Variability in Outcome After Elective Cerebral Aneurysm Repair in High-Volume Academic Medical Centers

Brad E. Zacharia, MD; Samuel S. Bruce, MA; Amanda M. Carpenter, BA; Zachary L. Hickman, MD; Kerry A. Vaughan, MD; Catherine Richards, MPH; William E. Gold, MD; June Lu, MD; Geoffrey Appelboom, MD, PhD; Robert A. Solomon, MD; E. Sander Connolly, MD

Background and Purpose—Unruptured intracranial aneurysm repair is the most commonly performed procedure for the prevention of hemorrhagic stroke. Despite efforts to regionalize care in high-volume centers, overall results have improved little. This study aims to determine the effectiveness in improving outcomes of previous efforts to regionalize unruptured intracranial aneurysm repair to high-volume centers and to recommend future steps toward that goal.

Methods—Using data obtained via the New York Statewide Planning and Research Cooperative System, this study included all patients admitted to any of the 10 highest volume centers in New York state between 2005 and 2010 with a principal diagnosis of unruptured intracranial aneurysm who were treated either by microsurgical or endovascular repair. Mixed-effects logistic regression was used to determine the degree to which hospital-level and patient-level variables contributed to observed variation in good outcome, defined as discharge to home, between hospitals.

Results—Of 3499 patients treated during the study period, 2692 (76.9%) were treated at the 10 highest volume centers, with 2198 (81.6%) experiencing a good outcome. Good outcomes varied widely between centers, with 44.6% to 91.1% of clipped patients and 75.4% to 92.1% of coiled patients discharged home. Mixed-effects logistic regression revealed that procedural volume accounts for 85.8% of the between-hospital variation in outcome.

Conclusions—There is notable interhospital heterogeneity in outcomes among even the largest volume unruptured intracranial aneurysm referral centers. Although further regionalization may be needed, mandatory participation in prospective, adjudicated registries will be necessary to reliably identify factors associated with superior outcomes.

Key Words: intracranial aneurysm • neurosurgery

Unruptured intracranial aneurysms (UIAs) are increasingly diagnosed, an expected consequence of their 1% to 3% global incidence, and the recent widespread use of noninvasive cranial imaging.1,2 Deciding whether to offer treatment for these lesions depends on several factors and involves balancing the risk of catastrophic rupture versus the risk and efficacy of invasive therapy. Bleeding from an intracranial aneurysm results in major morbidity or mortality in 65% of cases.3 However, rupture rates for a given aneurysm can vary from <1% per year to 33% per year depending on a variety of anatomic and patient-specific factors associated with the lesion.4,5 Further complicating the analysis is the fact that treatment risk is highly variable depending on a variety of factors associated with the lesion, the patient, the treating institution, the treating physician, and the mode of selected treatment.4,5

The decision to treat an intracranial aneurysm must be based on the knowledge that the treatment risk is significantly less than the natural history of the patient’s aneurysm left untreated for their lifetime. Although aneurysms have been typically treated with craniotomy and microsurgical clipping, during the past decade there has been a definite evolution toward the increased use of less morbid, albeit somewhat less protective, endovascular coil treatments.6 As well, there has been increased centralization of treatment to high-volume centers with the expectation of reduction of overall treatment morbidity.7

We began studying the public health implications of treatment of intracranial aneurysms in New York State in 1996. During the past decade, despite significant increases in the percentage of aneurysms being coiled (20%–57%), and the percentage of aneurysms being treated in high-volume centers (50%–81%), both of which are highly, and independently, correlated with good outcome, the data have shown little improvement in state-wide outcome.7–10 Previous evaluations have suggested that a shift in coiling venue from high-volume...
centers to low-volume facilities, and overall worsening in microsurgical results, especially in low-volume centers, have contributed to the worse than expected outcomes. More troubling is the possibility, explored in this article for the first time, that even the busiest high-volume centers may not be uniformly achieving rates of favorable outcome that justify invasive treatment in a group of patients that present almost exclusively as functionally independent.

Methods

We analyzed data obtained from the New York Statewide Planning and Research Cooperative System, curated by the New York State Department of Health. Patients are identified through admission and billing records, and data are collected on all hospital discharges, ambulatory surgical procedures, and emergency department admissions in New York State. This study was conducted with approval from the Institutional Review Board of Columbia University Medical Center.

