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Determinants of Resource Utilization in the Treatment of Brain Arteriovenous Malformations

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BACKGROUND AND PURPOSE: **Preoperative embolization of arteriovenous malformations (AVMs) is thought to improve outcome following surgical resection of these lesions. The purpose of this study was to examine the cost associated with preoperative embolization and different surgical risk categories in the surgical treatment of brain AVMs.**

METHODS: **In a review of 126 patients treated surgically for resection of AVMs, we noted the total days spent in the hospital and calculated the associated costs (from hospital and estimated professional fees). Surgical risk category was determined using the Spetzler-Martin grading system. We examined the effect of risk category, preoperative embolization, and outcome (Rankin score) on cost and inpatient days.**

RESULTS: **Preoperative embolization and greater surgical risk were independently associated with higher total costs. Average adjusted cost for embolization and surgery was $78,400 ± $4,900 versus $49,300 ± $5,800 for surgery alone. Patients ranged in preoperative risk category from Spetzler-Martin grades II through V, with an average increase of $20,100 in total cost per Spetzler-Martin grade (95% CI, $13,500 to $28,100). Higher surgical risk category was also associated with more days spent in hospital, with an average increase of 6 days per increment in Spetzler-Martin grade (95% CI, 4 to 8). After surgical resection of an AVM, new neurologic deficits were associated with large differences in cost: $68,500 ± $6,100 and 15 ± 2 days in hospital for patients who were neurologically worse after surgery, versus $44,700 ± $3,900 and 10 ± 1 days for patients who were unchanged.**

CONCLUSION: **Preoperative embolization in the treatment of AVMs is associated with higher cost but not more days in the hospital. Patients with higher Spetzler-Martin grade AVMs utilize more hospital resources, in part because they have poorer neurologic outcome, and postoperative deficits are associated with higher costs and more days in the hospital.**

Although hemorrhage from cerebral arteriovenous malformations (AVMs) accounts for only 4% of all strokes, the disease primarily affects young people in their most productive years (1, 2). Up to 50% of all AVM patients who do have a hemorrhage die or are left with a permanent neurologic deficit (3–5). Once an AVM is diagnosed, the primary goal of therapy is to prevent subsequent hemorrhage. Complete surgical resection is generally considered the definitive treatment of these lesions.

Many published reports have described the utility of preoperative embolization for patients who are to undergo surgical resection of cerebral AVMs (6–10). The proposed benefits include shorter operating time, decreased blood loss, and the control of deep inaccessible blood vessels. Although most of these reports are descriptive, some of the studies cited used historical control groups to quantitate the advantages of preoperative embolization. Pasqualin et al (8), using a variety of embolic agents and techniques, found a decrease in the rate of new major deficits for the treatment of AVMs in eloquent areas of the brain. Jafar et al (7) presented evidence that, after embolization, large, high-grade AVMs are equivalent in operating time and blood loss to smaller lesions. DeMeritt et al (6) showed that the combination of surgery and embolization produced

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better long-term outcomes than surgery alone, even in a control group of patients with smaller and lower-grade AVMs.

The indications for preoperative embolization are not well defined, owing to the scarcity of studies that have rigorously examined the effects of embolization and to the paucity of data relating to financial cost and cost-benefit analysis. Preoperative embolization does carry additional risk (primarily of hemorrhage or infarct in surrounding brain tissue) and increased financial cost. One study comparing the results of combined surgical/endovascular treatment in 25 patients against published results for surgery alone found a significant savings in cost per quality-adjusted life-year (QALY) (11).

The complexity of a cerebral AVM affects surgical risk, predicted outcome, and, presumably, hospital resource utilization. More complex lesions are more frequently treated with a combination of preoperative embolization and surgery, and any analysis of the effect of embolization on the costs associated with AVM treatment must control for lesion complexity. The Spetzler-Martin grading system for AVMs is a five-step classification for grading AVM complexity that has been shown to correlate with postoperative neurologic complications (12).

