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Impact of Hospital-Related Factors on Outcome After Treatment of Cerebral Aneurysms

Mitchell F. Berman, MD, MPH; Robert A. Solomon, MD; Stephan A. Mayer, MD; S. Claiborne Johnston, MD, PhD; Pixie P. Yung, BS

Background and Purpose—The goal of this study was to examine the impact of hospital characteristics on outcome after the treatment of ruptured and unruptured cerebral aneurysms.

Methods—We identified all discharges in New York State from 1995 through 2000 with a principal diagnosis of subarachnoid hemorrhage (SAH) or unruptured cerebral aneurysm (UCA) in patients who were treated by aneurysm clipping, wrapping, or endovascular coiling. An adverse outcome was defined as in-hospital death or discharge to a rehabilitation hospital or long-term facility. We examined the effect of hospital factors, including the rate of endovascular therapy and overall procedural volume, on outcome, length of stay, and total charges.

Results—There were 2200 (36.9%) and 3763 (63.1%) admissions for attempted treatment of UCA and SAH, respectively. The 10 highest-volume hospitals performed half of all the procedures. Overall, hospital volume was associated with fewer adverse outcomes and lower in-hospital mortality for both UCA (adverse outcome: odds ratio [OR], 0.89; P<0.0001; mortality: OR, 0.94; P=0.002 for each 10 additional procedures performed per year) and SAH (adverse outcome: OR, 0.94; P=0.03; mortality: OR, 0.95; P=0.005). Use of endovascular therapy (each additional 10% of cases performed endovascularly) was associated with fewer adverse outcomes after treatment of unruptured aneurysm (0.83, P=0.026). Hospital volume had more of an effect on outcome after aneurysm clipping than after endovascular therapy.

Conclusions—Hospital procedural volume and the propensity of a hospital to use endovascular therapy are both independently associated with better outcome. Improvement in outcome could be achieved by a program of regionalization and selective referral for the treatment of cerebral aneurysms. (Stroke. 2003;34:2200-2207.)

Key Words: cerebral aneurysm • endovascular therapy • surgical treatment

The impact of hospital volume and surgical experience on outcome after the treatment of cerebral aneurysms is a controversial topic. Although there is a generally recognized positive relationship between the volume of aneurysm patients treated at an institution and patient outcome,1–3 the strength of this conclusion is limited by issues of referral bias and changing treatment algorithms, which now routinely include endovascular therapy.

This study examines mortality and morbidity after treatment of cerebral aneurysms using New York State discharge data from 1995 through 2000 for both ruptured and unruptured aneurysms. We have used epidemiological methods that minimize the effect of referral bias and have examined the effect of endovascular therapy on treatment outcome.

Methods

Data Set and Identification of Cases
We analyzed data for 1995 through 2000 provided by New York State from SPARCS, its statewide database of hospital discharges.4

The database records diagnoses and procedures according to the International Classification of Diseases, 9th revision (ICD-9), and provides patient demographic information and discharge destination. Unique encrypted patient identifiers allow the differentiation of readmissions for the same patient from admissions of new patients.

Patient discharges with a principal diagnosis code for subarachnoid hemorrhage (ICD-9 430) or unruptured cerebral aneurysm (ICD-9 437.3) were selected from the SPARCS data set. Within these 2 groups, we identified patients who had 1 of 3 procedures performed on their aneurysm: surgical clipping (ICD-9 39.51), endovascular coiling (ICD-9 38.81 or, beginning October 2000, 99.29), or craniotomy with wrapping of the aneurysm (ICD-9 39.52). We refer to these patients as having received procedural treatment of the aneurysm.

Endovascular therapy of cerebral aneurysms is a relatively new procedure; thus, we sought to eliminate any question as to which code was being used in New York State to identify the procedure. After preliminary analysis, we contacted the 10 hospitals in New York State that reported the highest overall volume of procedural treatment on cerebral aneurysms. We were able to confirm that...
each followed the coding recommendations of the American Hospital Association and used ICD-9 38.81 for endovascular therapy of cerebral aneurysms before October 2000 and 94.29 after October 2000. We also contacted all other hospitals in the state that had reported endovascular therapy as a procedure for a cerebral aneurysm during the study period. Only 2 patient records included endovascular therapy for hospitals that did not perform the procedure. These 2 entries were eliminated from the data set.

