Risk of Reoperation for Hemorrhage in Patients After Craniotomy

Hanna Algattas, Kristopher T. Kimmell, George Edward Vates

OBJECTIVE: To identify clinical factors predictive of patients returning to the operating room (OR) for hemorrhage after craniotomy.

METHODS: A national surgical quality database (American College of Surgeons National Surgical Quality Improvement Project) was reviewed for patients undergoing craniotomy based on Current Procedural Terminology (CPT) code. CPT codes were also used to identify patients returning to the OR for hemorrhage.

RESULTS: Of 5520 patients who underwent craniotomy in 2012, 81 (1.5%) had a reoperation for hematoma evacuation. Preoperative and intraoperative factors associated with reoperation for hemorrhage included preexisting hypertension, bleeding disorder, and primary craniotomy for hematoma evacuation. Postoperative factors included ventilator dependence >48 hours, unplanned reintubation, and blood transfusion during or after the index operation. A risk score based on these factors was predictive of reoperation for hemorrhage with a receiver operating characteristic area under the curve of 0.767. Restricting the score to preoperative factors was still predictive of reoperation (area under the curve = 0.683).

CONCLUSIONS: Reoperation for evacuation of hematoma is influenced by several clinical factors. A risk score based on these factors is predictive of return to the OR and may be used to identify patients at risk.

INTRODUCTION

In the current era of health care reform, there is a major focus on cost reduction through curtailing excessive and duplicative care. Coinciding with this reform is an information era where quality metrics are recorded and tracked with hopes of reducing costs, improving outcomes, and using resources more efficiently. Cost-effectiveness and quality outcomes in neurosurgery have recently been explored at the institutional and national levels. An example of the latter is the National Neurosurgery Quality and Outcomes Database, which was started in 2012 as a pilot program to analyze risk-adjusted morbidity and outcomes among spine surgeries. More targeted approaches have been undertaken elsewhere; one example is the United Kingdom Cranial Reconstruction Registry, which is aimed at measuring perioperative complications, readmissions, and reoperations pertaining to cranioplasties.

Reoperation is a measure intricately tied to cost and quality measures. Rolston et al. analyzed >38,000 cranial and spinal cases and identified reoperation to occur in 4.3% of cases. The added expense of reoperations and the hospital care that ensues has a negative impact on costs and outcomes. In addition to added expenditures, hospitals may face financial penalties for failure to meet quality measures. A major quality concern for neurosurgeons is returning to the operating room (OR) for postoperative hemorrhage. Successful prophylactic efforts against reoperation for hemorrhage include placement of subdural drains after evacuation of chronic subdural hematoma (SDH). The rate of reoperation after evacuation of chronic SDH is cited as 12%, and reoperation has been linked to intraoperative factors including large original hematoma volume, presence of septations, and parenchymal atrophy. However, rates of reoperation for hemorrhage and

Key words
- Craniotomy
- Hemorrhage
- NSQIP
- Reoperation

Abbreviations and Acronyms
ICD-9: International Classification of Diseases, Ninth Revision
INR: International normalized ratio
NSQIP: National Surgical Quality Improvement Project
OR: Operating room
SDH: Subdural hematoma
VTE: Venous thromboembolism

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Available online: www.sciencedirect.com
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associated risk factors vary depending on the purpose of the index craniotomy. Few efforts at analyzing a wide breadth of craniotomies have been undertaken, and no studies that identify risk factors for postoperative hemorrhage in a heterogeneous craniotomy cohort have been completed. A goal of the present study is to provide insight into the risk factors contributing to reoperation for hemorrhage among all craniotomies.

The introduction of comprehensive surgical quality databases has provided new avenues to study outcomes. The National Surgical Quality Improvement Program (NSQIP) first arose from the Veterans Administration Health System and has enlisted 445 hospitals since its beginnings in 2004. Participating hospitals voluntarily contribute a sample of their surgical data in return for risk-adjusted outcome reports comparing their institution with others. NSQIP provides various data aimed at improving outcomes and has been used across many surgical specialties. Data included are demographics, preoperative morbidities, perioperative laboratory results, intraoperative variables, hospital course, and postoperative complications. The large collection of cases and numerous factors tracked make NSQIP a robust database.