We examined our own series of patients with AVMs to analyze the effect of preoperative embolization and surgical risk category on overall cost and days spent in the hospital to establish the relationship between commonly used indicators of surgical risk and resource utilization.

Methods

We retrospectively evaluated the data for 194 patients who had surgical resection of cerebral AVMs at our institution between 1992 and 1998. Of these, 122 patients had undergone preoperative embolization using *N*-butyl cyanoacrylate. In our institution, patients with AVMs are cared for by an interdisciplinary group, including neuroradiologists, neurosurgeons, neurologists, and neuroanesthesiologists. Patient data are maintained in a centralized database containing the results of examinations and procedures performed by all of the involved specialists.

The protocol called for all patients to received formal neurologic examinations by neurologists before being entered into the database, and entries were made before and after all surgical and endovascular procedures and at regular follow-up intervals. Modified Rankin scores were determined for each examination (13). Each AVM was graded using the Spetzler-Martin classification system for lesion size, eloquence of location, and nature of venous drainage (12). Of the 194 patients in the data set, 126 received Spetzler-Martin scores and neurologic examinations before and after their treatment course. The data from this subset of patients were used for analysis.

Costs of treatment included hospital costs for all inpatient and outpatient procedures at our medical center and estimates of professional fees for surgical and endovascular therapy. Patients were generally kept in an intensive care unit overnight following embolization and then discharged to be readmitted later for surgical AVM excision. Hospital charges for each patient were obtained from the medical center's financial system and were converted into costs using the medical center's annual ratio of costs to charges. These costs were adjusted to 1998 prices using the medical inflator of the U.S. government's consumer price index. Professional fees were estimated from Medicare's national physician fee schedule for 1998. Inpatient days were calculated from the total number of days spent in the hospital through all admissions. Data involving preoperative surgical risk and neurologic outcome were taken from a detailed analysis of this data set that appears elsewhere (14).

Statistical Analysis

Data were analyzed using SAS (SAS Institute, Cary, NC) and Statistica (StatSoft, Tulsa, OK) applications. Demographic and clinical characteristics were compared for the embolization and nonembolization groups using χ^2 and *t*-test for independent samples. The difference in Spetzler-Martin scores between these treatment groups was tested using the nonparametric Mann-Whitney *U* statistic. Data for cost and inpatient days were adjusted for nonnormality by applying a square-root transformation.

Analysis of variance (ANOVA) was used to test for an overall effect of Spetzler-Martin score and preoperative embolization on cost and inpatient days. Initial stepwise testing of the variables showed no effect of the interaction term and therefore it was dropped from the analysis. The statistical significance of differences between levels of grouping variables was determined using Gabriel's test. Adjusted means for different groups were calculated using the General Linear Module (SAS Institute). In studies relating surgical risk category to outcome and outcome to resource utilization, patients with normal neurologic status after surgery were grouped with those whose deficits were unchanged after surgery.

Estimates of difference in cost for increments of Spetzler-Martin grade were made using linear regression. Because back transformation to standard units of dollars and days in hospital results in asymmetric expressions for standard error of the mean (SEM), the larger, upside error has been used to describe the dispersion around the mean for adjusted means. This conservative approach is used for clarity and slightly overestimates the SEM. Confidence intervals have been used to describe results from linear regression, again because of asymmetry after back transformation. For the analysis of outcome as a binary dependent variable, logistic regression was used.

Results

Table 1 shows the demographic characteristics of the patients included in the study. Patients who underwent preoperative embolization had significantly larger AVMs ($P < .0001$), and patients with hemorrhage as the presenting symptom were more likely to proceed directly to surgery ($P < .0001$). The distribution of Spetzler-Martin scores is given in Table 2. The scores were higher among the patients who underwent preoperative embolization ($P = .030$). There were no other significant differences between the treatment groups.