The analysis involved patient demographic variables (sex, race, age, ethnicity) and hospital-specific characteristics, eg, existence of a dedicated neurological intensive care unit (NICU) and/or presence of a neurosurgical residency program. The SPARCS data set is similar to the US Census in that the Hispanic/Latino designation is coded separately as ethnicity. A neurosurgical residency was defined as a neurosurgical resident on site at a hospital 24 hours per day.

Analysis
We defined adverse outcome as a discharge other than to home. Discharge to nursing home or rehabilitation hospital has been shown to correlate well with Rankin Scale score. Mortality was defined as in-hospital death. To limit the confounding effect of preexisting neurological deficits, analysis of patients treated for unruptured aneurysms was limited to those without a preexisting diagnosis of subarachnoid hemorrhage.

The \( \chi^2 \) test for specified proportions was used to compare population demographics against census data; standard \( \chi^2 \) test was used to compare the population with unruptured aneurysms against the group with ruptured aneurysms. A 2-sided Cochran-Armitage test was used for analysis of binomial trends over time; Pearson’s correlation coefficient was used to test for simple volume trend over time.

For each hospital, we calculated the total procedural volume for the treatment of cerebral aneurysms. This number included all surgical clipping, wrapping, and endovascular therapy of aneurysms (ruptured and unruptured) during the 1995 to 2000 time period, without the exclusion of patients who had prior subarachnoid hemorrhage. This value was chosen to best reflect the overall experience of the hospital in treating cerebral aneurysms. When outcome and cost were analyzed, we looked only at discharges in which the patient had an aneurysm surgically clipped or received endovascular therapy, because surgical wrapping is not considered curative. For each hospital, the percentage of aneurysms treated endovascularly was calculated separately for unruptured and ruptured aneurysms; these diagnosis-specific percentages were used in the statistical analysis.

Generalized estimating equations (GEE) were used to allow observations to be clustered by hospital. Compound symmetry (exchangeable) was selected as the working correlation structure. This is a standard statistical technique used when other variables and characteristics of treatment that affect outcome are thought to exist and expected to cluster within predetermined groups.

For binary outcomes (adverse outcome, in-hospital mortality), the individual data points were modeled as a binomial response, with the overall distribution fit to a logistic regression (link function). Total hospital charges were converted to January 2000 dollars using the medical inflator of the Consumer Price Index. Length of stay and total hospital charges (continuous variables) were transformed by use of the natural logarithm to approximate statistical normality and to limit skew resulting from outliers, and the analysis was limited to patients who survived to discharge. These log-transformed continuous-variable outcomes were analyzed by use of an identity link function and standard normal distribution.

Hospital-related variables were first tested individually. All analyses were corrected for age, sex, race, and ethnicity. A statistical significance level of \( P<0.10 \) was used as a screening cutoff. Those factors achieving this level of significance were then included in a multivariate analysis, with those of greatest statistical significance included first in the model. Only variables achieving statistical significance of \( P<0.05 \) were left in the final multivariate model.

### Table 1. Demographics and Form of Presentation at First Admission For Treatment

<table>
<thead>
<tr>
<th>All Admissions, n</th>
<th>Unruptured Aneurysms</th>
<th>Subarachnoid Hemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admissions, n</td>
<td>5963</td>
<td>2200 (36.9)</td>
</tr>
<tr>
<td>Unique patients, n</td>
<td>5598</td>
<td>2010</td>
</tr>
<tr>
<td>Mean age, y</td>
<td>52.4±13.6</td>
<td>52.5±13.0</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>3940 (70.4)</td>
<td>1474 (73.3)</td>
</tr>
<tr>
<td>Race-ethnicity, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caucasian (67.9)</td>
<td>3153 (62.5)</td>
<td>1229 (69.3)</td>
</tr>
<tr>
<td>Black (15.9)</td>
<td>935 (18.5)</td>
<td>247 (13.9)</td>
</tr>
<tr>
<td>Asian (5.6)</td>
<td>106 (2.1)</td>
<td>24 (1.4)</td>
</tr>
<tr>
<td>Other (10.6)</td>
<td>851 (16.9)</td>
<td>273 (15.4)</td>
</tr>
<tr>
<td>Hispanic (15.1)</td>
<td>489 (10.7)</td>
<td>165 (10.1)</td>
</tr>
<tr>
<td>Non-Hispanic (84.9)</td>
<td>4081 (89.3)</td>
<td>1474 (89.9)</td>
</tr>
<tr>
<td>Unknown ethnicity</td>
<td>1028</td>
<td>371</td>
</tr>
</tbody>
</table>

Data are N (%) or mean±SD as appropriate.