As of 2012, records regarding reoperation were added to NSQIP, and efforts to analyze potential risk factors for reoperation have been undertaken in other surgical specialties. We sought to identify clinical factors associated with reoperation for hemorrhage after craniotomy with the intention of creating a risk score to stratify patients. A predictive model may be capable of targeting interventions toward patients at highest risk, which would improve outcomes and reduce costs.

MATERIALS AND METHODS

Based on primary Current Procedural Terminology (CPT) code as recorded in a national surgical quality database (American College of Surgeons NSQIP), from 2012, 5,520 adult patients underwent craniotomy. Factors in NSQIP were subjected to analysis and converted to binary variables where applicable. The ordinal and nominal variables were included in a univariate 2-tailed \( \chi^2 \) analysis or Fisher exact test where appropriate against patients reoperated on for hemorrhage. Preoperative and intraoperative factors from NSQIP analyzed in univariate analysis included primary evacuation (CPT and International Classification of Diseases, Ninth Revision [ICD-9] recorded), mortality, deep vein thrombosis, pulmonary embolism, venous thromboembolism (VTE), age \( \geq 60 \) years, ascites, angina, dialysis, diabetes, pregnancy, central nervous system tumor, functional status, emergency case, operation time \( > 3 \) hours, acute transfer from outside facility, sepsis, craniotomy for tumor, ventilator dependence, esophageal varices, peripheral vascular disease, transient ischemic attack, wound infection, wound class 3–4, hypertension, impaired sensorium, coma lasting \( > 24 \) hours, hemiplegia, cerebrovascular accident with and without neurologic deficit, bleeding disorder, congestive heart failure, rest pain, paraplegia, transfusion, American Society of Anesthesiologists class IV–V, sex, race, do not resuscitate status, general anesthesia use, attending presence in the OR, myocardial infarction, renal failure, quadriplegia, chemotherapy, surgical specialty performing operation, elective surgery, body mass index \( > 30 \), smoking, alcohol abuse, dyspnea, chronic obstructive pulmonary disease, pneumonia, percutaneous coronary intervention, previous cardiac surgery, disseminated cancer, and radiotherapy. Postoperative factors included length of hospital stay, superficial wound infection, deep wound infection, pneumonia, admission to OR time \( > 4 \) days, unplanned reintubation, ventilator dependence \( > 48 \) hours, renal insufficiency, renal failure, urinary tract infection, peripheral nerve deficit, cardiac arrest requiring cardiopulmonary resuscitation, myocardial infarction, bleeding transfusion, graft or prosthesis use, sepsis, septic shock, or infection (a grouped category). Reoperation for hemorrhage was selected based on CPT codes, including 61108, 61154, 61156, 61312, 61313, 61314, 61315, and 61322 (Table 1). CPT code 61322 indicates a decompressive craniectomy or craniotomy for intracranial hypertension; these cases were cross-referenced with ICD-9 codes to include only reoperations for hemorrhage diagnoses. Reoperation cases were characterized based on indication for principal operation (hematoma evacuation, tumor excision, aneurysm, other); Mann-Whitney U test was used for comparison of continuous variables. For univariate \( \chi^2 \) analysis, original \( z \) was set at .05 and \( P \) values were adjusted using Holm-Bonferroni correction.

Table 1. Frequency of Reoperation for Hemorrhage by Current Procedural Terminology and International Classification of Diseases, Ninth Revision, Codes

<table>
<thead>
<tr>
<th>CPT Code*</th>
<th>Number (%)</th>
<th>ICD-9 Code</th>
<th>Number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>61108</td>
<td>1 (2.00)</td>
<td>430</td>
<td>2 (2.86)</td>
</tr>
<tr>
<td>61154</td>
<td>2 (4.11)</td>
<td>431</td>
<td>19 (27.14)</td>
</tr>
<tr>
<td>61156</td>
<td>0 (0.00)</td>
<td>432</td>
<td>2 (2.86)</td>
</tr>
<tr>
<td>61312</td>
<td>41 (49.40)</td>
<td>432.1</td>
<td>12 (17.14)</td>
</tr>
<tr>
<td>61313</td>
<td>25 (30.12)</td>
<td>852</td>
<td>7 (10.00)</td>
</tr>
<tr>
<td>61314</td>
<td>9 (10.84)</td>
<td>Other</td>
<td>28 (40.00)</td>
</tr>
<tr>
<td>61315</td>
<td>4 (4.82)</td>
<td>Total</td>
<td>70</td>
</tr>
<tr>
<td>61322</td>
<td>1 (1.20)</td>
<td>Total</td>
<td>83</td>
</tr>
</tbody>
</table>

