The natural history of Parkinson’s disease (PD) has been well studied. In addition to the well-known motor symptoms such as rigidity, bradykinesia, and resting tremor, nonmotor symptoms such as dementia, sleep-wake dysregulation, and autonomic failure are major features of the illness. Several studies have found that patients with PD have a higher mortality than the age-matched population, approximately 44% after 9.4 years with the disease. The authors performed survival analyses using Kaplan-Meier estimation and multivariate regression using Cox proportional hazards modeling. Telephone surveys were used to determine long-term outcomes.

OBJECTIVE Deep brain stimulation (DBS) is an effective treatment for several movement disorders, including Parkinson’s disease (PD). While this treatment has been available for decades, studies on long-term patient outcomes have been limited. Here, the authors examined survival and long-term outcomes of PD patients treated with DBS.

METHODS The authors conducted a retrospective analysis using medical records of their patients to identify the first 400 consecutive patients who underwent DBS implantation at their institution from 1999 to 2007. The medical record was used to obtain baseline demographics and neurological status. The authors performed survival analyses using Kaplan-Meier survival analysis on a subset of patients with at least 10 years of follow-up (n = 200) revealed a survival probability of 51% (mean age at death 73 years). Using multivariate regression, the authors found that age at implantation (HR 1.02, p = 0.01) and male sex (HR 1.42, p = 0.02) were predictive of reduced survival. Number of medical comorbidities was not significantly associated with survival (p > 0.5). Telephone surveys were completed by 40 surviving patients (mean age 55.1 ± 6.4 years, 72.5% male, 95% subthalamic nucleus DBS, mean follow-up 13.0 ± 1.7 years). Tremor responded best to DBS (72.5% of patients improved), while other motor symptoms remained stable. Ability to conduct activities of daily living (ADLs) remained stable (dressing, 78% of patients; running errands, 52.5% of patients) or worsened (preparing meals, 50% of patients). Patient satisfaction, however, remained high (92.5% happy with DBS, 95% would recommend DBS, and 75% felt it provided symptom control).

CONCLUSIONS DBS for PD is associated with a 10-year survival rate of 51%. Survey data suggest that while DBS does not halt disease progression in PD, it provides durable symptomatic relief and allows many individuals to maintain ADLs over long-term follow-up greater than 10 years. Furthermore, patient satisfaction with DBS remains high at long-term follow-up.

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KEYWORDS deep brain stimulation; Parkinson’s disease; long-term outcomes; movement disorders; patient satisfaction; survival analysis; functional neurosurgery
Levodopa therapy improves motor symptoms but has a limited effect on nonmotor features of the disease. DBS is an effective treatment option for several movement disorders including PD, essential tremor (ET), and dystonia. This remarkable treatment modality has improved quality of life and functional outcomes for many patients. While DBS was FDA approved for ET/PD-associated tremor in 1997 (thalamic stimulation) and PD in 2003 (subthalamic nucleus [STN]/globus pallidus internus [GPi] stimulation), few studies have reported a series with follow-up of greater than 5 years. Published long-term DBS studies have included mean/median follow-up times of 2.5 years, 5 years, and 6 years. Bang Henriksen et al. reported the survival and outcomes of PD patients treated with DBS with at least 10 years of follow-up. In their study, the measured outcomes included presence of hallucinations, dementia, and nursing home placement. Other outcome domains, however, such as patient satisfaction, motor symptom control, and ability to perform activities of daily living (ADLs) were not reported. Another study did report outcomes of PD patients treated with DBS with a mean follow-up of 11 years; however, the cohort size was relatively small. In the present study, we investigated the long-term outcomes of PD patients treated with DBS to determine durability of treatment with regard to patient satisfaction, motor symptom control, and ability to perform ADLs.

Methods

Patient Selection

We obtained approval from our institutional review board (IRB) to retrospectively identify the first 400 consecutive patients at our institution who underwent DBS implantation for any indication. Of these patients, 320 underwent DBS for treatment of PD. The other 80 patients were implanted with DBS systems for treatment of essential tremor, dystonia, epilepsy, or tremor associated with multiple sclerosis. Only the PD patients were enrolled in the present study. The year of implantation ranged from 1999 to 2007.

Clinical Data Collection

Once the target patient population was identified, we collected data from medical records, both paper and electronic (Epic, Epic Systems Corporation). Demographic information, preoperative symptoms, ability to conduct basic ADLs, survival, DBS target, and complications were recorded. If a patient was unable to be contacted by phone, public death records were used to determine if the patient was still alive.