Demographic composition of patients at first presentation for treatment of cerebral aneurysm (clipping, wrapping, or endovascular therapy). Racial and ethnic composition of all admissions at first presentation varied significantly from what would be predicted from census data. Form of presentation (ruptured vs. unruptured) also varied significantly with sex and race. Patients with unknown race or ethnicity were not included in corresponding analysis.

*Percentage of New York State population.
†\( P<0.05 \);
‡\( P<0.001 \); \( P<0.0001 \).

To estimate potentially avoidable adverse outcome and in-hospital mortality resulting from a shift of care to high-volume hospitals, we calculated the average procedural volume for the top 10 high-volume hospitals. For each non–high-volume hospital, we then calculated the expected improvement in outcome (decrease in adverse outcome and in-hospital mortality) predicted by a change in volume from the hospital’s actual volume to the average volume of the high-volume group using our final GEE model. The sum of the increments for each low-volume hospital became the estimated overall improvement in adverse outcome and in-hospital mortality.

Statistical analyses were performed with SAS for Windows, version 8.02 (SAS Institute, Inc), and Stata, version 7.0 (Stata Corp).

### Results

During the 6-year period from 1995 through 2000, there were 13,399 discharges from hospitals in New York State with a primary diagnosis of either subarachnoid hemorrhage or unruptured cerebral aneurysm. Of these, 5963 were admissions in which the patient underwent craniotomy for clipping or wrapping of an aneurysm or received endovascular coiling (Table 1). Of the 257 inpatient hospitals in the state of New York extant during the study period, 113 reported performing at least 1 of these procedures on a patient with subarachnoid hemorrhage or unruptured aneurysm; 19 performed endovascular therapy. Twenty-one hospitals had coverage by neurosurgical residency programs; 14 had dedicated NICUs.

The racial composition of patients treated for aneurysms differed from state census data (Table 1). In addition, blacks and other minorities, as well as men, made up a higher percentage of the group that presented for treatment after
subarachnoid hemorrhage compared with the group presenting with an unruptured aneurysm. When the demographic factors were analyzed together in a multivariate model, race and sex remained significant predictors for presentation after rupture (nonwhite versus white: odds ratio [OR], 1.6; 95% confidence interval [CI], 1.4 to 1.8; \( P = 0.0001 \); male versus female: OR, 1.3; 95% CI, 1.2 to 1.5; \( P = 0.0001 \)).

The Figure shows the trend in volume of procedures during the study period. Volume increased over the 6 years for unruptured and ruptured aneurysms (\( P < 0.001 \)), as did the percentage of admissions involving endovascular therapy, increasing from 3% in 1995 to 15% in 2000 for ruptured aneurysms and from 13% to 24% for unruptured aneurysms (\( P < 0.0001 \) for both groups).

Table 2 shows overall outcome after treatment of aneurysms by surgical clipping or endovascular therapy. There were a total of 5687 procedures performed during 5656 separate admissions, because some patients had clipping and endovascular therapy performed on the same admission. As expected, patients whose aneurysms were treated before they ruptured had better outcomes and used fewer hospital resources. There were no discernible trends in outcome over the 6-year period except for a slight increase in adverse outcomes after treatment of subarachnoid hemorrhage (Table I, available online at http://stroke.ahajournals.org). The statistical significance of this trend (\( P < 0.001 \)) was due to an unusually low number of adverse outcomes in 1995 (48.6%) compared with the remaining years, which averaged 58.9 ± 1.7%; there was no significant trend when this single point was eliminated from the analysis.