*CPT code definitions:
- 61108: Twist drill hole for subdural or ventricular puncture, for evacuation and/or drainage of subdural hematoma
- 61154: Burr hole(s) with evacuation and/or drainage of hematoma, extradural or subdural
- 61156: Burr hole(s) with aspiration of hematoma or cyst, intracerebral
- 61312: Craniectomy/craniotomy for evacuation of hematoma, supratentorial; extradural or subdural
- 61313: Craniectomy/craniotomy for evacuation of hematoma, supratentorial; intracerebral
- 61314: Craniectomy/craniotomy for evacuation of hematoma, infratentorial; extradural or subdural
- 61315: Craniectomy/craniotomy for evacuation of hematoma, infratentorial; intracerebellar
- 61322: Craniectomy/craniotomy, decompressive, with/without duraplasty, for treatment of intracranial hypertension, without evacuation of associated intraparenchymal hematoma; without lobectomy

†Two patients underwent reoperation for hemorrhage twice each; there were 81 total patients undergoing reoperation for hemorrhage.
correction. Factors less than their specified adjusted \( z \) were considered statistically significant.

Preoperative, intraoperative, and postoperative factors significant in univariate analysis were subjected to a stepwise, forward, conditional multivariate binary logistic regression analysis (entry level = 0.05, exit = 0.10) to identify factors independently correlated with reoperation for hemorrhage. Where possible, postoperative events occurring after reoperation for hemorrhage were excluded. Covariate interactions were analyzed using \( \chi^2 \) analysis and included in stepwise iterations of multivariate regression. Inclusion of covariate interactions led to the removal of pneumonia and deep vein thrombosis from the postoperative multivariate model.

There were 12 significant factors in univariate analysis. After multivariate regression, 3 preoperative and 3 postoperative factors persisted. A risk score was created by assigning the presence or absence of each factor a value of 1 or 0, respectively. An alternative risk score using only preoperative factors was created after postoperative factors were adjusted based on relation in time to the reoperation. Receiver operating characteristic curve was completed for each risk score to determine predictive ability. Area under the curve values >0.70 represent acceptable discrimination, and values >0.80 indicate excellent discrimination.\(^{10,15,19}\) The Hosmer-Lemeshow test was used to assess the model’s ability to fit the data well (\( P > 0.05 \) suggests a good fit of data). All statistical analyses were performed using SPSS for Windows software version 18.0 (SPSS, Inc, Chicago, Illinois, USA).

**RESULTS**

In the cohort of 5520 patients, there were 81 (1.5%) reoperations for hemorrhage based on CPT code (Tables 2–4). The principal operations in the reoperated cases were for tumor excision (50.6%), hematoma evacuation (32.1%), and aneurysm (4.9%) (Table 2). Most principal operations for hematoma evacuation were for either SDH or epidural hematoma (88.5%), with only 3 cases done for intraparenchymal hemorrhage (11.5%). Patients presenting for evacuation of hematoma as the index case had a higher international normalized ratio (INR) (1.21 vs. 1.03, \( P < 0.05 \)) and activated partial thromboplastin time (30.5 seconds vs. 27.5 seconds, \( P < 0.05 \)) compared with patients undergoing a principal operation for tumor excision. Also, patients with evacuation of hematoma as the index case had lower hematocrit (38.8 vs. 41.6, \( P < 0.005 \)) and blood urea nitrogen/creatinine ratio (17.5 vs 22.9, \( P < 0.005 \)) compared with patients with a principal operation for tumor excision. Expectedly, index cases for hematoma evacuation were significantly shorter in length compared with cases for tumor excision (82.0 minutes vs. 215.5 minutes, \( P < 0.05 \)) (Table 3).

Most reoperations were coded as hematoma for either SDH or epidural hematoma (63.8%) followed by intracerebral hematoma (34.6%). Principal cases and their associated reoperations are detailed in Table 4. Most patients with SDH or epidural hematoma returned to the OR for a similar procedure (95.6%). A similar trend was seen for patients undergoing principal meningioma resection. However, principal cases for intracranial tumor excision showed a more even split between patients returning for SDH or epidural hematoma treatment and patients with intraparenchymal hemorrhage (58.1% vs. 41.9%). One patient originally presented for evacuation of a supratentorial SDH or epidural hematoma and later returned to the OR for evacuation of an infratentorial SDH or epidural hematoma in a remote location.

