Incidence of symptomatic hemorrhage after stereotactic electrode placement

CHARLES A. SANSUR, M.D., M.H.SC., ROBERT C. FRYINGER, PH.D., NADER POURATIAN, M.D., PH.D., KAI-MING FU, M.D., PH.D., MARKUS BITTL, M.D., ROD J. OSKOUIAN, M.D., EDWARD R. LAWS, M.D., AND W. JEFFREY ELIAS, M.D.

Department of Neurological Surgery, University of Virginia Health System, Charlottesville, Virginia

Object. Intracranial hemorrhage (ICH) is the most significant complication associated with the placement of stereotactic intracerebral electrodes. Previous reports have suggested that hypertension and the use of microelectrode recording (MER) are risk factors for cerebral hemorrhage. The authors evaluated the incidence of symptomatic ICH in a large cohort of patients with various diseases treated with stereotactic electrode placement. They examined the effect of comorbidities on the risk of ICH and independently assessed the risks associated with age, sex, use of MER, diagnosis, target location, hypertension, and previous use of anticoagulant medications. The authors also evaluated the effect of hemorrhage on length of hospital stay and discharge disposition.

Methods. Between 1991 and 2005, 567 electrodes were placed by two neurosurgeons during 337 procedures in 259 patients. Deep brain stimulation (DBS) was performed in 167 procedures, radiofrequency lesioning (RFL) of subcortical structures in 74, and depth electrodes were used in 96 procedures in patients with epilepsy. Electrodes were grouped according to target, patient diagnosis, use of MER, patient history of hypertension, and patient prior use of anticoagulant medication (stopped 10 days before surgery). The Charlson Comorbidity Index (CCI) was used to evaluate the effect of comorbidities. The CCI score, patient age, length of hospital stay, and discharge status were continuous variables. Symptomatic hemorrhages were grouped as transient or leading to permanent neurological deficits.

Results. The risk of hemorrhage leading to permanent neurological deficits in this study was 0.7%, and the risk of symptomatic hemorrhage was 1.2%. A patient history of hypertension was the most significant factor associated with hemorrhage (p = 0.007). Older age, male sex, and a diagnosis of Parkinson disease (PD) were also significantly associated with hemorrhage (p = 0.01, 0.04, 0.007, respectively). High CCI scores, specific target locations, and prior use of anticoagulant therapy were not associated with an increased risk of hemorrhage. The use of MER was not found to be correlated with an increased hemorrhage rate (p = 0.34); however, the number of hemorrhages in the patients who underwent DBS was insufficient to draw definitive conclusions. The mean length of stay for the DBS, RFL, and depth electrode patient groups was 2.9, 2.6, and 11.0 days, respectively. For patients who received DBS and RFL, the mean duration of hospitalization in cases of symptomatic hemorrhage was 8.2 days compared with 2.7 days in those without hemorrhaging (p < 0.0001). Three of the seven patients with symptomatic hemorrhages were discharged home.

Conclusions. The placement of stereotactic electrodes is generally safe, with a symptomatic hemorrhage rate of 1.2%, and a 0.7% rate of permanent neurological deficit. Consistent with prior reports, this study confirms that hypertension is a significant risk factor for hemorrhage. Age, male sex, and diagnosis of PD were also significant risk factors. Patients with symptomatic hemorrhage had longer hospital stays and were less likely to be discharged home.

(DOI: 10.3171/JNS-07/11/0998)

Key Words • complication • deep brain stimulation • electrode • hemorrhage • stereotaxy

Stereotactic insertion of electrodes into the brain is an integral part of functional neurosurgery, and ICH is the most feared complication associated with these procedures. Previous reports have demonstrated that hypertension and the use of MER are risk factors for hemorrhage.10,12 Neurosurgeons routinely insert intracerebral electrodes to treat movement disorders13 and provide improved localization in patients with epilepsy. The population of patients receiving stereotactic electrodes is broad, ranging from teenagers with epilepsy to elderly adults with PD. The effect of a patient’s comorbidities on the occurrence of ICH has not been well-defined. The CCI1 was used to predict surgical outcomes in several surgical fields;1,5,7-9,14,16,17 we hypothesized that this scale would be predictive of hemorrhage in this group of neurosurgical patients. In addition, we assessed the effect of hypertension, age, diagnosis, sex, electrode location, use of MER, and prior use of anticoagulant medication (stopped 10 days before surgery) on the incidence of ICH.