**Hospital-Related Factors**

Multivariate analysis was performed separately for unruptured and ruptured aneurysms, and the results for the variables retained in the final model are shown in Table 3. (Complete univariate and multivariate results are shown in Table II, available online at http://stroke.ahajournals.org.) Greater hospital procedural experience was associated with fewer adverse outcomes and in-hospital deaths for both unruptured and ruptured aneurysms and was associated with a decreased length of stay for unruptured aneurysms. The propensity to use embolization (percent embolization) was also associated with fewer adverse outcomes and shorter length of stay for the treatment of unruptured aneurysms but was associated with an increase in hospital charges for ruptured aneurysms. Presence of a neurosurgical residency was correlated only with higher hospital charges for ruptured aneurysms, while presence of an NICU did not remain an independently significant variable in any of the multivariate models.

We also examined the effect of procedural volume separately on outcome after clipping or endovascular therapy (Table 4). Higher volume was associated with better outcome (fewer in-hospital deaths and adverse outcomes) after clipping of both ruptured and unruptured aneurysms. For embolization, however, the association with hospital volume either was not significant or demonstrated a statistically weaker effect.

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**TABLE 2. Overall Outcome After Clipping or Endovascular Therapy for Treatment of Cerebral Aneurysm**

<table>
<thead>
<tr>
<th></th>
<th>By Diagnosis</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Admissions (Including Unruptured Aneurysms With Prior SAH)</td>
<td>Unruptured Aneurysms (Excluding Unruptured Aneurysms With prior SAH)</td>
<td>SAH</td>
</tr>
<tr>
<td>Admissions, n (%)</td>
<td>5656</td>
<td>1792 (31.7)</td>
<td>3645 (64.4)</td>
</tr>
<tr>
<td>Procedures (clipping or endovascular therapy), n (%)</td>
<td>5687</td>
<td>1796 (31.6)</td>
<td>3672 (64.6)</td>
</tr>
<tr>
<td>Adverse outcomes, n (%)</td>
<td>2509 (44.4)</td>
<td>382 (21.3)</td>
<td>2087 (57.3)*</td>
</tr>
<tr>
<td>In-hospital deaths, n (%)</td>
<td>559 (9.9)</td>
<td>44 (2.5)</td>
<td>511 (14.0)*</td>
</tr>
<tr>
<td>Admissions involving endovascular therapy, n (%)</td>
<td>739 (13.1)</td>
<td>361 (20.1)</td>
<td>331 (9.1)*</td>
</tr>
<tr>
<td>Length of stay (95% CI), d</td>
<td>12.6 (12.3–12.9)</td>
<td>6.2 (6.0–6.5)</td>
<td>19.9 (19.4–20.4)*</td>
</tr>
<tr>
<td>Total hospital charges (95% CI), $</td>
<td>45 000 (44 000–46 100)</td>
<td>24 800 (24 000–25 600)</td>
<td>66 300 (64 700–68 000)*</td>
</tr>
</tbody>
</table>

Differences in outcome for treatment of unruptured vs ruptured aneurysms. Statistical comparisons are between patients with subarachnoid hemorrhage (SAH) and patients with unruptured aneurysms without prior SAH.

*\( P < 0.0001 \).
Analysis of High-Volume Hospitals

The 10 hospitals in New York with the highest volume of procedures for aneurysm treatment (clipping, wrapping, endovascular therapy) during the study period accounted for 3064 or 50.4% of the 6074 total procedures. Within this group, there was a considerable range in procedural volume (from 35 to 133 a year) and marked differences in the percentage of cases performed with endovascular therapy (from 1% to 38%). We performed a multivariate analysis examining the effect of procedural volume and percent endovascular therapy, limiting the analysis to the 10 hospitals with greatest overall volume. Procedural experience decreased adverse outcomes for ruptured and unruptured aneurysms (OR for each additional 10 cases performed per year, 0.85; 95% CI, 0.81 to 0.89; \( P < 0.0001 \) for ruptured aneurysms; and OR, 0.89; 95% CI, 0.85 to 0.93; \( P < 0.0001 \) for unruptured aneurysms). Higher rates of treatment by embolization lowered in-hospital deaths for treatment of unruptured aneurysms (OR for each additional 10% of cases done by embolization, 0.68; 95% CI, 0.58 to 0.80; \( P < 0.0001 \)).