Patients undergoing reoperation for hemorrhage were similar to the entire cohort and patients undergoing any reoperation in most demographic measures (Table 5). The average time from principal operation to reoperation was 6 days (6.0 days ± 6.9). The overall rate of all reoperations in the entire cohort was 6.1% with the largest proportion of reoperations being for hemorrhage (Table 6). Patients undergoing reoperation spent significantly longer time in the hospital (\( P < 0.001 \)) and were at higher risk

<table>
<thead>
<tr>
<th>Principal Procedure (n)</th>
<th>Age (SD)</th>
<th>Sex, % Male</th>
<th>HTN, %</th>
<th>Bleeding Disorder, %</th>
<th>BUN/Cr (SD)*</th>
<th>Hct (SD)*</th>
<th>Platelets (SD)</th>
<th>aPTT (SD)*</th>
<th>INR (SD)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematoma evacuation (26)</td>
<td>67.2 (14.4)</td>
<td>73.1</td>
<td>69.2</td>
<td>42.3</td>
<td>17.5 (6.7)</td>
<td>38.8 (5.2)</td>
<td>222 (86)</td>
<td>30.5 (5.2)</td>
<td>1.21 (0.3)</td>
</tr>
<tr>
<td>SDH/epidural hematoma (23)</td>
<td>68.6 (11.3)</td>
<td>78.3</td>
<td>65.2</td>
<td>47.8</td>
<td>17.6 (7.0)</td>
<td>38.8 (5.6)</td>
<td>223 (92)</td>
<td>31.0 (5.1)</td>
<td>1.24 (0.3)</td>
</tr>
<tr>
<td>IPh (3)</td>
<td>56.0 (31.0)</td>
<td>33.3</td>
<td>100.0</td>
<td>0.0</td>
<td>17.0 (5.9)</td>
<td>39.1 (1.5)</td>
<td>217 (7)</td>
<td>23.9 (2.0)</td>
<td>1.02 (0.1)</td>
</tr>
<tr>
<td>Tumor excision (41)</td>
<td>61.7 (13.7)</td>
<td>58.5</td>
<td>56.1</td>
<td>7.3</td>
<td>22.9 (8.2)</td>
<td>41.6 (5.3)</td>
<td>220 (75)</td>
<td>27.5 (4.8)</td>
<td>1.03 (0.1)</td>
</tr>
<tr>
<td>Intracranial (27)</td>
<td>62.4 (15.1)</td>
<td>66.7</td>
<td>63.0</td>
<td>11.1</td>
<td>22.2 (7.6)</td>
<td>41.6 (6.3)</td>
<td>218 (75)</td>
<td>27.3 (4.7)</td>
<td>1.05 (0.1)</td>
</tr>
<tr>
<td>Meningioma (14)</td>
<td>60.4 (10.7)</td>
<td>42.9</td>
<td>42.9</td>
<td>0.0</td>
<td>24.3 (9.3)</td>
<td>41.5 (2.8)</td>
<td>225 (7)</td>
<td>27.9 (5.3)</td>
<td>1.01 (0.1)</td>
</tr>
<tr>
<td>Aneurysm (4)</td>
<td>45.5 (6.2)</td>
<td>25.0</td>
<td>75.0</td>
<td>0.0</td>
<td>15.8 (8.5)</td>
<td>35.5 (9.5)</td>
<td>191 (50)</td>
<td>28.1 (1.3)</td>
<td>1.03 (0.1)</td>
</tr>
</tbody>
</table>

HTN, hypertension; BUN/Cr, blood urea nitrogen/creatinine; Hct, hematocrit; aPTT, activated partial thromboplastin time; INR, international normalized ratio; SDH, subdural hematoma; IPh, intraparenchymal hemorrhage.

*\( P < 0.05 \) for hematoma evacuation versus tumor excision.

\( \dagger \)One case of preoperative blood transfusion within aneurysm category.
of mortality within 30 days postoperatively (Table 6). The mean length of stay for patients returning to the OR for hemorrhage was 16.6 days compared with a mean length of stay of 6.9 days for patients not returning to the OR.

