 (359)	12 (6.6%)	NR	5 (2.7%)	13 (7.18%)	2 (1.1%) (0.5%)	8 (4.4%) (2.2%)	NS	NS
Doshi (8)	153 (298)	6 (3.9%)	3 (1.9%)	2 (1.3%) (0.6%)	7 (4.5%) (2.7%[†])	4 (2.5%) (1.3%)	NR	2 (1.4%) (0.9%[†])	NR
Zhang et al. (12) [*]	478	NS	NS	NS	20 (4.1%)	NS	1 (0.2%)	1 (0.2%)	-
Bhatia et al. (13)	191 (330)	NS	NS	7 (3.6%) (2.1%)	28 (14.6%)	-	-	-	-
Voges et al. (14)	262 (472)	NS	NS	1 (0.3%) (0.2%)	15 (5.7%)	2.8%	2.8%	NR	6.7%
Abode-Iyamah et al. (15)	242 (464)	-	-	-	25 (9.5%) (10.2%)	-	-	-	-
Patel et al. (16)	510 (1020)	18 (3.53%)	NS	24 (4.7%)	18 (3.52%)	-	2 (0.39%)	-	4 (0.78%)
This series	**519 (1023)**	**31 (5.9%)**	**3 (0.5%)**	**7 (1.3%) (0.6%)**	**22 (4.2%) (2.9%[‡])**	**6 (1.15%) (0.6%)**	**2 (0.4%) (0.2%)**	**2 (0.4%) (0.3%[‡])**	**3 (0.4%)**
Falowski et al. (17)	432 (1077)	NS	NS	11 (2.5%)	5 (3.4%) (1.4%)	NS	34 (6.8%)	NS	

[*]Includes 32 lead revisions and/or replacements.
[†]Includes 54 additional procedure of IPG replacement.
[‡]Includes 232 additional procedure of IPG replacement.
[§]Lead and extension considered as one unit.
NR, not reported; NS, not studied.

Table 3. Logistic Regression Model-Confusion.

Variable	Odds ratio	95% CI	*p* value
Age			
15–65	Reference		
>65	2.70	0.98–7.41	0.054
Gender			
Female	Reference		
Male	0.54	0.21–1.40	0.20
Duration			
0–9	Reference		
≥10	1.09	0.42–2.82	0.86
MMSE			
0–25	Reference		
>25	0.28	0.09–0.84	0.024
MER			
0–5	Reference		
≥6	1.84	0.67–5.07	0.24
Target			
GPi	Reference		
STN	0.12	0.02–0.65	0.014

proportions in the given group of patients was done using chi-square test or Fisher's exact test for low expected cell counts. Also, for predicting the dependent variable from the independent variable, logistic regression was used for multivariate analysis. We estimated the odds ratios (OR) and their 95% confidence intervals (CIs) for these variables. The factors included in the model were age, sex, duration of disease, MER trajectories, target, and mini-mental scale evaluations (MMSE). A *p* value of <0.05 was considered to be statistically significant.

RESULTS

Demographic Data

Between 1999 and 2019, 519 patients underwent DBS surgery, involving 1024 lead implantations. IPG replacement was performed in 232 patients during this period, with a total of 748 IPGs implanted (surgery was abandoned in three cases). Of these, 508 patients underwent bilateral surgery, eight patients underwent unilateral surgery and surgery was abandoned in three cases. One cerebellar outflow tremor patient received two electrodes (VIM + CZI) on one side. DBS leads were not externalized in any patients. Patient age ranged from 7 to 85 years. Three patients were under the age of 10 and 120 (23.16%) patients were above 65 years. 67.7% patients were male. The maximum follow-up period was 20 years. The breakdown of indications is provided in Table 1. We have a low number of patients with essential tremors (ET), which could be due to cultural reasons, affordability, acceptance of tremor disability, and hesitancy in referral by neurologist. Similarly, we have an unusually large series of PPN stimulation, as based on our work, we had been the only center offering pedunculopontine (PPN) stimulation for progressive supranuclear palsy (8).

Complications were divided into two categories—1) perioperative complications: for example, confusion, vasovagal attack, respiratory distress, intracerebral hemorrhage (ICH), aggressiveness, and blepharospasm and 2) hardware-related complications: for example, lead misplacement, extension wire failure, erosion and infection (infections in perioperative period were also included together for ease of analysis), malfunction of IPG, and hardware discomfort.