Table 3 shows the cost and days spent in hospital for all patient groups. The unadjusted averages shown in Table 4 were calculated for the two treatment groups by combining all surgical risk classes. Unadjusted averages were calculated for the different risk grades as well. Analysis by ANOVA revealed that preoperative embolization and higher Spetzler-Martin grade were independently associated with higher costs ($P < .0001$ for both), whereas only Spetzler-Martin grade was associated with

TABLE 1: Patient demographics

	Embolization and Surgery	Surgery Alone	Total	*P*
No. of patient	91	35	126	
Age (y)	35 ± 13	34 ± 13	35 ± 13	
Sex (M/F)	54/37	18/17	72/54	
AVM size (mm)	35.0 ± 13.0	21.3 ± 12.3	31.2 ± 14.2	<.0001
Hemorrhage as presenting symptom	32/84 (38%)	27/35 (77%)	59/119 (50%)	<.0001

Note.—Values are mean ± S.D.; totals for hemorrhage as presenting symptom do not reach the numbers for each treatment group, because some data for this variable were unavailable.

TABLE 2: Distribution of Spetzler-Martin scores for patients who only had surgery, those who had embolization and surgery, and all patients combined

	No. (%)		
Grade	Surgery	Embolization and Surgery*	All Patients
I	. . .	. . .	. . .
II	5 (14)	6 (7)	11 (9)
III	14 (40)	26 (29)	40 (32)
IV	13 (37)	39 (43)	52 (41)
V	3 (9)	20 (22)	23 (18)
Total	35	91	126
Median grade	III	IV	

* Spetzler-Martin scores were higher among patients who underwent embolization and surgery ($P = .030$).

an increase in inpatient days ($P < .0001$). The effect of preoperative embolization on overall cost (after adjusting for differences in distribution of Spetzler-Martin scores between the two groups) was approximately $30,000: $78,400 ± 4,900 for surgery with embolization versus $49,300 ± $5,800 for surgery alone (mean ± SEM). Figure 1 shows the effect of surgical risk category on cost and days in hospital after adjusting for the average costs associated with embolization. The average increase in cost per increment in Spetzler-Martin grade was $20,100 (95% CI, $13,500 to $28,100). The increase in inpatient days per Spetzler-Martin grade was 6 days (95% CI, 4 to 8 days).

TABLE 4: Cost and days in hospital for all risk categories combined

	Cost (in $1,000)	Days in Hospital
Embolization and surgery	88.8 ± 50.4	18.9 ± 13.7
Surgery alone	51.6 ± 46.8	18.2 ± 25.4
All patients	78.5 ± 52.0	18.7 ± 17.6
Surgical risk (Spetzler-Martin Grade)		
I	. . .	. . .
II	43.9 ± 18.6	8.9 ± 5.5
III	57.3 ± 33.6	12.6 ± 9.2
IV	81.8 ± 46.5	22.8 ± 23.2
V	124.3 ± 67.5	24.8 ± 12.5

Note.—Values are mean ± SD. Analysis by ANOVA showed that preoperative embolization and higher Spetzler-Martin grade were associated with higher costs (both $P < .0001$); higher Spetzler-Martin grade was also associated with more days spent in the hospital ($P < .0001$).

Table 5 shows the relationship between postoperative deficits and overall cost and days spent in the hospital. Long-term postoperative Rankin scores ranged from 0 to 3 (postoperative deaths were excluded from this analysis). We grouped patients with normal neurologic status after surgery with those whose deficits were unchanged. For statistical analysis, the patients were categorized on the basis of the presence of any postoperative change in Rankin score (Fig 2). Postoperative neurologic deficit was shown to be associated with higher costs ($68,500 ± $6,100 versus $44,700 ±

TABLE 3: Total cost and days in hospital by surgical risk category and use of preoperative embolization