After univariate analysis and Holm-Bonferroni correction, a group of factors remained significantly associated with reoperation for hemorrhage (Table 7). These factors were entered in a multivariate binary logistic regression to identify the factors independently associated with reoperation for hemorrhage. Factors that persisted included history of bleeding disorder, history of hypertension, primary procedure for hematoma evacuation (based on CPT code), postoperative ventilator dependence >48 hours, bleeding transfusion, and unplanned intubation. The average time between unplanned reintubation and return to the OR for hemorrhage was 0.60 days (Table 7). As recorded in NSQIP, intubations for an unplanned return to the OR are considered planned and not recorded as this type of postoperative complication.

Each patient case was scored for the presence of factors significant after multivariate binary logistic regression with a score of 1 for each factor present. The range of scores was 0–6 (median = 0). A receiver operating characteristic curve with area under the curve analysis demonstrated a significant ability to predict reoperation (area under the curve = 0.767; 95% confidence interval = 0.711–0.823; P < 0.001). A second model employing only preoperative factors was used with scores of 0–3 (median = 0). The rate of reoperation for hemorrhage with a score
of 0 was 0.7%, and the rate of reoperation for hemorrhage with a score of 3 was 9.6% (Table 8 and Figure 1). Use of 3 factors alone was still predictive of reoperation for hemorrhage (area under the curve = 0.683; 95% confidence interval = 0.623–0.744; \( P < 0.001 \) (Figure 2). The Hosmer-Lemeshow test demonstrated that the model fit the data well (\( P > 0.05 \)).

### Table 6. Reoperation Rates and Mortality Rate

<table>
<thead>
<tr>
<th>Group</th>
<th>Number (%)</th>
<th>30-Day Mortality, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire cohort</td>
<td>5520</td>
<td>3.9</td>
</tr>
<tr>
<td>All reoperations</td>
<td>337 (6.1%)</td>
<td>9.2</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>81 (1.5%)</td>
<td>12.3</td>
</tr>
<tr>
<td>Ventriculoperitoneal shunt</td>
<td>30 (0.5%)</td>
<td>*</td>
</tr>
<tr>
<td>Tracheostomy</td>
<td>39 (0.7%)</td>
<td>*</td>
</tr>
<tr>
<td>Upper GI endoscopy</td>
<td>10 (0.2%)</td>
<td>*</td>
</tr>
</tbody>
</table>

Gl, gastrointestinal.
*Mortality not calculated for ventriculoperitoneal shunt placement, tracheostomy, or upper GI endoscopy procedures.

### Table 7. Factors Associated with Reoperation for Hemorrhage in Univariate Analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>( P ) Value</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding disorder*</td>
<td>&lt; 0.001</td>
<td>4.8 (2.7–8.7)</td>
</tr>
<tr>
<td>Hypertension*</td>
<td>&lt; 0.001</td>
<td>2.4 (1.5–3.7)</td>
</tr>
<tr>
<td>Emergency case</td>
<td>&lt; 0.001</td>
<td>3.4 (2.2–5.3)</td>
</tr>
<tr>
<td>Intraoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary CPT code for evacuation*</td>
<td>&lt; 0.001</td>
<td>4.7 (2.9–7.5)</td>
</tr>
<tr>
<td>ASA score IV–V</td>
<td>&lt; 0.001</td>
<td>2.6 (1.7–4.3)</td>
</tr>
<tr>
<td>Postoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilator dependence &gt;48 hours*</td>
<td>&lt; 0.001</td>
<td>7.4 (4.6–12.1)</td>
</tr>
<tr>
<td>Unplanned reintubation*</td>
<td>&lt; 0.001</td>
<td>8.9 (4.9–15.9)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>&lt; 0.001</td>
<td>6.8 (3.7–12.6)</td>
</tr>
<tr>
<td>Bleeding transfusion*</td>
<td>&lt; 0.001</td>
<td>4.8 (2.9–7.9)</td>
</tr>
<tr>
<td>DVT</td>
<td>&lt; 0.001</td>
<td>4.9 (2.3–10.4)</td>
</tr>
<tr>
<td>VTE</td>
<td>&lt; 0.001</td>
<td>4.1 (2.0–8.3)</td>
</tr>
<tr>
<td>Postoperative infections\dagger</td>
<td>0.001</td>
<td>3.9 (1.9–7.9)</td>
</tr>
<tr>
<td>Septic shock</td>
<td>0.003</td>
<td>7.6 (2.6–21.8)</td>
</tr>
</tbody>
</table>

OR, odds ratio; CI, confidence interval; CPT, current procedural terminology; ASA, American Society of Anesthesiologists; DVT, deep vein thrombosis; VTE, venous thromboembolism.
\*Factors that remained significant in multivariate binary logistic regression.
\daggerPostoperative infections included pneumonia, urinary tract infections, sepsis, and septic shock events.