Phone surveys were conducted to determine long-term outcomes and patient satisfaction with DBS. Patients’ phone numbers were obtained from the medical record and a minimum of 3 separate attempts were made to contact each patient. Questions regarding motor symptoms and ADLs were binary yes/no questions. Likert-type response choices were used for the patient satisfaction portion of the survey. For this portion, answer choices were: “completely agree,” “mostly agree,” “unsure,” “mostly disagree,” or “completely disagree.” “Completely agree” and “mostly agree” were scored as affirmative responses.

Statistical Analysis

Statistical analysis was performed using Microsoft Excel and MATLAB (MathWorks, Inc.). We performed survival analyses using Kaplan-Meier estimation and multivariate regression using Cox proportional hazards modeling. Results were considered significant if p < 0.05. Averages are presented as mean ± standard deviation unless otherwise specified.

Results

Patient Population

Of the first 400 consecutive patients at our institution implanted with a DBS system, 320 were implanted for treatment of PD (Table 1). The average age at implantation was 61.1 ± 9.4 years and the majority of patients were male (n = 225, 70%). The STN was the stimulation target for the majority of patients (n = 304, 95%). The GPi was targeted in 16 (5%) patients. The vast majority of patients received bilateral stimulation (n = 295, 92%). Only 25 patients (8%) were implanted with unilateral systems. We also examined the longevity of patients’ implantable pulse generators (IPGs). Excluding patients who transferred their care to another facility or patients for whom date of death could not be definitively determined, we found an average IPG longevity of 3.7 ± 0.1 years (SEM).

Survival Analysis

In a subset of patients who had at least 10 years of follow-up, we performed a Kaplan-Meier survival analysis (Fig. 1). We found that 51% of patients survived through the follow-up interval. For patients who died during the follow-up interval, the mean age of death was 73 years. We performed multivariate regression analysis to assess factors that were associated with survival probability. We found that age at implantation (HR 1.02, p = 0.01) and male sex (HR 1.42, p = 0.02) were predictive of reduced survival. The number of medical comorbidities was not significantly associated with survival (p > 0.5).

Telephone Survey

The surviving patients were surveyed by telephone to determine patient outcomes and satisfaction. Of the sur-
viving patients, 40 patients had completed both a preoperative questionnaire and the follow-up telephone survey (Table 2). The average age at DBS implantation in this cohort (55.1 ± 6.4 years) was less than the mean age of the entire study cohort. Otherwise, the demographics of this cohort of patients were similar to the demographics of the entire study cohort. The majority were male (n = 29, 72.5%) and were treated with STN stimulation (n = 38, 95%). Only 2 (5%) patients were treated with GPi stimulation. All patients in this group received bilateral stimulation (Table 2). Average length of follow-up was 13.0 ± 1.7 years (range 10.6–18.0 years).

Long-Term Motor Function Outcomes
The presence of several motor manifestations of PD (tremor, freezing, speech difficulty, and swallowing difficulty) was assessed with a preoperative questionnaire and a long-term follow-up telephone survey (Table 3). Tremor was the most common preoperative motor symptom in this patient population (n = 34, 85%). The majority of patients also reported freezing (n = 27, 68%) and difficulty with speech (n = 24, 60%) preoperatively. Only 15 patients (38%) reported difficulty with swallowing preoperatively. At long-term follow-up, tremor was effectively abolished in the majority of patients; 29 patients (72.5%) saw improvement in tremor at long-term follow-up. Only 6 patients (15%) reported presence of tremor at long-term follow-up. Other motor symptoms of PD including freezing, speech difficulty, and swallowing difficulty were stable in the majority of patients (n = 23, 57.5%), (n = 27, 67.5%), and (n = 22, 55%), respectively.

Long-Term ADL Outcomes
Preoperative questionnaires and long-term follow-up surveys were also used to assess patients’ ability to perform ADLs. Preoperatively, the majority of patients were able to clothe themselves (n = 38, 95%), prepare their own meals (n = 31, 78%), and run errands (n = 30, 75%). While the majority of patients could still clothe themselves at long-term follow-up (n = 29, 73%), many patients lost the ability to prepare meals or run errands. Only 13 patients (33%) could prepare their own meals or run errands at long-term follow-up. Twenty patients (50%) lost the ability to prepare their own meals, and 18 patients (45%) lost the ability to run errands (Table 4).

Patient Satisfaction
Phone surveys were conducted to assess patient satisfaction with DBS therapy (Table 5). The vast majority were pleased with their DBS system (n = 37, 92.5%) and would recommend it to their friends/family (n = 38, 95%). A majority of patients felt that the DBS system ameliorated their symptoms (n = 30, 75%). DBS relies on an IPG that could be seen as bothersome; however, only a small minority of patients (n = 5, 12.5%) felt this way. Furthermore, very few patients were fearful of their DBS system (n = 3, 7.5%). A high frequency of IPG changes could negatively impact patient satisfaction and our results could be confounded if survey participants had less frequent battery changes due to survey participation bias. We, however, found no statistically significant difference (p = 0.92, unpaired t-test) between IPG lifespan in survey participants (3.72 ± 0.16 years, mean ± SEM) and nonparticipants (3.68 ± 0.13 years, mean ± SEM).