Clinical Material and Methods

Patient Characteristics

Between 1991 and 2005, two neurosurgeons placed 567
Hemorrhage in stereotaxy

electrodes during 337 procedures in 259 patients. These procedures included 167 DBSs, 74 RFL of subcortical structures, and 96 depth electrode placements in patients with epilepsy. A retrospective review was performed of the medical records and postoperative cerebral imaging including CT or MR imaging studies. The CCI score for each patient was calculated on the basis of the appropriate weighted Charlson criteria (Table 1). Patients were classed as hypertensive if the diagnosis was noted in the medical record or if they used antihypertensive medication. (Intraoperative blood pressure is strictly controlled before any electrode insertion.) Similarly, use of anticoagulant medications (such as aspirin, plavix, lovenox, or coumadin) was noted, but these medications were discontinued prior to surgery; preoperative coagulation studies and platelet counts in all patients were within normal limits at the time of surgery. Age, diagnosis, sex, and the use of MER were identified for each patient.

Intracerebral hemorrhages were detected on review of postoperative images and on the independent radiologist’s final report. The length of hospitalization and discharge disposition were documented for all patients. Patients with epilepsy who underwent depth electrode implantation were excluded from the length of stay calculations because of prolonged hospitalizations for monitoring intracranial electroencephalography. Patients in the depth electrode group were also excluded in assessments of the differences in hemorrhage rates between DBS and RFL, and in assessments of the difference in length of hospital stays between DBS and RFL patients. Only DBS cases were included when analyzing the risks of MER.

Surgical Procedure

In our stereotactic protocol, the frame is placed on the morning of surgery with the patient in a state of local anesthesia. High-resolution MR images with volumetric magnetization-prepared rapid gradient echo imaging and T2-weighted sequences are obtained and transferred to a Stealth planning station (Medtronic, Inc.). During stereotactic planning of the target coordinates, the patient is returned to the operating room for positioning.

We use a semirecumbent position for patient comfort while elevating the head to minimize cerebrospinal fluid loss. Patients with epilepsy or dystonia typically receive general anesthesia, while patients with movement disorders undergo operations while awake or with light sedation with dexmedetomidine or propofol. Once normal blood pressure is confirmed, the electrodes are stereotactically inserted through precoronal bur holes and anchored after correct placement is confirmed on fluoroscopy. Hippocampal depth electrodes are ordinarily inserted through occipital bur holes. Microelectrode recording is utilized to confirm placement in cases of movement disorders or PD.

Statistical Analysis

Each electrode placed was assigned to a group on the basis of type (DBS, RFL, or depth electrode), patient sex, diagnosis, targeted area, and patient status of hypertension and anticoagulant use. Statistical analysis was performed using commercially available software (JMP, SAS Institute). Differences in the frequency of hemorrhages across groups were evaluated with chi-square tests. Correction for continuity was used if expected frequencies were less than five in 20% of cells. Mean age, CCI score, and length of hospital stay were calculated for each group. Differences between group means were tested with paired t-tests and were considered statistically significant if the probability value was less than 0.05.

Results

A total of 567 electrodes were stereotactically inserted during three types of procedures: DBS to treat movement disorders (219 electrodes), RFL for movement disorders (74 electrodes), and intracerebral depth electrodes for seizure localization (274 electrodes) (Table 2). The mean patient ages were 61, 63, and 30 years in the DBS, RFL, and depth electrode groups, respectively. Fifty-five percent of electrodes were placed in male patients. The mean CCI scores were 0.7, 0.6, and 0.09 for the DBS, RFL, and depth electrode groups, respectively. A diagnosis of hypertension was associated with 81 DBS electrode insertions, 20 RFL electrode procedures, and two depth electrode insertions. In the DBS group, 31 electrodes were placed in patients who had been taking anticoagulant medications 10 days preoperatively, with six patients in the RFL group, and none in the depth electrode group. Electrodes were placed for the treatment of the following conditions: PD (199 electrodes), epilepsy (274), tremor (55), dystonia (37), and pain (two electrodes).