### DISCUSSION
From the present analysis, the rate of reoperation for hemorrhage after craniotomy was 1.5%. Patients undergoing reoperation for hemorrhage had increased total length of stay and mortality. In multivariate analysis, 6 factors were associated with reoperation: hypertension, bleeding disorder, principal procedure for hematoma evacuation, prolonged postoperative ventilator use, unplanned intubation, and transfusion for bleeding. Transforming these factors into a risk score led to a model that successfully predicted reoperation for hemorrhage. Narrowing the risk model to strictly preoperative factors produced a model that is useful, given that knowledge of these factors could improve intraoperative management, for example, by promoting meticulous hemostasis or tight perioperative blood pressure control in patients at increased risk.

The rate of reoperation for postoperative hemorrhage varies throughout the neurosurgery literature. Seifman et al.\textsuperscript{16} stated that an adequate definition of postoperative intracranial hemorrhage is a hematoma that requires surgical evacuation. Fukamachi et al.\textsuperscript{20} evaluated computed tomography images after 1074 craniotomies and found medium to large hemorrhage in 3.9%. However, computed tomography imaging after craniotomy often identifies asymptomatic hematomas, inflating the true incidence; overall, reports cite the rate as 0.8%–50%.\textsuperscript{21,22} One of the first reports among predominantly postcraniotomy cases stated the rate as 1.1%.\textsuperscript{4} In another study, most postoperative hemorrhages were intracerebral (60%) followed by epidural (28%) and subdural (7.5%).\textsuperscript{21} Considering all reports in the extant literature, the range likely falls between 0.8%–6.9% when detecting hemorrhage based on clinical deterioration and 10.8%–50.0% when detecting hemorrhage based on radiographic imaging.\textsuperscript{4} In our analysis, reoperations were predominantly for epidural hematoma and SDH rather than intraparenchymal hemorrhage, which is counter to the findings of Kalfas and Little,\textsuperscript{15} who found intraparenchymal hemorrhage to predominate. In that study, there were only 40 cases, and the indication for the index procedure was more often tumor resection, which may explain the discrepancy.

Other factors have been associated with postoperative hemorrhage and reoperation. Intraoperative blood loss is not recorded by NSQIP. However, median blood losses of 500 mL increase the rate of postoperative hemorrhage as a result of reduced platelets and coagulation factors;\textsuperscript{23} a surrogate, qualitative NSQIP measure is the discrepancy. Other studies\textsuperscript{24} have replaced the NSQIP hematoma evacuation, prolonged postoperative ventilator use were additional factors associated with reoperation for hemorrhage. Per NSQIP, intubation during a reoperation is considered planned; unplanned intubations occurred an average of 14–15 hours after reoperation. Additionally, patients reintubated after failing immediate postoperative weaning trials are not included in the “unplanned intubation” category. Postoperative ventilator
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Table 8. Hemorrhagic Risk Score

<table>
<thead>
<tr>
<th>Risk Score</th>
<th>Number of Patients (%)</th>
<th>Number of Reoperations for Hemorrhage (%)</th>
<th>Number of Cases With 30-Day Mortality (%)</th>
<th>Mean Total Length of Stay, Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3001 (54.4)</td>
<td>20 (0.7)</td>
<td>50 (1.7)</td>
<td>6.0</td>
</tr>
<tr>
<td>1</td>
<td>2093 (37.9)</td>
<td>40 (1.9)</td>
<td>92 (4.3)</td>
<td>7.8</td>
</tr>
<tr>
<td>2</td>
<td>332 (6.0)</td>
<td>12 (3.6)</td>
<td>42 (12.7)</td>
<td>11.4</td>
</tr>
<tr>
<td>3</td>
<td>94 (1.7)</td>
<td>9 (0.6)</td>
<td>29 (30.8)</td>
<td>9.2</td>
</tr>
<tr>
<td>Totals</td>
<td>5520</td>
<td>81</td>
<td>213</td>
<td>7.1</td>
</tr>
</tbody>
</table>

dependence >48 hours was a cumulative variable and may have included time points before the reoperation. These confounding variables were part of the rationale behind including a risk score using only preoperative factors.