We reviewed New York Statewide Planning and Research Cooperative System data from 2005 to 2010 to identify treatment and outcome trends for UIA. Database records are categorized into diagnoses and procedures according to the International Classification of Diseases, Ninth Revision (ICD-9). Using a previously published search strategy, the following ICD-9 codes were used to identify patients for inclusion: 437.3 (unruptured cerebral aneurysm), 39.51 (clipping of cerebral aneurysm), and 39.72 (endovascular repair or occlusion of head and neck vessels).

Data recorded for all treated UIA patients included the hospital where treatment was performed, treatment modality (microsurgical versus endovascular), and discharge destination. Our primary outcome was discharge destination. Good outcome was defined as discharge to home under self-care and poor outcome as discharge to any other location. Discharge to home after definitive UIA treatment has been noted previously as an acceptable marker for good outcome in large databases and is appropriate given the elective nature of UIA treatment in these often fully independent patients. Case volumes were recorded for each treatment center. We restricted our analysis to the 10 largest treatment centers by volume. For patients with multiple entries in the database, the earliest entry was used.

Statistical analysis was performed using R environment for statistical computing. The R package lattice was used to create Figure 1. Mixed-effects logistic regression using hospital-level and patient-level variables was used to determine the degree to which these factors were responsible for observed variation in discharge status between hospitals. At the patient level, sex, race, age, and admission type were treated as fixed effects. Hospital-level fixed effects included proportion of endovascular aneurysm repair cases and total aneurysm repair case volume. A hospital-level intercept was included in all models as a random effect. The R package lme4 was used to perform the mixed-effects regression analysis. To calculate the reduction from the null model of between-hospital variability, the difference between the variance of the hospital-level intercept of the null model and the specified model was calculated and then divided by the variance of the intercept of the null model. Mixed-effects logistic regression models were used to estimate the theoretical rates of good outcome for each hospital used in Figure 2. For each model, the logit of the total population proportion of good outcome was added to the hospital-level intercepts, and the inverse logit was applied to the results. Error bars represent 95% confidence intervals.

Results

From 2005 to 2010, there were 3499 patients who underwent surgical or endovascular treatment for UIA. We have previously published the demographic characteristics of this UIA population. Of these patients, 2692 (76.9%) were treated at the 10 largest treatment centers by volume in New York State. All 10 of these centers were tertiary care centers with the Accreditation Council for Graduate Medical Education accredited neurosurgical residency programs. This translates to an average of 269 cases per center during the study period or 45 cases annually per center.

Overall treatment volume ranged from 152 in the 10th highest volume center to 547 in the highest volume center during the 5-year study period (Table 1). Good outcomes were recorded for 2198 (81.6%) of all treated patients. There were 1199 (44.5%) surgical cases and 1493 (55.5%) endovascular cases with good outcomes noted in 73.2% and 88.4% of patients, respectively. The percentage of good outcomes witnessed varied from 58.6% to 91.4% across all procedures among the 10 highest volume centers. The most common poor outcome was discharge to home under skilled care, followed by inpatient rehabilitation facility (Figure 1).

Figure 1. A and B. Discharge types by center. Other is an aggregation of discharge types with extremely low frequencies: cancer center or children’s hospital, left against medical advice or discontinued care, discharged to court/law enforcement, and hospice. Centers are numbered by decreasing aneurysm case repair volume.
With regards to surgical clipping, 1 center performed 395 surgical repairs from 2005 to 2010 (60 annually), whereas the remaining centers had case volumes ranging from 45 to 153 (annually 8–26). Average volume across all centers was 120 cases per hospital during the study period, or 20 annually. Excluding the highest volume center, average volume was 89 during the study and 15 annually. Discharge to home per clipping procedure ranged from 44.6% to 91.1% (average 65.5%; Figure 2A) and was highly associated with volume treated.

With regards to endovascular coiling, 1 center performed 366 procedures from 2005 to 2010 (61 annually), whereas the remaining centers had case volumes ranging from 69 to 165 (annually 12–28). Average volume across all centers was 149 cases per hospital during the study period, or 25 annually. Excluding the highest volume center, average volume was 125 during the study and 21 annually. Discharge to home per coiling procedure ranged from 75.4% to 92.1% (average 86.7%; Figure 2B).