Surgical Risk (Spetzler-Martin Grade)		No. of Patients	Cost (in $1,000)	Days in Hospital
I	Embolization and surgery	. . .		
	Surgery alone	. . .		
II	Embolization and surgery	6	50.6 ± 18.3	8.8 ± 4.1
	Surgery alone	5	35.9 ± 17.3	9.0 ± 7.4
III	Embolization and surgery	26	67.9 ± 33.2	13.3 ± 7.8
	Surgery alone	14	37.5 ± 24.7	11.5 ± 11.6
IV	Embolization and surgery	39	88.2 ± 42.6	21.2 ± 16.4
	Surgery alone	13	62.6 ± 54.1	27.5 ± 37.5
V	Embolization and surgery	20	128.5 ± 64.6	24.9 ± 11.9
	Surgery alone	3	96.3 ± 96.1	24.3 ± 19.3

Note.—Values are mean ± SD; no patients had Spetzler-Martin grade-I lesions.

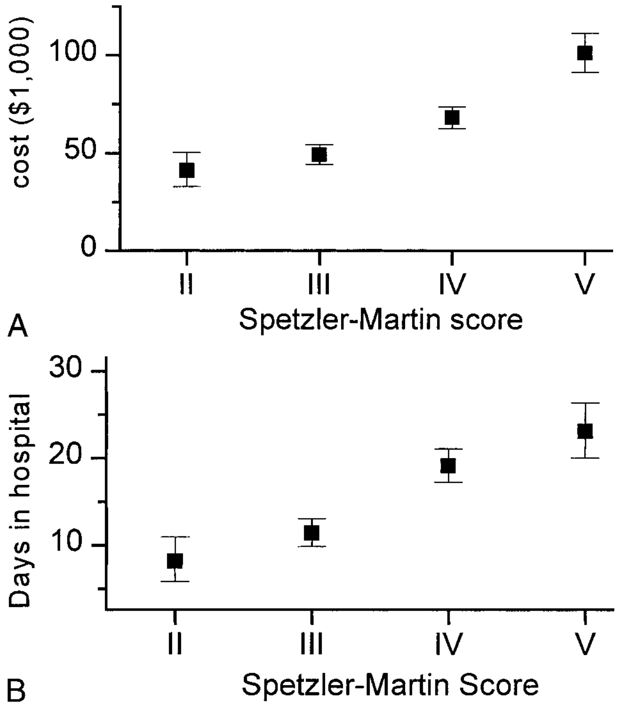

FIG 1. *A,* Surgical risk versus cost (adjusted for cost of embolization). Spetzler-Martin grades V and IV differed from all other grades ($P < .005$ and $P < .05$, respectively).

B, Surgical risk versus days in the hospital (adjusted for effect of embolization). Spetzler-Martin grades V and IV differed from grades III and II ($P < .005$ and $P < .05$, respectively).

All values shown as mean ± SEM.

TABLE 5: Effect of postoperative deficit on cost and days in hospital

Postoperative Deficit (Rankin Score)	No. of Patients	Cost (in $1,000)	Days of Hospital
0	50	54.3 ± 32.7	12.5 ± 9.7
1	24	97.7 ± 56.0	22.9 ± 13.8
2	9	74.9 ± 35.9	12.1 ± 4.34
3	2	144.2 ± 78.2	28.5 ± 6.4

Note.—Results shown as mean ± SD; Rankin group 0 includes patients whose deficits were unchanged after surgery as well as patients with no deficit.

$3,900) and more inpatient days (15 ± 2 days versus 10 ± 1 days) (adjusted means ± SEM, $P = .0005$ and $P = .008$, respectively).

Finally, to address the relationship between cost of embolization and postoperative benefit, we examined our data for an effect of preoperative embolization or Spetzler-Martin score on new postoperative neurologic deficit. As expected, higher Spetzler-Martin scores were associated with worse postoperative status ($P = .010$), with grade V significantly different from other grades (odds ratio, 6.3; 95% CI, 2.0 to 24.6; $P = .003$); the effect of embolization was not significant.