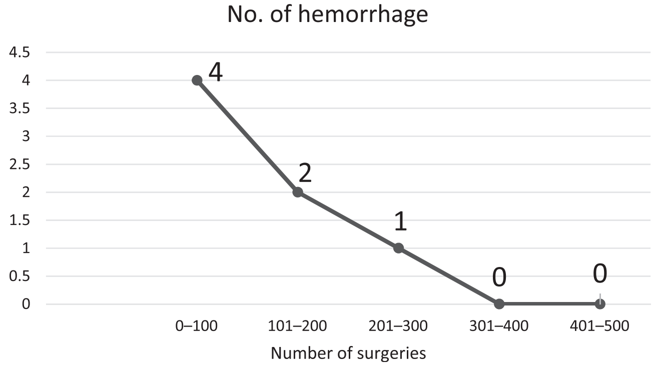

Figure 1. Surgical experience and incidence of hemorrhage.

Perioperative Complications

Confusion

Confusion was the most common perioperative complication, it occurred in 31 patients (5.98%) (Table 2). Confusion was found only in Parkinson's disease patients. In most of the patients, it continued up to one to five days after lead insertion, except in one case, in which it lasted for one week. It was less common in subthalamic nucleus (STN) DBS (25/437 cases) than Globus pallidus pars interna (GPi) DBS (6/20 cases). The intensity of confusion varied from minimal to marked disorientation, with associated incontinence in two cases. IPG insertion was done after the confusion phase was over. Surgery had to be abandoned in one patient as he aspirated during surgery due to severe confusion. The proportion of confusion was significantly higher in those above the age of 65 years (19 cases) as compared with those up to 65 years (13% vs. 5%; p = 0.003). Similarly, the proportion of confusion was significantly higher in patients undergoing GPi DBS (6/20 cases) as compared with STN DBS (25/437) ($p < 0.001$).

Multivariate analysis was performed to correlate various factors like age, sex, duration of disease, MER trajectories, target, and MMSE. In the multivariate analysis, we found that confusion was less likely in those with MMSE scores of more than 25 (OR = 0.28, 95% CI = 0.09–0.84; p = 0.024) and those with STN target (OR = 0.12, 95% CI = 0.02–0.65; p = 0.014) (Table 3). Age did not reach level of significance in multivariate analysis.

Intracerebral Hemorrhage

The next common perioperative complication was ICH which was observed in seven patients (Table 2). Out of seven cases, two patients were asymptomatic. A small amount of bleeding along the MER tract was found on routine postoperative scan. In two patients, procedure had to be abandoned due to hemorrhage as they developed hemiparesis. The CT scan showed small hematoma along MER tract. Another two patients developed hemorrhage at the lead contact point, with development of hemiparesis on one side, which recovered over a period of time. One more patient had a prosthetic cardiac valve and we had to start the anticoagulant after fifth postoperative day, following which he developed hemorrhage. He was left with a residual hemiparesis.

Various factors like age, sex, MMSE evaluations, MER trajectories, and target were analyzed for the cause of hemorrhage. MER trajectory more than two per side was associated with increased

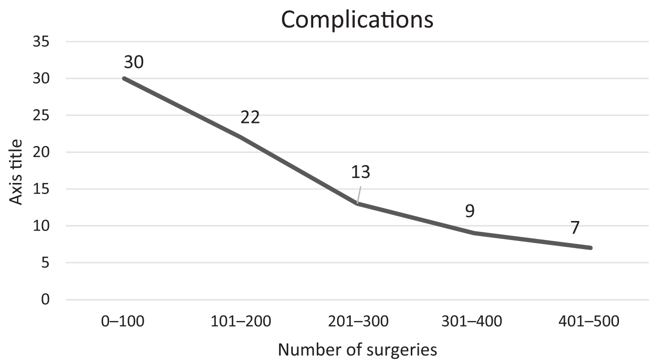

Figure 2. Relationship of complications to number of surgeries.

risk of hemorrhage ($p < 0.001$). We also analyzed occurrence of hemorrhage during different cohorts of 100 surgeries (Fig. 1). It was found that the incidence decreased as the experience improved and in last 200+ surgeries there was not a single incidence of hemorrhage.

Vasovagal Attack

Vasovagal syncope was observed in three patients. The episode of syncope was transient in all and manifested as loss of consciousness with fall in blood pressure. The episodes occurred during the time of frame fixation. All the patients recovered within few minutes and surgical procedures continued without any further difficulties.