Complications
We reviewed patient charts to determine complications following DBS surgery (Table 6). Infection requiring surgical washout or hardware removal/replacement was

![FIG. 1. Kaplan-Meier survival curves in patients with PD following DBS with at least 10 years of follow-up (n = 200) stratified by age at implantation (A), sex (B), and number of medical comorbidities (C). Dotted lines represent 95% confidence intervals. num comorb = number of comorbidities. See main text for statistical analysis details.](image-url)
of 200 patients with confirmed 10-year follow-up. Second, non–tremor
motor symptoms such as freezing and dysarthria persisted at long-
term follow-up. While these patients may have had transient improvement
of these symptoms postoperatively, relief was not sustained at long-term
follow-up.

We found that tremor associated with PD responded best to DBS, and that symptomatic improvement was durable even at long-term follow-up of more than 10 years. However, non–tremor motor symptoms such as freezing and dysarthria persisted at long-term follow-up. While these patients may have had transient improvement of these symptoms postoperatively, relief was not sustained at long-term follow-up.

We found that the 10-year survival following DBS for PD was 51%. Multivariate regression analyses showed that survival probability was higher in younger patients and women. We did not observe an association between survival and number of medical comorbidities as we have previously reported when studying 30-day readmission rates.23 The 10-year survival probability reported in our study is similar to those in previous studies of PD that report a mortality rate of approximately 44% after 9.5 years with the disease.6,11,14 However, our 10-year survival probability (51% in 200 patients) is lower than that reported by Bang Henriksen and colleagues (70% in 79 patients).1 This discrepancy is likely a result of regression to the mean and differences in the patient samples, although we did not identify any obvious differences in age at implantation, sex distribution, or medical comorbidities between the two studies.

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These results are in agreement with and expand upon previous data. Lezcano and colleagues reported that tremor improved at 5-year follow-up relative to baseline while speech and communication worsened.16 A meta-analysis demonstrated that STN and GPi DBS results in durable tremor suppression up to 5 years postoperatively.23 Another study revealed that tremor had improved at the 11-year mean follow-up and speech had worsened.23 Our results confirm these findings in a larger patient cohort.

Importantly, the DBS-treated PD patients in this cohort maintained their ability to perform basic tasks at long-term follow-up, such as dressing themselves. On the other hand, the majority of patients could not accomplish more complex tasks at long-term follow-up, such as preparing meals or running errands independently.

One study demonstrated that patients’ self-reported im-

### TABLE 3. Motor function

<table>
<thead>
<tr>
<th>Motor Symptom</th>
<th>Preop vs FU Stable vs Improved vs Worsened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tremor</td>
<td>34 (85%) vs 6 (15%) 10 (25%) vs 29 (72.5%) vs 1 (2.5%)</td>
</tr>
<tr>
<td>Freezing</td>
<td>27 (68%) vs 24 (60%) 23 (57.5%) vs 10 (25%) vs 7 (17.5%)</td>
</tr>
<tr>
<td>Speech difficulty</td>
<td>24 (60%) vs 31 (78%) 27 (67.5%) vs 3 (7.5%) vs 10 (25%)</td>
</tr>
<tr>
<td>Swallowing difficulty</td>
<td>15 (38%) vs 15 (38%) 22 (55%) vs 9 (22.5%) vs 9 (22.5%)</td>
</tr>
</tbody>
</table>

Values are number of patients (%). Boldface type indicates the result with the highest percentage for each symptom.

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One study demonstrated that patients’ self-reported im-

### TABLE 4. Activities of daily living

<table>
<thead>
<tr>
<th>Activity</th>
<th>Able Preop vs at FU Stable vs Improved vs Worsened</th>
</tr>
</thead>
<tbody>
<tr>
<td>Putting clothing on</td>
<td>38 (95%) vs 29 (73%) 31 (78%) vs 0 (0%) vs 9 (23%)</td>
</tr>
<tr>
<td>Preparing meals</td>
<td>31 (78%) vs 13 (33%) 18 (45%) vs 2 (5%) vs 20 (50%)</td>
</tr>
<tr>
<td>Running errands</td>
<td>30 (75%) vs 13 (33%) 21 (52.5%) vs 1 (2.5%) vs 18 (45%)</td>
</tr>
</tbody>
</table>