Intracerebral Hemorrhage

There were a total of seven (1.2%) symptomatic hemorrhages in our patients (Table 3 and Fig. 1). Hemorrhages were defined as symptomatic if they were detectable on CT or MR imaging and changes were observed on neurological examination. The hemorrhages were associated with targeting the STN in three patients, the globus pallidus internus in two, and the thalamus in one, and the remaining hemorrhage occurred after placement of a hippocampal
depth electrode. Only one of these seven hemorrhages occurred in the targeted location; the other six hemorrhages were either subcortical or intraventricular. Four of the hemorrhages were associated with DBS electrodes, two were present after RFL, and one was associated with a hippocampal depth electrode. Of these patients, four (0.9%) had hemorrhages leading to permanent neurological deficits (three in the DBS group and one in the RFL group). There was no significant difference in the rate of hemorrhage between the RFL and DBS groups (p = 0.66).

Risk Factors for Hemorrhage

In the overall group analysis, a history of hypertension was the most significant risk factor associated with hemorrhage (p = 0.007; Table 4). Five (8.6%) of the 58 patients with hypertension in the present study experienced symptomatic hemorrhages. This is in contrast with only two (1.0%) of the 201 nonhypertensive patients. Eighteen percent (103/567) of the electrodes were placed in patients who had received a diagnosis of hypertension, and 71% (5/7) of the electrode insertions with symptomatic hemorrhage occurred in patients with a history of hypertension (p = 0.002).

Parkinson disease (p = 0.007) was also significantly associated with hemorrhage, as five of the seven patients with symptomatic hemorrhaging were being treated for PD. Age was also significantly associated with hemorrhage (p = 0.01). The mean age of patients with symptomatic hemorrhage was 65 years, while the mean age of the remaining patients was 41 years. Male sex was also significantly associated with hemorrhage, as all seven patients with hemorrhages were men (p = 0.04). A high CCI score, specific target location, and previous use of anticoagulants were not significantly associated with hemorrhage (p = 0.23, 0.79, and 0.95, respectively).

Because of the inherent differences in the types of comorbidities present in the patients who received depth electrodes compared with the other patient groups, and the possibility for confounding, a separate analysis was performed with the depth electrodes removed to see the effect of CCI score, history of hypertension, age, sex, use of MER, comorbidities, target location, and previous use of anticoagulants on hemorrhage risk. A history of hypertension and diagnosis of PD were predictive of symptomatic hemorrhage (p = 0.03 and 0.001, respectively). Age and sex were no longer predictive of hemorrhage when the depth electrodes were removed from the analysis (p = 0.19 and 0.12, respectively), although all six hemorrhages in the 293 DBS and RFL patients occurred in men. The CCI score, target location, use of MER, and prior use of anticoagulants continued not to be predictive of hemorrhage (p = 0.56, 0.89, 0.34, and 0.99, respectively).

### TABLE 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>DBS</th>
<th>RFL</th>
<th>DE</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of patients</td>
<td>115</td>
<td>50</td>
<td>94</td>
<td>259</td>
</tr>
<tr>
<td>no. of procedures</td>
<td>167</td>
<td>74</td>
<td>96</td>
<td>337</td>
</tr>
<tr>
<td>no. of electrodes</td>
<td>219</td>
<td>74</td>
<td>274</td>
<td>567</td>
</tr>
<tr>
<td>mean age (yrs)</td>
<td>61</td>
<td>63</td>
<td>30</td>
<td>46</td>
</tr>
<tr>
<td>CCI score</td>
<td>0.7</td>
<td>0.6</td>
<td>0.09</td>
<td>0.4</td>
</tr>
<tr>
<td>no. of electrodes in patients w/ hx hypertension</td>
<td>81</td>
<td>20</td>
<td>2</td>
<td>103</td>
</tr>
<tr>
<td>no. of procedures w/ hx anticoag therapy</td>
<td>31</td>
<td>6</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>mean length of stay (days)</td>
<td>2.9</td>
<td>2.6</td>
<td>11.0</td>
<td>5.8</td>
</tr>
<tr>
<td>no. of patients not discharged home†</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>no. of patients w/ symptomatic hemorrhage</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>no. of patients w/ hemorrhage &amp; permanent neurological deficit</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

* anticoag = anticoagulation; DE = depth electrode; hx = history.
† Patients died or were transferred to a rehabilitation or skilled nursing facility.