Respiratory Distress

Respiratory distress occurred in two patients during surgery. In one patient, it was transient and surgery proceeded as usual. Another patient had developed acute stridor after unilateral lead placement leading to postponement of surgery on the other side, which was completed after two weeks.

Table 4. Logistic Regression Model-All Complications.

Variable	Odds ratio	95% CI	*p* value
Age			
15–65	Reference		
>65	1.56	0.82–2.95	0.17
Gender			
Female	Reference		
Male	0.94	0.52–1.73	0.85
Duration			
0–9	Reference		
≥10	1.01	0.57–1.79	0.98
MMSE			
0–25	Reference		
>25	0.68	0.30–1.51	0.34
MER			
0–5	Reference		
≥6	1.84	1.04–3.27	0.038
Target			
GPi	Reference		
STN	0.66	0.26–1.68	0.38

Aggressiveness

One patient developed undue aggressiveness after bilateral lead insertion. His aggressiveness was managed with subsequent programming and psychiatric medications.

Blepharospasm

Severe blepharospasm was observed in two patients after surgery and it continued for three to five days postoperatively. The patients remained sleepy during this period but subsequently recovered and improved by programming.

Hardware Complications

Inaccurate Lead Placement/Migration

Leads positioning was inaccurate in six patients including five cases of STN stimulation for Parkinson's disease (PD) and one case of GPi stimulation for Dystonia. Lead migration was not reported in the series.

Out of five cases of STN stimulation, marked intraoperative confusion led to difficulty in accurate neurophysiological exploration of target in three cases, brain shift due to pneumocephalus in one case and in one case exact cause of inaccurate positioning could not be recognized. However, in all five cases, the misplacement was only less than 2 mm in anteroposterior and lateral directions, leading to suboptimal response and/or limited threshold to stimulation for side-effects. Two patients agreed to repositioning the leads but the other three wanted to manage without changing the electrodes.

In one case of dystonia, the lead fell short of target by around 3–4 mm along the intended tract due to constant head and neck movement throughout the procedure which was readily recognized in postop CT scan. The lead was repositioned to the intended target on the next day under image intensifier guidance.

Infection and Erosion

Infection alone and/or erosion involving DBS hardware was observed in 22 (2.95%) cases (Table 2). In three cases, there was only infection without erosion which was controlled with antibiotics. The remaining 19 cases had variable levels of infections, ranging from simple skin erosion, skin erosion, and granulation tissue or florid infection with pus discharge. Full system explantation was done in nine patients, partial explantation of hardware (lead and connecting wire) was done in five patients, and IPG was explanted in five patients. Two of the patients whose full system was explanted chose to undergo a repeat surgery and they were reimplanted.

Lead Fracture/Extension Wire Failure

In two patients with PD, the lead fracture/extension wire failure was suspected when during reprogramming we found very high impedance in one of the leads. We found that the extension wires had partially broken leading to high impedance. Normalcy was restored following replacement of the extension wires.

Malfunction of IPG

IPG malfunction was diagnosed when we were not able to interrogate the IPG. It was seen in two patients, one year after DBS surgery. On inquiring, it was revealed that in one of the cases the IPG was reset by the patient himself and all efforts to reprogram it failed. In another case, no cause could be ascertained. The IPG had to be replaced in both these patients.

Table 5. Number of Surgeries to Develop Expertise.

Number of surgeries	Complication		Hemorrhage		Total
	No	Yes	No	Yes	
0–200	155	45	194	6	200
Percentage	77.5	22.5	96.5	3.5	100
>200	291	28	318	1	319
Percentage	91.19	8.81	99.69	0.31	100
Total	445	73	512	7	519
Percentage	85.91	14.09	98.46	1.54	100
		$p < 0.001$			$p = 0.004$

Hardware Discomfort

Three patients complained some form of hardware discomfort. It manifested by swelling at IPG site in two patients. In one patient, the swelling appeared on the next day of IPG insertion and on further examination, hematoma was found over the IPG. The hematoma was drained and bleeding point secured after exploration of the IPG site. In second patient, the swelling was gradual involving soft tissue above the IPG implantation site and no exact cause was found. In the third patient, we found skin reaction and irritation near the IPG implantation site which was treated appropriately.