Hypertension is also implicated in hemorrhage risk. Patients experiencing intracranial hemorrhage are significantly more likely to have hypertension. Abrupt intraoperative hypertension is thought to perturb cerebral autoregulation and, in the setting of a surgically disrupted blood-brain barrier, increase risk of bleeding into the surgical field. Intraoperative and postoperative systolic blood pressure >160 mm Hg (intraoperative, odds ratio = 2.618, P = 0.007; postoperative, odds ratio = 2.660, P = 0.022) and intraoperative and postoperative mean blood pressure >110 mm Hg (intraoperative, odds ratio = 2.600, P = 0.037; postoperative, odds ratio = 3.600, P = 0.001) are associated with postransection hemorrhoma requiring evacuation. Determining the degree of hypertension associated with reoperation could further elucidate the patients at highest risk. Such a determination, based on our findings and findings reported by others, may prompt more aggressive management of hypertension before operation. Additional quantitative measures may be useful in refining the risk model. Amount of blood loss, craniotomy length, and craniotomy area all are associated with postoperative epidural hematoma. Also, specifying the bleeding site would be useful because hematomas occasionally develop in sites remote from that of the principal procedure. At the present time, NSQIP does not record the anatomic site of reoperation, hematoma volume, or incision details. However, based on CPT code, there was 1 case of a patient presenting with SDH or epidural hematoma in a location remote from the index procedure.

Finding that a principal procedure for evacuation of hematoma was associated with reoperation was expected. Elevated INR values in patients undergoing a principal operation for hematoma evacuation is a partial explanation (1.21 vs. 1.03, P < 0.05), yet an INR of 1.21 is not high enough in itself to be an absolute contraindication to surgery. The INR comparison corresponds with our finding that preoperative bleeding disorders were associated with reoperation risk. The higher INR may be due to patients with initially elevated INR secondary to warfarin or another cause whose INR was reversed before surgery with vitamin K, fresh frozen plasma, or other agents. Per NSQIP, bleeding disorders may include vitamin K deficiency, hemophilia, thrombocytopenia, or long-term anticoagulation (which includes warfarin or heparin use). Patients on long-term antiplatelet therapy are not included in the category of bleeding disorder; consideration of preoperative use of anticoagulants or antiplatelets is critical when framing the present results. Another analysis of postoperative hemorrhage identified more frequent occurrence after craniotomy for an anterior circulation aneurysm (2.1%) and for tumor removal (4.4%), but there was no statistical analysis in that study. In the present analysis, 53.1% of reoperations for hemorrhage had the principal procedure listed as a craniotomy for tumor resections compared with 32.1% for cases with the principal operation for hematoma evacuation. However, in univariate analysis, there was no significant association between craniotomy for tumor and reoperation for hemorrhage.

Efforts to reduce reoperations are currently underway. Seifman et al. reviewed postoperative hemorrhage and discussed perioperative efforts to improve outcomes. Preoperatively, managing coagulopathic concerns and controlling hypertension are useful. Intraoperatively, ensuring hemostasis, slowly weaning anesthesia, and avoiding hypertension while replacing lost blood products are key. Lastly, postoperatively, proper positioning in addition to already stated protocols is helpful.

A risk model such as ours that could identify patients at increased risk of postoperative hemorrhage may inform perioperative protocols where such management principles are applied and outcomes, in the form of decreased returns to the OR, are tracked. Also, as previously mentioned and in combination with the literature, confirming that preoperative hypertension has a role in reoperation risk warrants further research and may suggest more aggressive management of preoperative hypertension would

![Figure 1. Rate of reoperation for hemorrhage for each risk score.](image-url)
be useful in reducing risk. Before reaching such conclusions, more quantitative blood pressure data are required. Additionally, NSQIP indirectly accounts for anticoagulated patients but fails to record whether patients use long-term antiplatelet therapy. The addition of such data may reveal a stronger trend in the current association. Lastly, from a health systems standpoint, being able to identify risk for reoperation for hemorrhage, even if retrospectively, may be useful for quality metrics. Hospitals are increasingly judged by achievement of certain quality standards, and identifying patients at higher risk for complication may separate patients inherently more likely to experience complication from patients who experience the same complication as a result of poor clinical practice. More aggressive clinical care protocols may also be initiated in these patients to prevent and limit the effects of such complications.