We then calculated the potentially avoidable in-hospital mortality and adverse outcome that might derive from directing all aneurysm treatment to the top 10 high-volume hospitals. In absolute numbers, the largest potential improvement in outcome would be projected to occur with the treatment of subarachnoid hemorrhage (Table 5).

### Discussion

We reviewed all hospital discharges from New York State between 1995 and 2000 involving treatment for cerebral aneurysms. We found that the increase in treatment volume during this period came predominantly from an increase in the number of unruptured aneurysms being treated and that endovascular coiling is being used to treat an increasing percentage of both unruptured and ruptured aneurysms. At the institutional level, overall hospital experience treating cerebral aneurysms and the propensity to treat aneurysms with endovascular therapy were both independently associated with improved outcome.

The overall rate for in-hospital death after clipping or coiling of ruptured cerebral aneurysms in New York State was 14%. This is lower than the 15% to 25% mortality generally reported in the literature for follow-up periods ranging from 1 month to 1 year. Part of this difference is due to the fact that our measured mortality rate was limited to in-hospital death, although improvements in surgical technique and hospital care over the past 20 years are undoubtedly contributing factors.

### TABLE 3. Effect of Hospital-Related Variables on Outcome and Resource Utilization

<table>
<thead>
<tr>
<th></th>
<th>Unruptured Aneurysms</th>
<th></th>
<th></th>
<th></th>
<th>Ruptured Aneurysms</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>OR 95% CI P</td>
<td>OR 95% CI P</td>
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<tr>
<td>Adverse outcome</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedural experience</td>
<td>0.89 0.84–0.94 &lt;0.0001</td>
<td>0.94 0.89–0.99 0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent embolization</td>
<td>0.83 0.71–0.98 0.026</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>In-hospital death</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedural experience</td>
<td>0.94 0.90–0.98 0.002</td>
<td>0.95 0.92–0.98 0.005</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Percent embolization</td>
<td>0.95 0.94–0.96 &lt;0.0001</td>
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</tr>
<tr>
<td>Total charges (increase in overall charges)</td>
<td>0.93 0.90–0.96 &lt;0.0001</td>
<td>0.94 0.89–0.99 0.003</td>
<td></td>
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<tr>
<td>Percent embolization</td>
<td>1.07 1.01–1.15 0.034</td>
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<tr>
<td>Neurosurgical residency</td>
<td>1.26 1.06–1.50 0.009</td>
<td></td>
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</tr>
</tbody>
</table>

Table shows multivariate analysis combining hospital related variables. Model was corrected for age, sex, race, and ethnicity. Only variables achieving statistical significance were retained in the final model. Effects of procedural experience are expressed in terms of each additional 10 cases performed per year; effect of embolization is expressed per additional 10% cases done by embolization.

### TABLE 4. Comparison of the Effect of Hospital Volume on Outcome After Clipping Versus Coiling of Cerebral Aneurysms

<table>
<thead>
<tr>
<th></th>
<th>Unruptured Aneurysms</th>
<th></th>
<th></th>
<th></th>
<th>Ruptured Aneurysms</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
<td>Clipping Embolization</td>
</tr>
<tr>
<td></td>
<td>OR 95% CI P</td>
<td></td>
<td></td>
<td></td>
<td>OR 95% CI P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adverse outcome</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clipping</td>
<td>0.85 0.82–0.88 &lt;0.0001</td>
<td>0.94 0.87–1.02 0.116</td>
<td>0.93 0.88–0.99 0.013</td>
<td>0.93 0.91–0.97 0.029</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embolization</td>
<td>0.94 0.90–0.98 0.004</td>
<td>NA</td>
<td>0.93 0.89–0.97 &lt;0.001</td>
<td>0.97 0.92–1.02 0.007</td>
<td>0.97 0.92–1.02 0.007</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NA indicates too few cases for algorithm to converge. Table shows effect of hospital volume on clipping and coiling of cerebral aneurysms separately. Expressed as OR for each additional 10 cases per year in total procedural volume.
TABLE 5. Potentially Avoidable Deaths and Adverse Outcomes per Year