Learning Curve

We looked at the data to determine if there was a learning curve effect in the reduction in the complications. Data were evaluated for overall complications and also for hemorrhage, as these two are the most important concerns in DBS surgery. The data were divided in to two sets, one 1–200 and the second, 201 onward. We found that there was a significant reduction, from 3.5% to 0.31%, in the risk of hemorrhage, between these two sets ($p = 0.004$) and the rate of complication was similarly reduced from 22.5% to 8.8% ($p < 0.001$) (Table 5). An almost linear trend was found with the reduction in the number of hemorrhage and confusion as the number of surgeries increased (Figs. 1 and 2).

DISCUSSION

The applications of DBS surgery are rapidly expanding as it is perceived to be safe and reversible. However, it does carry risk of complications. There are very few literature reports of large series of DBS conducted by a single surgeon (9,11–15,17,18). This series has one of the largest number of patients operated by a single surgeon, followed up and analyzed over two decades.

Complications are reported differently in different series, making it difficult to compare total complications across centers (19). The details of our observed complications along with those from other representative large series are presented (Table 2). We found, on multivariate logistic regression model analysis, that the number of MER trajectories > 5 (total for both sides) correlated with increased rate of complication (Table 4). MER and number of MER trajectories have been attributed to increased incidence of complications in various reports; mainly hemorrhage (20,21), whereas others have not found any association (22). Other factors, such as age, target, or duration of disease which were found to be risk factors in some studies, had no influence in our univariate or multivariate analysis. We found that complications reduce over time as the experience of the team increases (Table 5). Only few people have made such observations, but they either did not consider all complications or did not recommend a minimum number of surgeries to obtain reduction in complications (11). Eskandar and Kalakoti, in two studies from United States which evaluated the complications of DBS across all the centers in the country, at two different time frames, found that centers with a higher volume of cases (23,24) and surgeons with increased experience (24) had significant reduction in the number of complications. Kalakoti et al. arbitrarily defined the high volume centers as those performing >45 DBS/year with an experience of >450 DBS procedures (23). Eskandar defined experience as number of surgeries performed by an individual surgeon. Surgeons performing between one and nine surgeries per year were in quartile 1 as compared to those performing more than 21 surgeries per year in quartile 4. Falowski et al. attributed changes in surgical technique and improved hardware to reduction in complications (17). Bhatia et al. found that increasing years of experience, better patient selection, and improved hardware designs helped reduce complications (13). Guidelines by European Society for Stereotactic and Functional Neurosurgery suggest that a center should have had an experience of 200 surgeries and routinely performing 20 procedures/year to effectively train neurosurgeons (25). As observed, though there are some suggestions that the experience helps in reducing the rate of complication, none of the studies above were based on a single institute's and single surgeon's experience. In light of that, this is the first time we have been able to demonstrate statistically that the experience of the team, over and above all the factors, is responsible for a reduction in complications. We found that our complication rate reduced significantly after 200 surgeries (Table 5). Our observation of 200 cases being the inflection point for significantly reducing the surgical complications is partly in line with the proposed guidelines by the European Society for Stereotactic and Functional Neurosurgery (25). This can have a bearing for future accreditation of a center for training and also continued mentorship for upcoming centers.

Confusion was the most common (5.98%) complication in our series. It has also been reported in various other studies and ranged from 4.7% to 27.7% (9,11,16,26). Hu et al. found, bilateral simultaneous implantation and Hoehn and Yahr stage above IV was associated with increased confusion, whereas age and number of MER trajectory had no influence (26). Confusion and behavioral problems are reported to occur more frequently in patients undergoing STN stimulation by some groups (27,28); however, others have not found significant difference (29,30). Ventricular wall transgression was found to be associated with increased confusion in some studies (9,31). In our series, there was not a single case with ventricular transgression of the lead. Age, longer disease duration, and perioperative delirium are some other factors reported to be associated with postoperative confusion/delirium (32,33). Fenoy et al. reported at least 25% of the patients who had STN as a target had ventricular penetration. Further, each of the ten patients with STN as target and confusion had ventricular penetration. (9) In our series, confusion was observed only in PD patients. MMSE was used as a screening tool for cognitive changes and routine neuropsychology was not performed in all patients. Confusion had no correlation with duration of disease or number of MER trajectories. As we had chosen to offer DBS to some patients with <25 MMSE, we found that they did have an increased rate of confusion (20% with MMSE ≤ 25 vs. 4% with MMSE 26 and above). Patients below 66 years had decreased confusion in univariate analysis ($p = 0.003$), but was slightly above the threshold of significance in multivariate analysis. Confusion was found to be higher in GPi than in STN as a target (Table 3). This was a surprise to us as we had believed that GPi DBS had lower incidence of behavioral changes in postoperative period. Due to this impression, we had offered GPi DBS to elderly and patients with lower cognitive function. We tried to analyze the subgroup by target and preoperative MMSE scores, to see if this was due to any selection bias (GPi DBS being offered to lower MMSE patients). We found that though the confusion was similar in patients with MMSE above 25, it was observed more frequently ($p = 0.04$) in patients undergoing GPi stimulation, even in this subgroup analysis. Thus GPi, as a target for PD, has been associated with increased rate of confusion, in our series.