There was a marked variation in the proportion of patients undergoing endovascular repair across hospitals, ranging from 27.8% to 74.2% of all UIA treatments. Of note, the highest percentage of patients experiencing good outcome were treated at the least balanced centers. Those hospitals with the best outcomes overall were the 2 centers with the highest percentage of endovascular repairs and the center with the lowest percentage of endovascular repairs (Figure 2C). By comparing total case volume with total proportion of good outcomes, we note that there may be a nearly linear association between overall UIA volume and discharge to home (Figure 2D), consistent with prior observations of improved outcomes at higher volume centers, but there were exceptions that did not prove the rule.7,8,12

The results of the mixed-effects regression models (Table 2) suggest that hospital total aneurysm repair case volume is the dominant factor affecting variation in good outcome between hospitals. Adjusting for patient sex, race, age, admission type,

**Table 1. Case Volume and Good Outcomes in the 10 Highest Volume Centers of New York State From 2005 to 2010 for Total, Surgical, and Endovascular Treatments**

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Treated, n</th>
<th>Good Outcome, %</th>
<th>Clipped, n (%)</th>
<th>Good Outcome, %</th>
<th>Coiled, n (%)</th>
<th>Good Outcome, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>547</td>
<td>500 (91.4)</td>
<td>395 (72.2)</td>
<td>360 (91.1)</td>
<td>152 (27.8)</td>
<td>140 (92.1)</td>
</tr>
<tr>
<td>2</td>
<td>493</td>
<td>429 (87.0)</td>
<td>127 (25.8)</td>
<td>93 (73.2)</td>
<td>366 (74.2)</td>
<td>336 (91.8)</td>
</tr>
<tr>
<td>3</td>
<td>318</td>
<td>251 (78.9)</td>
<td>153 (48.1)</td>
<td>103 (67.3)</td>
<td>165 (51.9)</td>
<td>148 (89.7)</td>
</tr>
<tr>
<td>4</td>
<td>229</td>
<td>185 (80.8)</td>
<td>81 (35.4)</td>
<td>54 (66.7)</td>
<td>148 (64.6)</td>
<td>131 (88.5)</td>
</tr>
<tr>
<td>5</td>
<td>221</td>
<td>173 (78.3)</td>
<td>116 (52.5)</td>
<td>85 (73.3)</td>
<td>105 (47.5)</td>
<td>88 (83.8)</td>
</tr>
<tr>
<td>6</td>
<td>220</td>
<td>189 (85.9)</td>
<td>59 (26.8)</td>
<td>44 (74.6)</td>
<td>161 (73.2)</td>
<td>145 (90.1)</td>
</tr>
<tr>
<td>7</td>
<td>175</td>
<td>120 (68.6)</td>
<td>85 (48.6)</td>
<td>47 (55.3)</td>
<td>90 (51.4)</td>
<td>73 (81.1)</td>
</tr>
<tr>
<td>8</td>
<td>170</td>
<td>134 (78.8)</td>
<td>55 (32.4)</td>
<td>32 (58.2)</td>
<td>115 (67.6)</td>
<td>102 (88.7)</td>
</tr>
<tr>
<td>9</td>
<td>167</td>
<td>128 (76.6)</td>
<td>45 (26.9)</td>
<td>23 (51.1)</td>
<td>122 (73.1)</td>
<td>105 (86.1)</td>
</tr>
<tr>
<td>10</td>
<td>152</td>
<td>89 (58.6)</td>
<td>83 (54.6)</td>
<td>37 (44.6)</td>
<td>69 (45.4)</td>
<td>52 (75.4)</td>
</tr>
<tr>
<td>Total</td>
<td>2692</td>
<td>2198 (81.6)</td>
<td>1199 (44.5)</td>
<td>878 (73.2)</td>
<td>1493 (55.5)</td>
<td>1320 (88.4)</td>
</tr>
</tbody>
</table>
and hospital proportion of endovascular aneurysm repair cases resulted in an 10.5% reduction in between-hospital variation, whereas adjusting for hospital total aneurysm repair case volume in addition to all of the aforementioned variables resulted in an additional 85.8% reduction or a total 96.3% reduction in between-hospital variation from the null model (Figure 3).

**Discussion**

Patients with UIA are increasingly being encouraged to undergo intervention to obliterate their aneurysms. Regardless, there remains significant controversy on the ideal management strategy for many UIA. Although certain patient and aneurysm-specific characteristics, such as age, medical comorbidities, aneurysm size, location, and morphology, should influence the choice of treatment modality, often the final decision to pursue conservative management or invasive therapy (surgical or endovascular) is randomly based on the expertise and bias of the consulting physician, as well as regional access to the various treatment modalities. Therefore, because of the public health implications, developing an approach for standardization of patient selection, and achieving uniformly excellent outcomes when invasive therapy is delivered, is paramount.