<table>
<thead>
<tr>
<th>Treated at Low Volume</th>
<th>Unruptured Aneurysms</th>
<th>Ruptured Aneurysms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals, n/Total (%)</td>
<td>716/1792 (40)</td>
<td>2093/3645 (57)</td>
</tr>
<tr>
<td></td>
<td>Adverse Outcome</td>
<td>In-Hospital Deaths</td>
</tr>
<tr>
<td>Observed poor outcomes</td>
<td>64</td>
<td>7</td>
</tr>
<tr>
<td>Estimated poor outcomes with selective referral to high-volume hospitals</td>
<td>51 (47–56)</td>
<td>6 (6–7)</td>
</tr>
<tr>
<td>Potential Improvement in aggregate outcome</td>
<td>13 (8–17)</td>
<td>1 (CI 0–1)</td>
</tr>
<tr>
<td>Improvement, %</td>
<td>20</td>
<td>11</td>
</tr>
</tbody>
</table>

Data are n (95% CI) Table shows theoretically avoidable adverse outcomes and in-hospital deaths resulting from selective transfer of all patients with cerebral aneurysms to high-volume hospitals for curative treatment. Because of rounding, estimated poor outcome and potential improvement do not always sum to observed poor outcome.

For unruptured aneurysms, we found a statewide rate for in-hospital mortality of 2.5%. This is virtually identical to the 2.6% rate cited by the Raaymakers et al15 meta-analysis covering studies published between 1966 and 1996, the 2.3% found by the International Study of Unruptured Intracranial Aneurysms,16 and the 3.0% found in the analysis of California discharge data.3 We found a 21.3% rate of adverse outcomes in the treatment of unruptured aneurysms in the New York State data, again quite similar to the 22.4% previously found with discharge data from California.3 It is difficult to compare results for adverse outcome based on discharge data with results from other types of clinical series. Most clinical studies group patients with Glasgow Outcome Scale (GOS) scores of 4 and 5 as good outcome, although this includes patients with permanent disability who are unable to return to work or perform certain household chores. Presumably, many of the patients categorized as poor outcome by virtue of not being sent directly home in discharge studies eventually recover to a Glasgow Outcome Scale score of 4.

The International Study of Unruptured Intracranial Aneurysms (ISUIA) included a more conservative criterion for good outcome, combining mental status changes with disability on the Rankin Scale,16 a method more appropriate for comparison with our data based on discharge destination. The ISUIA showed an overall 1-month morbidity and mortality of 17.5% for patients with no preexisting subarachnoid hemorrhage after surgery compared with the 21.3% that we found for a similar group of patients.

Hospital-Related Factors

We found that hospital-related factors had more of an impact on outcome after treatment of unruptured aneurysms than ruptured aneurysms. This is expected because patients with ruptured aneurysms carry the preexisting morbidity of their subarachnoid hemorrhage. Discharge data sets cannot provide reliable risk stratification by initial neurological condition (eg, Hunt and Hess grade17); thus, our data on subarachnoid hemorrhage patients have less power for identifying the effect of hospital-related factors than our data for unruptured aneurysm patients.

Our results showing independent beneficial effects of both hospital volume and the use of endovascular therapy in the treatment of cerebral aneurysms are supported by earlier outcomes research using New York1 and California3 discharge data sets and Medicare data.2 Conclusions concerning the role of endovascular therapy have been especially controversial in the past.18 Johnston19 has combined ecological variables (variables describing practice styles in a region or institution or the overall surgical volume of an institution) with adjustment for potentially prognostic individual-level variables (age, race, sex) to evaluate the effect of endovascular therapy on outcome after treatment of unruptured cerebral aneurysms. The assumption is that, all things being equal, if endovascular therapy has a better immediate outcome than surgical clipping for any subtype of cerebral aneurysm (subtype based on size, shape, or anatomic location), hospitals with a higher propensity to treat with endovascular therapy will show better outcome statistics. This method avoids the referral bias inherent in the direct comparison of treatment protocols in nonrandomized studies in which patients with a better prognosis may be directed toward a particular type of treatment.19