ICH is the most dreaded of all the complications in DBS surgery. The incidence of ICH has been relatively low, 1.3% per person and 0.93% per lead, in this series. This is considerably lower than the figure reported in literature (1.0–25%) (8,9,21,26,34,35). Large number of ICH are asymptomatic or small enough not to require surgical intervention (9). Various factors have been linked with increased incidence of ICH. The two most common factors are ventricular transgression and number of MER trajectories. Falowski et al. found the risk of hemorrhage is 2.9 times more in patients having more than one MER trajectory (17). Other study found that patients without hemorrhage had mean of 2.9 ± 1.8 passes as compared with 4.1 ± 2.0 passes in those who had hemorrhage (21). Number of MER trajectory was the only factor that could be correlated with the risk of hemorrhage, in our series. We usually use a minimum of two and maximum of five MER trajectory per side, the most common being three. Six out of seven hemorrhages had occurred in patients with three or more passes per side. In this series, meticulous planning of the electrode trajectories, as described above, helped us to reduce this complication. The role of anesthetist is also vital in maintaining the mean arterial pressure below 100 mm Hg. All patients undergoing DBS had their antiplatelets stopped from four to seven days prior to surgery to five days after the DBS.

Vasovagal attack has been infrequently described during DBS (9,36). In our series, it manifested as transient loss of consciousness followed by fall in blood pressure during the stereotactic frame fixation. Careful preparation of the patient and frame fixation in OR with a secure IV access and hydration are some of the measures that have been incorporated to reduce their occurrence. We have not had any vasovagal episode in last 300+ cases.

Risks of hardware complications cannot be dissociated from DBS. They are the major cause of morbidity, repeated surgical procedures, and high cost of DBS surgery (23,37). Various series and databases reported hardware-related complications to be in the range of 5.4–25.3% (10,19,37–39). In our series, 34 out of 519 (6.5%) patients had suffered from some form of hardware-related complications.

Infection is the most common hardware complication and it occurs from 1.2% to 14.7% across several series (Table 2). In our series, IPG pocket (2.27%), followed by the scalp (1.35%) and extension wire (0.67%) behind the ear, were the common sites of infection. The occurrence of this ranged from two weeks postoperatively to seven years. Some series have found that diabetes mellitus, anemia, poor nutrition, smoking, thickness of scalp and chest wound, and so on have been attributed to increased infection (13,40) whereas others have not (14,22,41,42). Constantoyannis et al. compared overall infection rate and types of scalp incision, that is, straight-parasagittal incision versus curvilinear incision and demonstrated a statistically significant sixfold increase in the rate of infection following a straight scalp incision (39). In all of our cases, we have used either bilateral C-shaped scalp incision or a single bi-coronal scalp incision accommodating both side burr holes. Nonadherence in maintaining proper hygiene and self-care also contributes to higher risk of infection (43) as evidenced in some patients in this series with dystonia. Another patient with Tourette syndrome (TS) constantly had a tendency to scratch his wound over the implantation site which ultimately gave rise to nonhealing ulcer with exposure of the hardware leading to complete explantation of his DBS system. Servello et al. reported a statistically significant correlation between the TS subgroup and infections along the DBS hardware (44).

Management of hardware-related infections differs among different centers. In our center, we treat infection aggressively at the first sign of inflammation. We completely or partially explanted device in 87% of cases, as we feel that once any pus formation occurs, it is in the best interest to explant the device, let the wound heal and implant it at a different site. This also has been the observation by other groups (15,22).