### TABLE 3

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yrs)</th>
<th>Diagnosis</th>
<th>Procedure</th>
<th>Radiology Report</th>
<th>Clinical Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>epilepsy</td>
<td>hippocampal depth pallidotomy</td>
<td>punctate midbrain hemorrhage</td>
<td>transient &amp; minimal up-gaze palsy</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>PD</td>
<td>pallidotomy</td>
<td>massive rt ICH</td>
<td>initially conversant but deteriorated to unresponsiveness &amp; died</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>TN</td>
<td>thalamotomy</td>
<td>1-cm thalamic ICH</td>
<td>transient intraop speech arrest</td>
</tr>
<tr>
<td>4</td>
<td>71</td>
<td>PD</td>
<td>globus pallidus internus DBS</td>
<td>5.5 × 2.5–cm rt parietal ICH</td>
<td>initially unresponsive, regained localizing but not verbal responses localizes with lt upper extremity to painful stimulation</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>PD</td>
<td>STN DBS</td>
<td>6 × 3–cm lt frontal ICH</td>
<td>persistent rt hemiplegia</td>
</tr>
<tr>
<td>6</td>
<td>75</td>
<td>PD</td>
<td>STN DBS</td>
<td>3.3 × 2–cm lt frontal ICH</td>
<td>transient intraop agitation &amp; confusion</td>
</tr>
<tr>
<td>7</td>
<td>70</td>
<td>PD</td>
<td>STN DBS</td>
<td>rt IVH</td>
<td></td>
</tr>
</tbody>
</table>

* See Fig. 1 for imaging of hemorrhages in Patients 4 through 7. Abbreviations: IVH = intraventricular hemorrhage; TN = trigeminal neuralgia.
Exclusion of the depth electrode group also allowed a comparison of the hemorrhage risk between patients who underwent RFL and those who received DBS. There was no significant difference in hemorrhage rate for patients who received RFL compared with DBS (p = 0.99). There were two hemorrhages after placement of 74 electrodes (2.7%) in the RFL group, and four hemorrhages (1.8%) after placement of 219 electrodes in the DBS group.

Impact of Hemorrhage

As expected, patients with symptomatic hemorrhage had longer hospital stays and were more likely to be discharged to either a rehabilitation center or skilled nursing facility. For these calculations, only the DBS and RFL groups were considered because their surgeries would normally have similar length of stays, while the patients who underwent depth electrode placement had extended hospital stays for seizure localization. There was no significant difference in the length of stay between patients undergoing DBS and RFL (2.9 and 2.6 days, respectively; p = 0.44). Patients with symptomatic hemorrhages had significantly longer hospital stays: 8.2 days compared with 2.7 days (< 0.0001). Of the seven patients with symptomatic hemorrhages, three were discharged to a rehabilitation center or skilled nursing facility, three went home, and one died. There was one additional death in this study in a patient without ICH who died of cardiac failure.

Table 4

<table>
<thead>
<tr>
<th>Prognostic Factor</th>
<th>p Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>hx hypertension</td>
<td>0.007</td>
<td>8.6% of hypertensive patients had hemorrhage; 1.0% of normotensive patients had hemorrhage</td>
</tr>
<tr>
<td>PD diagnosis</td>
<td>0.007</td>
<td>5 of 7 hemorrhages were in patients with PD</td>
</tr>
<tr>
<td>age</td>
<td>0.01</td>
<td>mean 64.6 years compared with 41.2 years</td>
</tr>
<tr>
<td>male sex</td>
<td>0.04</td>
<td>all 7 hemorrhages were in men</td>
</tr>
<tr>
<td>target location</td>
<td>0.79</td>
<td>no significance</td>
</tr>
<tr>
<td>CCI score</td>
<td>0.23</td>
<td>no significance</td>
</tr>
<tr>
<td>prior anticoagulant use</td>
<td>0.95</td>
<td>no significance</td>
</tr>
</tbody>
</table>

Discussion

This study is intended to assess the factors that are significantly associated with ICH during stereotactic electrode procedures. This project is timely as stereotactic techniques are increasingly applied in neurosurgery. Although prior studies have documented the rate of hemorrhage with stereotactic surgery, we sought to comprehensively analyze a broad population of patients of varying ages and diagnoses who have undergone stereotactic insertion of intracerebral electrodes. Our hypothesis was that the rate of hemorrhagic complications is increased in older patients with additional comorbidities, and thus we utilized the CCI in the assessment of hemorrhagic complications.