Using an analysis that combined ecological and individual variables for California State discharge data from 1990 through 1998, Johnston et al3 showed that adverse outcomes were less likely after treatment of unruptured cerebral aneurysms at hospitals with a high percentage (>10%) of cases performed endovascularly (OR, 3.7) and that length of stay was shorter.3 This group also showed that high-volume hospitals had fewer adverse outcomes after treatment of subarachnoid hemorrhage but that propensity to use endovascular therapy was not associated with difference in outcome.20

We performed a similar analysis using New York State discharge data, incorporating further refinements into our analytic methods. We expressed hospital volume and institutional propensity to use endovascular therapy as continuous variables; thus, no arbitrary cutoffs were imposed a priori. In addition, institutional propensity to use endovascular therapy was calculated separately for ruptured and unruptured aneurysms. We
analyzed outcome for subarachnoid hemorrhage and unruptured cerebral aneurysms using the same data set and time period.

Our results demonstrate a broader range of effect of hospital volume. For unruptured aneurysms, hospital procedural experience had beneficial effects on adverse outcomes, in-hospital mortality, and length of stay; higher procedural volume also improved outcome and decreased mortality in the clipping of ruptured aneurysms. Propensity to use embolization was associated with decreasing adverse outcomes and length of stay after treatment of unruptured aneurysms but had no effect on ruptured aneurysms except a modest increase in charges.

These trends continued even among the 10 highest-volume hospitals in New York State. Within this group, the beneficial effect of institutional volume on adverse outcomes for both unruptured and ruptured aneurysms was about as large as it was for the overall state data. Propensity to use endovascular therapy still affected outcome, although it was associated only with decreased in-hospital mortality.

We also found that outcome after embolization of cerebral aneurysms is less affected by overall procedural volume than is clipping of cerebral aneurysms. This is not surprising because endovascular treatment is already limited primarily to high-volume centers, whereas 50% of aneurysm clipping is still done in low-volume settings. In addition, craniotomies for aneurysm clipping are more invasive procedures and require more complicated anesthetic and postoperative care. These results are consistent with (but cannot prove) the finding that outcome after aneurysm clipping is more dependent on both operator experience and the facility of the hospital in providing necessary support for this type of patient.

Regionalization of Services

The desirability of regionalization of medical services and the advantages of selective referral to high-volume hospitals have been discussed for a variety of surgical procedures, including the treatment of cerebral aneurysms. Although we have estimated potentialy avoidable in-hospital deaths and adverse outcomes, the relationship between volume and outcome is an association only. There are many causative factors, and these may differ for improvement in morbidity versus improvement in mortality.

As discussed elsewhere, the benefits of an active regionalization and selective referral program for the treatment of cerebral aneurysms might be fewer than predicted. Some patients might be too unstable for transfer to a referral center, and increased volume at already high-volume hospitals might disrupt patient care by overburdening clinical resources and creating new queues for services. Instituting a regionalized selective referral program might be difficult for political and practical reasons, including issues of insurance coverage. Still, there is evidence that regionalization and selective referral could improve overall outcome. In New York State, efforts to direct cardiac surgery to high-volume surgeons reduced overall mortality by 41% between 1989 and 1992. Regionalization of major surgical procedures (including neurosurgical procedures) in Edmonton, Alberta (Canada), in 1995 resulted in decreased length of stay with no change in mortality rate or readmission rate, although the postregionalization patient population had greater comorbidity. Our data suggest that regionalization might also decrease death and other adverse outcomes after curative treatment for cerebral aneurysms.

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Spontaneous Subarachnoid Hemorrhage: Volume, Experience, and Outcome

In recent years, there has been a trend in neurosurgery and other fields toward both subspecialization (as evidenced by the recent accreditation of the specialty Endovascular Surgical Neuroradiology by the ACGME) and regional specialization. This trend has been propelled by increases in medical and technical knowledge. The current medicolegal environment also has probably fueled this trend. It has been hypothesized that regional specialization permits greater efficiency and improved outcome while minimizing costs and complications. Accordingly, Kalkanis et al examined a cohort of patients with cranial neuralgia who required microvascular decompression. These authors found that higher-volume hospitals and surgeons had better discharge outcomes with fewer complications and more discharges to home. Similarly, Long and colleagues examined patients who received craniotomies for tumor resection. The mortality rates, hospital costs, and length of stay were all more favorable in higher-volume centers.