Inaccurate lead placement was the second most common hardware-related complication, reported in 6 (1.15%) of the patients in this series. This incidence is very low as compared to several other centers. We attribute this to careful preoperative preparation of the patient to ensure good cooperation (as majority of our misplaced leads were due to intraoperative confusion) and strict adherence of surgical protocol. Intraoperative pneumocephalus, brain shift, movement of the lead due to improper fixation, and lack of availability of C-arm imaging are some of the causes of misplaced leads reported in various reported series (8). We have used various fixation devices in our practice and had not had a single case of lead migration. Inaccurate placement is reduced by using more than one MER trajectory (the other trajectory works as an anchor, while the MER electrode is replaced with lead). Morishita et al. found excessive tension applied to the lead at the time of its connection to the IPG, repetitive head movements due to dystonia and Twiddler's syndrome were some of the risk factors associated with DBS lead migration (45). Trauma is the other cause that has been associated with lead migration (12).

Lead fracture/extension wire failure was observed in 2 (0.26%) patient in this series. Among different reported series, the incidence of electrode fracture or failure ranges from 0.2% to 9.3%% (Table 2). Careful handling of the extension wire, its connections, and providing a little laxity for the freedom of movement are some of the strategies that have helped us reduce the incidence of this complication.

Other hardware complications were infrequent occurrences and hence have not been discussed.

CONCLUSION

As the availability and indications of the DBS surgery expand, the need to identify and understand risk factors for complications becomes more important. Improved surgical techniques using advanced technologies and better understanding of the risk factors would help reduce complications. In addition, this study reaffirms the role of the cumulative experience of an individual center (and surgeon) and a multidisciplinary team, working together over a period, in reducing the rate of complications.

Acknowledgement

We would like to thank Jaslok Hospital and Research center for supporting our work, Ms. Bharati Karkera for records keeping, and Dr. Maninder Setia for his help in statistical analysis.

Authorship Statement

Dr. Doshi designed and conducted the study; all the authors collected the data and helped in analysis; Dr. Das contributed the first draft; all the authors reviewed and edited the manuscript, and approved the final manuscript. All the authors had complete access to the study data.

How to Cite this Article:

Doshi P.K., Rai N., Das D. 2021. Surgical and Hardware Complications of Deep Brain Stimulation—A Single Surgeon Experience of 519 Cases Over 20 Years. Neuromodulation 2021; E-pub ahead of print. DOI:10.1111/ner.13360