At the University of Virginia during the study period, the rate of symptomatic hemorrhage after stereotactic surgical procedures for electrode placement was 1.2%. The risk of hemorrhage leading to permanent neurological deficits was 0.7% for the 259 patients who underwent 337 procedures and 567 electrode insertions. Previously published risks of hemorrhage following stereotactic surgery have ranged from 0.6 to 2.1% (Table 5).

In another large series of 481 electrode insertions, Binder et al. reported symptomatic and asymptomatic ICHs. The overall rate of hemorrhage was 3.3%, and only 0.6% were associated with permanent neurological deficits. Lyons and colleagues reported one hemorrhage in a series of 160 procedures involving DBS of the STN, but the neurological outcome in these patients was not reported and potential risk factors were not addressed.

Effect of Hypertension

Hypertension was the most significant risk factor (p = 0.007) predictive of ICH after stereotactic surgery. Previous studies have also documented hypertension as a risk factor for ICH. The patients in our practice are maintained normotensive during the procedure, particularly at the time of intracerebral electrode insertion. The definition of hypertension in our study included patients whose history of hypertension was significant enough to require anti-hypertensive medications. Five (8.6%) of the 58 patients with hypertension in our series experienced symptomatic hemorrhages. This is in contrast with only two (1.0%) of 201 nonhypertensive patients. Gorgulho and associates reported five hemorrhages after 248 total electrode inser-
in our subset analysis reported higher rates of hemorrhage during reported a hemorrhage rate of 2.9% in a report. It has been previously suggested but this was not our experience. This scale is weighted by the STN (2.5%), and there were no hemorrhages in our series, six occurred while targeting the basal ganglia, and only one occurred at the target itself. There was one hemorrhage in a patient with epilepsy who was undergoing depth electrode insertion to the hippocampus. However, there was no statistically significant correlation between hemorrhage and target location (p = 0.79).

Beric et al. reported an increased hemorrhage rate in the thalamus compared with the STN and globus pallidus during RFL procedures. Hemorrhage rates are probably higher in the basal ganglia than in cortical targets. It has been previously suggested that more hemorrhages occur at the target site than along the trajectory, but this was not our experience.

**Effect of Stereotactic Target**

Our initial impression was that target location would correlate with an increased risk of hemorrhage. Of the seven hemorrhages in our series, six occurred while targeting the basal ganglia, and only one occurred at the target itself. There was one hemorrhage in a patient with epilepsy who was undergoing depth electrode insertion to the hippocampus. However, there was no statistically significant correlation between hemorrhage and target location (p = 0.79).

Bender et al. reported higher rates of hemorrhage during DBS procedures targeted to the globus pallidus (6.7%), followed by the STN (2.5%), and there were no hemorrhages in the thalamus. Conversely, Terao and associates reported an increased hemorrhage rate in the thalamus compared with the STN and globus pallidus during RFL procedures. Hemorrhage rates are probably higher in the basal ganglia than in cortical targets. It has been previously suggested that more hemorrhages occur at the target site than along the trajectory, but this was not our experience.

**Effect of Age and Parkinson Disease**

Consistent with an earlier report, in our subset analysis in which young patients with epilepsy were excluded from the calculation, age was no longer predictive of an increased risk of hemorrhage in adult patients undergoing DBS or RFL. A diagnosis of PD is an important factor, however. In our patients, five of the seven ICHs occurred in parkinsonian patients.

**Effect of Comorbidities**

In this study we uniquely analyze the effect of comorbidities in patients undergoing stereotactic procedures as related to the development of symptomatic ICH. The CCI is a tool for assessing the risks and outcomes of surgical procedures, and has been used in general, transplant, oncological, and urological surgeries. This scale is weighted toward morbid underlying conditions, and thus we thought it would be a good predictor of hemorrhage in the neurosurgical population. In our series, however, the CCI score was not statistically associated with symptomatic hemorrhage. We do believe that this index may be predictive of nonhemorrhagic complications, and this will be the subject of a future report. There were only two deaths among our patients, and thus the CCI could not be used to predict mortality rates.