Focusing on subarachnoid hemorrhage (SAH), Bardach et al reviewed the admission diagnoses of SAH over a 10-year period in California using an available database for nonfederal hospitals. Rates of mortality, adverse outcome, length of stay, and hospital charges were computed and analyzed with multivariate analysis. Hospital volume directly impacted mortality, with the lowest quartile having a 49% rate compared with the highest quartile (32%, \( P<0.001 \)). In multivariate analysis, the difference persisted with an odds ratio of 0.57 (95% CI 0.48 to 0.67, \( P<0.001 \)). In looking at therapy for SAH in patients older than 65 with Medicare, Taylor and colleagues undertook an analysis to determine if a relationship existed between surgical volume and mortality rates. These authors found that surgical treatment of aneurysms improved with the number of craniotomies (>5 craniotomies per year) performed. Johnston and colleagues examined the impact of endovascular therapy in a different cohort. Over a 9-year period, 2069 patients were treated for unruptured aneurysm in California, with 82% undergoing surgery. Adverse outcomes and in-hospital mortality were significantly lower in patients treated with endovascular therapy, as were hospital charges and length of stay.

In this issue of Stroke, Berman and colleagues carried out an analysis of a cohort of patients treated for cerebral aneurysm. Over a 6-year period, these authors obtained information on hospital discharges from a central database in New York State. The diagnosis of SAH or unruptured cerebral aneurysm was used as an inclusion criterion. Data were collected on surgical clipping and endovascular treatment. Adverse outcome was defined appropriately as a discharge to a facility other than home. Rates of mortality and adverse outcome were recorded along with standard demographic data. Both univariate and multivariate analyses were undertaken. However, the focus of the article, through multivariate analysis, was on the relationship to adverse outcome/mortality and hospital volume, length of stay, and cost.

During the 6-year period of 1995 to 2000, 13 399 discharges were related to cerebral aneurysm, with 5963 patients undergoing treatment. Of those treated, 63.1% had suffered SAH. One hundred thirteen of 257 hospitals reported performing either craniotomy for clipping/wraping of an aneurysm and/or endovascular therapy. During this period, the volume of patients treated for cerebral aneurysm increased significantly, as did the frequency for which endovascular therapy was utilized. As expected, patients treated before aneurysm rupture had better outcomes with less use of hospital resources.

Multivariate analyses revealed that greater hospital procedural experience was associated with fewer adverse outcomes and in-hospital deaths for both unruptured and ruptured aneurysms and was associated with a decreased length of stay for unruptured aneurysms. The propensity to use endovascular therapy was also linked to a lower mortality and shorter hospital stay. The outcome from surgical clipping was more favorable in higher-volume centers.

The authors should be commended on their work. This study by Berman and colleagues is a detailed analysis of a cohort of patients with cerebral aneurysms treated at several hospitals with different treatment modalities. All patients appeared eligible for either therapy; no bias was shown toward hospital selection. According to evidence-based guidelines, this cohort analysis would best represent class II data from which a treatment guideline could be drawn. For a disease as complex as cerebral aneurysm, it would not be surprising to observe the results obtained by Berman et al. Hospitals with higher volumes of cerebral aneurysms have more staff and resources dedicated to the treatment of these difficult patients. Consequently, these centers would be expected to have fewer adverse outcomes and in-hospital mortality rates. The conclusion from the study of Berman et al should be that regionalization of SAH treatment be considered.

One must avoid the tendency, though, to conclude that small-volume centers cannot adequately treat SAH and that regionalization of SAH is a simple task. Naso et al evaluated a series of 68 patients who underwent surgical treatment of aneurysms presenting with SAH over a 3-year period. These authors found acceptable clinical outcomes in their series for all grades of SAH patients. Regionalization of SAH may be easier said than done. Many SAH patients may have difficulty tolerating hospital transfer. Other studies have shown that interhospital transfers may have a negative impact on out-
comes. As Berman and colleagues alluded to in their study, many high-volume centers may already be taxed in terms of the acuity of their patients and the availability of resources and staff.

Paul G. Matz, MD, Guest Editor
Division of Neurosurgery
University of Alabama
Birmingham, Alabama

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