REFERENCES

1. Benabid AL, Pollak P, Louveau A, Henry S, de Rougemont J. Combined (thalamotomy and stimulation) stereotactic surgery of the VIM thalamic nucleus for bilateral Parkinson disease. *Appl Neurophysiol* 1987;50:344–346.
2. Doshi PK. Expanding indications for deep brain stimulation. *Neurol India* 2018;66:S102–S112.
3. Doshi PK, Chhaya NA, Bhatt MA. Bilateral subthalamic nucleus stimulation for Parkinson's disease. *Neurol India* 2003;51:43–48.
4. Vats A, Amit A, Doshi P. A comparative study of bilateral subthalamic nucleus DBS in Parkinson's disease in young versus old: a single institutional study. *J Clin Neurosci* 2019;70:85–91.
5. Sathe KP, Hegde AU, Doshi PK. Deep brain stimulation improves quality of life in pantothenate kinase-associated neurodegeneration. *J Pediatr Neurosci* 2013;8:46–48.
6. Doshi PK, Desai JD, Karkera B, Wadia PM. Bilateral pedunculopontine nucleus stimulation for progressive supranuclear palsy. *Stereotact Funct Neurosurg* 2015;93:59–65.
7. Doshi PK, Ramdasi R, Thorve S. Deep brain stimulation of anteromedial globus pallidus internus for severe Tourette syndrome. *Indian J Psychiatry* 2018;60:138–140.
8. Doshi PK. Long-term surgical and hardware-related complications of deep brain stimulation. *Stereotact Funct Neurosurg* 2011;89:89–95.
9. Fenoy AJ, Simpson RK Jr. Risks of common complications in deep brain stimulation surgery: management and avoidance. *J Neurosurg* 2014;120:132–139.
10. Baizabal Carvallo JF, Mostile G, Almaguer M, Davidson A, Simpson R, Jankovic J. Deep brain stimulation hardware complications in patients with movement disorders: risk factors and clinical correlations. *Stereotact Funct Neurosurg* 2012;90:300–306.
11. Sorar M, Hanalioglu S, Kocer B, Eser MT, Comoglu SS, Kertmen H. Experience reduces surgical and hardware-related complications of deep brain stimulation surgery: a single-center study of 181 patients operated in six years. *Parkinsons Dis* 2018;2018:3056018.
12. Zhang J, Wang T, Zhang CC et al. The safety issues and hardware-related complications of deep brain stimulation therapy: a single-center retrospective analysis of 478 patients with Parkinson's disease. *Clin Interv Aging* 2017;12:923–928.
13. Bhatia S, Oh M, Whiting T, Quigley M, Whiting D. Surgical complications of deep brain stimulation. A longitudinal single surgeon, single institution study. *Stereotact Funct Neurosurg* 2008;86:367–372.
14. Voges J, Waerzeggers Y, Maarouf M et al. Deep-brain stimulation: long-term analysis of complications caused by hardware and surgery–experiences from a single centre. *J Neurol Neurosurg Psychiatry* 2006;77:868–872.
15. Abode-Iyamah KO, Chiang HY, Woodroffe RW et al. Deep brain stimulation hardware-related infections: 10-year experience at a single institution. *J Neurosurg* 2019;130:629–638.
16. Patel DM, Walker HC, Brooks R, Omar N, Ditty B, Guthrie BL. Adverse events associated with deep brain stimulation for movement disorders: analysis of 510 consecutive cases. *Neurosurgery* 2015;11:190–199.
17. Falowski SM, Ooi YC, Bakay RA. Long-term evaluation of changes in operative technique and hardware-related complications with deep brain stimulation. *Neuromodulation* 2015;18:670–677.
18. Frizon LA, Hogue O, Wathen C et al. Subsequent pulse generator replacement surgery does not increase the infection rate in patients with deep brain stimulator systems: a review of 1537 unique implants at a single center. *Neuromodulation* 2017;20:444–449.
19. Videnovic A, Metman LV. Deep brain stimulation for Parkinson's disease: prevalence of adverse events and need for standardized reporting. *Mov Disord* 2008;23:343–349.
20. Alkhani A, Lozano AM. Pallidotomy for parkinson disease: a review of contemporary literature. *J Neurosurg* 2001;94:43–49.
21. Deep-Brain Stimulation for Parkinson's Disease Study Group, Obeso JA, Olanow CW et al. Deep-brain stimulation of the subthalamic nucleus or the pars interna of the globus pallidus in Parkinson's disease. *N Engl J Med* 2001;345:956–963.
22. Bjerknes S, Toft M, Konglund AE et al. Multiple microelectrode recordings in STN-DBS surgery for Parkinson's disease: a randomized study. *Mov Disord Clin Pract* 2018;5:296–305.
23. Kalakoti P, Ahmed O, Bollam P, Missios S, Wilden J, Nanda A. Predictors of unfavorable outcomes following deep brain stimulation for movement disorders and the effect of hospital case volume on outcomes: an analysis of 33, 642 patients across 234 US hospitals using the national (nationwide) inpatient sample from 2002 to 2011. *Neurosurg Focus* 2015;38:E4.
24. Eskandar EN, Flaherty A, Cosgrove GR, Shinobu LA, Barker FG 2nd. Surgery for Parkinson disease in the United States, 1996 to 2000: practice patterns, short-term outcomes, and hospital charges in a nationwide sample. *J Neurosurg* 2003;99:863–871.
25. Krauss JK, Broggi B, Reulen HJ et al. Training chart in movement disorders surgery added competence: as approved by the ESSFN and UEMS Section of Neurosurgery (March 2009). *Acta Neurochir* 2009;151:1505–1509.
26. Hu X, Jiang X, Zhou X et al. Avoidance and management of surgical and hardware-related complications of deep brain stimulation. *Stereotact Funct Neurosurg* 2010;88:296–303.
27. Anderson VC, Burchiel KJ, Hogarth P, Favre J, Hammerstad JP. Pallidal vs subthalamic nucleus deep brain stimulation in Parkinson disease. *Arch Neurol* 2005;62:554–560.
28. Smeding HM, Speelman JD, Koning-Haanstra M et al. Neuropsychological effects of bilateral STN stimulation in Parkinson disease: a controlled study. *Neurology* 2006;66:1830–1836.
29. Odekerken VJ, van Laar T, Staal MJ et al. Subthalamic nucleus versus globus pallidus bilateral deep brain stimulation for advanced Parkinson's disease (NSTAPS study): a randomised controlled trial. *Lancet Neurol* 2013;12:37–44.
30. Follett KA, Weaver FM, Stern M et al. Pallidal versus subthalamic deep-brain stimulation for Parkinson's disease. *N Engl J Med* 2010;362:2077–2091.
31. Gologorsky Y, Ben-Haim S, Moshier EL et al. Transgressing the ventricular wall during subthalamic deep brain stimulation surgery for Parkinson disease increases the risk of adverse neurological sequelae. *Neurosurgery* 2011;69:294–299.
32. Paim Strapasson AC, Martins Antunes AC, Petry Oppitz P, Dalsin M, de Mello Rieder CR. Postoperative confusion in patients with Parkinson disease undergoing deep brain stimulation of the subthalamic nucleus. *World Neurosurg* 2019;125:e966–e971.
33. Carlson JD, Neumiller JJ, Swain LD, Mark J, McLeod P, Hirschauer J. Postoperative delirium in Parkinson's disease patients following deep brain stimulation surgery. *J Clin Neurosci* 2014;21:1192–1195.
34. Krack P, Batir A, Van Blercom N et al. Five-year follow-up of bilateral stimulation of the subthalamic nucleus in advanced Parkinson's disease. *N Engl J Med* 2003;349:1925–1934.
35. Goodman RR, Kim B, McClelland S 3rd et al. Operative techniques and morbidity with subthalamic nucleus deep brain stimulation in 100 consecutive patients with advanced Parkinson's disease. *J Neurol Neurosurg Psychiatry* 2006;77:12–17.
36. Kenney C, Simpson R, Hunter C et al. Short-term and long-term safety of deep brain stimulation in the treatment of movement disorders. *J Neurosurg* 2007;106:621–625.
37. Jitkritsadakul O, Bhidayasiri R, Kalia SK, Hodaie M, Lozano AM, Fasano A. Systematic review of hardware-related complications of deep brain stimulation: do new indications pose an increased risk? *Brain Stimul* 2017;10:967–976.
38. Oh MY, Abosch A, Kim SH, Lang AE, Lozano AM. Long-term hardware-related complications of deep brain stimulation. *Neurosurgery* 2002;50:1268–1274.