The present analysis has limitations. Although NSQIP lists reoperations and accompanying CPT and ICD-9 codes, there are few additional data concerning additional operations. There is an inherent assumption that all reoperations for hemorrhage are captured by using CPT codes as a surrogate measure for reoperation because of hemorrhage. In preliminary analysis, stratification based on CPT codes provided a larger volume of reoperation cases (1.6%) than separation based on ICD-9 diagnoses (<1.0%). Additionally, separation based on ICD-9 diagnoses identified 27% of reoperations for hemorrhage as intracerebral compared with 34.9% when using CPT codes. The discrepancy is likely due to variations in recording.

There are other limitations to the use of the NSQIP data set, including the retrospective study design and generalizability to only hospitals participating in NSQIP—often large academic centers. There is also the risk of random sampling error and failure to capture patient records. For example, compared with the Thoracic Morbidity and Mortality database, NSQIP captured only 21.3% of patients recorded within the Thoracic Morbidity and Mortality database, which led to variations in the rates of recorded procedures. In other specialties, discordance between reviewed cases and cases entered in NSQIP was 27.7%, and certain events, such as postoperative bleeding requiring transfusion, were commonly misclassified. The latter finding potentially affects our multivariate risk model. Furthermore, compared with the Vascular Quality Initiative, outcomes reported in NSQIP had acceptable concordance for most preoperative factors, but variable concordance for postoperative complications. Also, the heterogeneity of the surgical cases included may reduce the strength of the risk model. Because reoperations have only more recently been tracked by NSQIP, data were limited, which would have made a homogeneous subgroup analysis less statistically useful. However, data span both sides of the spectrum, and some studies suggest that NSQIP provides a better foundation of data than other surgical databases. Lastly, our large number of statistical comparisons may produce statistical error, although use of the Holm-Bonferroni method of sequential correction accounted for that issue. Some reports argued that hospital participation in NSQIP has improved outcomes, whereas other data suggested involvement in NSQIP alone has failed to do so, whether by means of complication rates, reoperation, mortality, or mean total Medicare payments. NSQIP is a relatively young endeavor and may require prolonged efforts before these impacts are felt; however, we believe it provides robust, comprehensive, and increasingly reliable data for the present analysis.

The findings of preoperative hypertension, bleeding disorder, and principal procedure for evacuation of hemorrhage being associated with reoperation may not be surprising to clinicians, yet the results are clinically relevant. For example, identification of these factors may have an impact on the preoperative informed consent process. These factors may offer patients a better
understanding of the risk they incur before craniotomy. Additionally understanding preoperatively the reoperation risk may influence the neurosurgeon’s decision to operate, especially in situations where the indication for the principal operation is questionable.

The negative findings of our analysis are also insightful. Only a small group of factors were associated with reoperation for hemorrhage, and some preoperative factors hypothesized to be associated (either positively or negatively) were not. These factors included increased operation time, advanced age, smoking, preoperative sepsis, VTE, body mass index, impaired sensorium, and emergency case as well as others. In previous analyses of risk factors for VTE after craniotomy, there numerous associations. One could expect to have similar association of factors for VTE and hemorrhage but varied in terms of a positive or negative relationship. We previously completed a similar analysis regarding risk for VTE after craniotomy. Combining the present data with that research has large implications for risk stratification of patients after craniotomy. A Bayesian-type analysis examining thrombosis and hemorrhage on both sides of the spectrum may provide a manner for dual stratification of patients after craniotomy. Such a model may be more refined and offer additional advantages in determining the risk/benefit ratio for the use of prophylactic anticoagulation in patients after craniotomy.

The present findings suggest future areas of investigation. The average time from principal operation to reoperation for hemorrhage was 6 days, which is longer than expected. This length of time questions whether reoperation for hemorrhage occurs more because of postoperative anticoagulation for VTE prophylaxis rather than technical errors from the initial procedure. As mentioned, we conducted similar analyses of the NSQIP database in regard to VTE risk reduction. Additionally, comparison of the present findings with institutional data and revalidating data on additional NSQIP data would make the model more robust.

CONCLUSIONS

Many factors are associated with reoperation for hemorrhage; yet, the incorporation of only a few factors into a risk score is capable of predicting reoperations for hemorrhage, increased length of stay, and mortality. Identifying patients at greater risk for reoperation may potentially modify care before and during craniotomy to reduce costs and improve quality metrics.

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