Evidence suggests that procedural outcomes are intimately linked to hospital volume, and, as such, further centralization of UIA treatment to higher volume centers would likely be both feasible, given the elective nature of treatment, and beneficial. However, in New York State, centralization has

---

### Table 2. Mixed-Effects Logistic Regression Models

<table>
<thead>
<tr>
<th></th>
<th>Null Model</th>
<th>Model 1</th>
<th>OR (95% CI)</th>
<th>P Value</th>
<th>OR (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient-level fixed effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male sex</td>
<td>...</td>
<td>...</td>
<td>1.17 (0.91–1.49)</td>
<td>0.22</td>
<td>1.17 (0.92–1.49)</td>
<td>0.21</td>
</tr>
<tr>
<td>Race (ref=unknown)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>...</td>
<td>...</td>
<td>0.77 (0.38–1.54)</td>
<td>0.46</td>
<td>0.83 (0.43–1.62)</td>
<td>0.59</td>
</tr>
<tr>
<td>Black</td>
<td>...</td>
<td>...</td>
<td>0.49 (0.24–1.01)</td>
<td>0.05</td>
<td>0.52 (0.26–1.05)</td>
<td>0.07</td>
</tr>
<tr>
<td>Other</td>
<td>...</td>
<td>...</td>
<td>0.51 (0.25–1.03)</td>
<td>0.06</td>
<td>0.54 (0.27–1.06)</td>
<td>0.07</td>
</tr>
<tr>
<td>Admission type (ref=emergency)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urgent</td>
<td>...</td>
<td>...</td>
<td>0.97 (0.64–1.48)</td>
<td>0.90</td>
<td>1.16 (0.77–1.75)</td>
<td>0.47</td>
</tr>
<tr>
<td>Elective</td>
<td>...</td>
<td>...</td>
<td>1.82 (1.38–2.41)</td>
<td>&lt;0.001</td>
<td>2.00 (1.52–2.62)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age</td>
<td>...</td>
<td>...</td>
<td>0.96 (0.95–0.97)</td>
<td>&lt;0.001</td>
<td>0.96 (0.95–0.97)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Hospital variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of endovascular repair cases</td>
<td>...</td>
<td>...</td>
<td>1.00 (0.98–1.02)</td>
<td>0.89</td>
<td>1.01 (1.00–1.01)</td>
<td>0.24</td>
</tr>
<tr>
<td>Total aneurysm repair case volume</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>1.00 (1.00–1.00)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hospital-level random intercept variance</td>
<td>0.269</td>
<td>0.229</td>
<td>0.010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction from null model of between-hospital variance</td>
<td>...</td>
<td>...</td>
<td>10.5%</td>
<td>96.3%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Good outcome is response variable for all models.

---

**Figure 3.** A to C. Reduction of between-center variability in good outcome after adjusting for individual and hospital-level characteristics. Theoretical percentages of good outcome estimated via population proportion of good outcome and hospital-level intercepts of mixed-effects logistic regression models. Centers are numbered by decreasing aneurysm case repair volume.
failed to result in improvements in outcome, and it seems that substantial variation in outcome at the highest volume referral centers is in part to blame. As procedural volume varies greatly between even these centers and, even in these centers, remains the single recorded variable most predictive of outcome, it is tempting to conclude that what is needed is further centralization of care. However, there are hints in the data to suggest that outcome in these relatively high-volume centers might also be related to factors that are unrecorded in these administrative datasets and that more centralization may lead to equally disappointing results without first understanding why volume seems to be so critical.

One such hint can be seen in the striking observations on microsurgical treatment of UIA (Figure 2A). Here, although it is true that the busiest center recorded the best outcomes and the lower volume centers tended to have results that were markedly worse, only the highest volume center achieved results that are likely to have benefited the average patient, and one of the lowest volume centers achieved the second best results. In fact if one excludes the busiest center from the analysis, the impact of volume on outcome seems modest and overall results seem disastrously poor. Thus, although a correlation between better microsurgical outcome and higher case volume is suggested, there are alternative explanations, including referral bias, patient selection bias, and variations in technical ability.

Although the statewide endovascular results were better overall (Figure 2B), and less variable it should be noted that much more of the quality associated with endovascular repair is likely obscured from this type of data analysis as incomplete treatment, which is more likely with endovascular therapy, would not affect discharge to home. This caveat aside, the variability with endovascular treatment seems to be almost exclusively related to volume with morbidity improving in a logarithmic fashion with a treatment threshold of 100 cases in variability with endovascular treatment seems to be almost wide variation in outcome exists for UIA treatment, suggesting that additional hospital, socioeconomic, and provider level characteristics are operational.