39. Constantoyannis C, Berk C, Honey CR, Mendez I, Brownstone RM. Reducing hardware-related complications of deep brain stimulation. *Can J Neurol Sci* 2005; 32:194–200.
40. Brandmeir N, Nehrbass E, McInerney J. An analysis of scalp thickness and other novel risk factors for deep brain stimulator infections. *Cureus* 2016;8:e792.
41. Boviatsis EJ, Stavrinou LC, Themistocleous M, Kouyialis AT, Sakas DE. Surgical and hardware complications of deep brain stimulation. A seven-year experience and review of the literature. *Acta Neurochir* 2010;152:2053–2062.
42. Sillay KA, Larson PS, Starr PA. Deep brain stimulator hardware-related infections: incidence and management in a large series. *Neurosurgery* 2008;62:360–366.
43. Pepper J, Zrinzo L, Mirza B, Foltynie T, Limousin P, Hariz M. The risk of hardware infection in deep brain stimulation surgery is greater at impulse generator replacement than at the primary procedure. *Stereotact Funct Neurosurg* 2013;91:56–65.
44. Servello D, Sassi M, Gaeta M, Ricci C, Porta M. Tourette syndrome (TS) bears a higher rate of inflammatory complications at the implanted hardware in deep brain stimulation (DBS). *Acta Neurochir* 2011;153:629–632.
45. Morishita T, Hilliard JD, Okun MS et al. Postoperative lead migration in deep brain stimulation surgery: incidence, risk factors, and clinical impact. *PLoS One* 2017;12:e0183711.

COMMENTS

The paper confirms a common notion that experience makes a difference in terms of clinical outcomes. The meticulous attention to details, thoroughness of data collection and consistency with surgical protocols are indeed commendable – and I may only hope that the authors of this paper continue to observe the same improvement curve in the future, ultimately reducing the complication rate to zero.

Konstantin Slavin, MD
Chicago, IL USA

***

This single-center DBS case series, demonstrates, as expected, that complication rates decrease as experience increases. I will note that some of the authors' claims as to complication reduction, namely the importance of the anesthetist in maintaining appropriate blood pressure and the meticulous trajectory planning, make sense, but are not backed up by clear evidence in the paper. Nonetheless, two decades of experience is a worthwhile addition to the literature.

Alon Mogilner, MD, PhD
Great Neck, NY USA