**Effect of Stereotactic Target**

Our initial impression was that target location would correlate with an increased risk of hemorrhage. Of the seven hemorrhages in our series, six occurred while targeting the basal ganglia, and only one occurred at the target itself. There was one hemorrhage in a patient with epilepsy who was undergoing depth electrode insertion to the hippocampus. However, there was no statistically significant correlation between hemorrhage and target location (p = 0.79).

Bender et al. reported higher rates of hemorrhage during DBS procedures targeted to the globus pallidus (6.7%), followed by the STN (2.5%), and there were no hemorrhages in the thalamus. Conversely, Terao and associates reported an increased hemorrhage rate in the thalamus compared with the STN and globus pallidus during RFL procedures. Hemorrhage rates are probably higher in the basal ganglia than in cortical targets. It has been previously suggested that more hemorrhages occur at the target site than along the trajectory, but this was not our experience.

**Effect of MER**

There has been considerable debate over the use of MERs to provide electrophysiological confirmation of stereotactic targeting. We did not find a significant correlation between hemorrhage and the use of MER; however, there were three hemorrhages in the 86 patients (3.4%) who underwent DBS with MER, compared with one hemorrhage in 133 patients (0.75%) who underwent DBS without MER. The observed risk with MER is more than four times that without MER, but the difference does not reach statistical significance (Yates corrected p = 0.33). We believe the number of hemorrhages in our study population to be insufficient to determine whether the use of MER increases the risk of ICH. An additional study is currently underway to better understand the association.

Gorgulho et al. reported a hemorrhage rate of 2.9% in a MER group compared with 1.4% in a macroelectrode stimulation group, but this difference did not reach statistical significance (p = 0.65). However, Honey et al. reported a significantly increased rate of hemorrhage in their MER group compared with the macroelectrode stimulation group (1.3% compared with 0.2%, p = 0.012). Consideration of the number of MER penetrations is also valid. Bender et al. in 2005 reported a nonsignificant trend toward increased MER penetrations in patients who developed hemorrhages (p = 0.21). An overall review of the literature by Hariz revealed that MER techniques do not necessarily improve targeting accuracy or clinical results compared with techniques using impedance monitoring and macrostimulation, but they are five times more likely to lead to hemorrhagic complications.

**Discharge Disposition**

The effect of ICH on discharge disposition and length of stay are predictable but important to document. Patients with symptomatic ICHs had longer hospital stays and were less likely to be discharged home.

**Conclusions**

The use of stereotactic techniques to insert intracerebral electrodes is rapidly expanding as new applications for functional neurosurgery develop. The most feared complication of stereotactic surgery is ICH. In our study with a large cohort of patients with a broad age range and diagnoses, we achieved a symptomatic hemorrhage rate of 1.2%, with only 0.7% of these causing permanent neurological deficits. In only one case did we observe ICH at the level of the stereotactic target. In six patients, the hemorrhages were subcortical along the electrode trajectory or within the ventricular system. Diligent preoperative planning to avoid traversing sulci may thus reduce the risk of subcortical vascular injury.

Consistent with prior studies, we found that hypertension was the most significant risk factor for ICH—hypertensive
Hemorrhage in stereotaxy

patients suffered hemorrhagic complications eight times more frequently. Thus, meticulous intraoperative control of blood pressure is recommended, and early preoperative management should be considered before proceeding with surgery. There was also an association with age, male sex, and PD. Surprisingly, comorbidities as assessed with the CCI, the use of MER, the target location, and previous use of anticoagulation medications were not statistically associated with ICH. Hemorrhagic complications were associated with longer hospital stays as patients were less likely to be discharged home. Further studies are underway to determine if the CCI is a useful tool for detecting nonhemorrhagic complications and death.

Acknowledgment

We thank Cindy Roberson for her assistance with the preparation of this manuscript.

References


Address correspondence to: W. Jeffrey Elias, M.D., Department of Neurological Surgery, University of Virginia, Box 800212, Charlottesville, Virginia 22908. email: wje4r@virginia.edu.