Values are number of patients (%). Boldface type indicates the result with the highest percentage for each activity.
improvement with ADLs was sustained up to 5 years after surgery. Another study with a mean follow-up time of 11 years, however, reported worsening of ability to perform ADLs. The former study grouped several ADLs together when doing the analysis. This difference in the data analysis method could explain the difference in our findings. Another study compared PD patients treated with STN-DBS with those treated with medication alone at 6 year follow-up and found that ability to perform ADLs (as measured by mean UPDRS-II [Unified Parkinson’s Disease Rating Scale II] score remained stable in the DBS group but worsened in the medication-alone group. Furthermore, another group demonstrated that even older patients (≥ 65 years old) treated with STN-DBS exhibited improvement in ability to perform ADLs at follow-up of 3–5 years. Our results extend these findings by examining patient outcomes for a mean follow-up time of over 10 years.

Our survey data demonstrate that satisfaction with DBS remains high even at long-term follow-up. The majority of patients felt that their DBS helps control their symptoms. The vast majority of patients were happy with their DBS system and would recommend DBS to family/friends. Having an implanted device could result in patient anxiety; however, very few patients endorsed fears regarding their DBS system and few found it bothersome. One study examined patient satisfaction with STN-DBS at the 6-month follow-up and found that the majority of patients felt that they made the right decision to get DBS (89%) and would recommend it to other patients (72%).

We tracked surgical complications in our patients and found that the majority of complications were a result of infections requiring surgical treatment. This finding is in agreement with those of prior studies of DBS complications. We have implemented measures to reduce our infection rate, including irrigation with povidone-iodine and placement of vancomycin powder in the cranial and chest wounds. Relative to other intracranial procedures, DBS is considered relatively safe. We did unfortunately observe one death due to PE in the perioperative period. We have since implemented treatment with subcutaneous heparin preoperatively for DVT/PE prophylaxis during DBS implantation. Prophylaxis is continued in the postoperative period as well.

Study Limitations

Our study has several limitations. First, we had a number of patients drop out of the study due to death, inability to contact the patient, or patient refusal to take the surveys. Second, our outcome metrics were not based on widely used scales such as the UPDRS so our findings may not be comparable to those of other studies. Our study also included a retrospective component to identify the patient cohort. The above limitations may limit the generalizability of our results.

Conclusions

The current study demonstrates that while DBS does not stop disease progression in all domains, it does provide durable symptomatic relief of tremor and allows many individuals to maintain ADLs over a long-term follow-up of more than 10 years. Furthermore, patient satisfaction with DBS remains high even at a mean follow-up of more than 10 years.

Acknowledgments

We thank the members of the Neurosurgery Clinical Research Division (NCRD) for their assistance with IRB approval and data collection.

References

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<table>
<thead>
<tr>
<th>Question</th>
<th>No. (%) Replying in Affirmative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does your DBS control your symptoms?</td>
<td>30 (75)</td>
</tr>
<tr>
<td>Are you happy with your DBS system?</td>
<td>37 (92.5)</td>
</tr>
<tr>
<td>Would you recommend DBS to friends/family?</td>
<td>38 (95)</td>
</tr>
<tr>
<td>Are you fearful of or do you worry about your DBS?</td>
<td>3 (7.5)</td>
</tr>
<tr>
<td>Does your DBS battery bother you?</td>
<td>5 (12.5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complication</th>
<th>No. of Pts (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infection requiring surgery</td>
<td>35 (10.94)</td>
</tr>
<tr>
<td>DVT/PE</td>
<td>4 (1.25)</td>
</tr>
<tr>
<td>Extension wire revision</td>
<td>4 (1.25)</td>
</tr>
<tr>
<td>Lead placement revision</td>
<td>3 (0.94)</td>
</tr>
<tr>
<td>Intracranial hemorrhage</td>
<td>3 (0.94)</td>
</tr>
<tr>
<td>Device removal</td>
<td>3 (0.94)</td>
</tr>
<tr>
<td>IPG site hematoma</td>
<td>2 (0.63)</td>
</tr>
<tr>
<td>Seizure</td>
<td>2 (0.63)</td>
</tr>
<tr>
<td>PD crisis</td>
<td>1 (0.31)</td>
</tr>
<tr>
<td>IPG discomfort</td>
<td>1 (0.31)</td>
</tr>
<tr>
<td>Device turned off</td>
<td>1 (0.31)</td>
</tr>
<tr>
<td>Death</td>
<td>1 (0.31)</td>
</tr>
</tbody>
</table>

Pts = patients.
on quality of life in movement disorders. J Neurol Neurosurg Psychiatry 76:1188–1193, 2005

Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: Baltuch. Acquisition of data: Ramayya, McShane. Analysis and interpretation of data: Hitti, Ramayya.

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