The differential pattern of outcome from surgical and endovascular approaches, especially as it relates to volume, is difficult to scientifically explain from this data set. It is possible that administrative databases are not equally effective in gauging the benefits afforded by these 2 different approaches. This fact and the overall poor and inconsistent results, especially but not exclusively related to microsurgery, make it critical that patients, third-party payers, and treating physicians understand with a greater degree of granularity the institutional variables associated with true procedural success.

For instance, physicians even in some of the busiest centers might lack experience in evaluation and selection of patients for conservative treatment, endovascular coiling, or microsurgical clipping. Some evidence that patient selection may differ between the centers can be seen in Figure 2C. Centers that have developed a weighted bias toward either endovascular repair or microsurgical repair seem to fare better than centers where treatment seems to me made by almost random allocation. Influence of local expertise, availability of senior mentoring, and concentration of cases to experienced practitioners are all possibilities that might improve outcome. Random allocation, however, suggests that patient-specific factors might not be as important as other issues such as call schedules, financial concerns, hospital politics, and availability of high-tech equipment. It seems likely that the high-volume centers studied actually were referred patients with similar risk profiles, and that inferior results could have been avoided by adopting the best practices of the better performing centers. The public health issues related to these possibilities call for a mandatory, adjudicated registry to identify those factors associated with the best outcomes. Adoption of best practices could then be studied prospectively to ensure improved outcomes. There is significant precedence for such an endeavor in the New York State mandatory outcomes reporting for coronary artery bypass graft program.18,19 Subsequent standardization of care has allowed for significant decreases in adverse outcomes. Our data indicate that even with high procedural volumes a wide variation in outcome exists for UIA treatment, suggesting that additional hospital, socioeconomic, and provider level characteristics are operational.

The use of large third-party databases entails several limitations. Our discussion of UIA management is dependent on the accuracy of diagnostic codes designated for patients. The ICD-9 coding system has numerous known limitations but remains a widely accepted tool in cerebrovascular research.20,21 Patient-specific characteristics and anatomic details about the aneurysms are not included in New York Statewide Planning and Research Cooperative System, and unrecorded comorbid conditions and lesions complexities may also negatively affect results and lead to differential outcomes. We were also unable to track long-term outcomes through New York Statewide Planning and Research Cooperative System, as clinical events are only recorded up to discharge. Thus, our analysis does not consider recovery or any adverse events after discharge. Postprocedural complications that may be more frequent with endovascular treatment, such as recanalization and aneurysmal rupture, are not accounted for here.22 Potentially slower recovery with longer lengths of stay and rehabilitation in surgical patients could also bias discharge outcomes in favor of endovascular intervention.23 Discharge to home has been validated previously as a surrogate for good outcome in large databases and used as a measure of acceptable outcome in this analysis. Discharge itself as an outcome does not fully portray the functional status of a patient although it does allow for some insight into procedural outcomes and has been reported widely as an acceptable approximation of modified Rankin Scale scores for UIA and stroke research.9,10,24,25

Conclusions
The data show that there are wide variations in treatment outcome for patients with UIAs, even at the highest volume centers in New York State. A detailed examination of the most successful centers, as might be achieved with a mandatory hospital based reporting system, would highlight successful best practices and may help to reduce interhospital variation in results of treatment.

Sources of Funding
Clinical Research Fellow Kerry Vaughan was funded by a grant from the Doris Duke Charitable Foundation. All other aspects of the study were funded by the Department of Neurological Surgery.
Disclosures

None.

References


15. Bates D, Maechler M, Bolker B. Lme4: Linear mixed-effects models using s4 classes. R package version 0.999999-0. 2012.


Variability in Outcome After Elective Cerebral Aneurysm Repair in High-Volume Academic Medical Centers
Brad E. Zacharia, Samuel S. Bruce, Amanda M. Carpenter, Zachary L. Hickman, Kerry A. Vaughan, Catherine Richards, William E. Gold, June Lu, Geoffrey Appelboom, Robert A. Solomon and E. Sander Connolly

*Stroke*. 2014;45:1447-1452; originally published online March 25, 2014; doi: 10.1161/STROKEAHA.113.004412
*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2014 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/45/5/1447

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Stroke* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Stroke* is online at:
http://stroke.ahajournals.org/subscriptions/