Discussion

Our investigation showed that preoperative embolization in the treatment of AVMs is associated

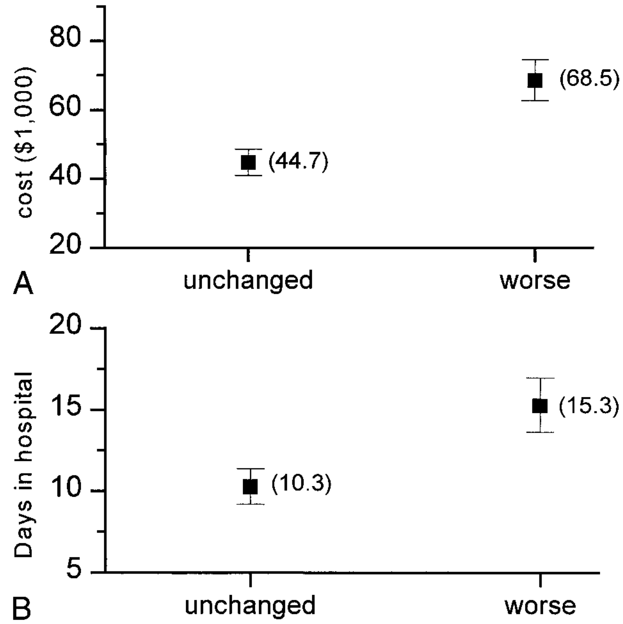

FIG 2. *A,* Postoperative neurologic status versus cost (adjusted for preoperative embolization). Difference in cost was significant ($P = .016$).

B, Postoperative neurologic status versus days in hospital (adjusted for preoperative embolization). Difference in length of stay was significant ($P = .008$).

All values shown as mean ± SEM.

with greater cost, although not necessarily with more days spent in the hospital. This is of significance because preoperative embolization has become a widely used adjunct in the surgical treatment of AVMs (6, 7, 10).

The extra cost relating to embolization varies among hospitals, depending on how the service is administered. For example, differences in the use of an intensive care bed after embolization will affect days in the hospital and overall cost. Regional differences in professional fees and hospital costs also exist.

We found that a higher Spetzler-Martin score correlates with hospital resource utilization, which is consistent with the score's use as a prospective grading system for surgical outcome (12). We were also able to document that patients with new postoperative deficits stayed in the hospital longer and accrued more charges, presumably for evaluation of neurologic change and issues relating to rehabilitation and placement. This represents at least part of the link between Spetzler-Martin grade and cost.

Given the current health care environment and the need to include cost-benefit analysis in the overall decision-making process for treating disease, it has become important to collect cost data on a wide variety of medical procedures. To analyze the treatment of brain AVMs, cost and outcome data will need to be pooled from a variety of medical centers. The biases in our data set—the small number of AVMs with low Spetzler-Martin scores—may reflect our status as a tertiary referral hospital and the fact that smaller, less complicated AVMs are excised closer to the source of referral. It also explains why only one fourth of our patients had surgery without embolization.

Jordan et al (11) have published the only existing cost-benefit analysis of endovascular therapy for the treatment of brain AVMs. Although they found embolization to be advantageous at $6,700 per QALY, the authors did not have the benefit of a standardized outcome score; using nonspecific definitions of morbidity, they derived surgical controls from literature extending to the 1950s. These authors found a cost increment for embolization of approximately 12%, which was calculated using overall institutional averages for surgery and embolization. Our average increment for embolization (59%) was corrected for differences in Spetzler-Martin score and based on actual charges for each patient. Interestingly, the 30% to 40% increment in cost for embolization that Jordan et al cite for the experience in Great Britain is closer to our own results (15). In any case, these differences point out the need for an open comparison of data from a variety of institutions.

We were unable to directly quantitate the benefit in postoperative outcome provided by embolization. The sensitivity of our analysis was limited by the small number of complex AVMs resected without embolization (only three of 23 grade-V lesions received surgery alone). Other potential benefits, such as reduced operating time and less blood loss, would not be recognized by our analysis, because these factors represent a very small part of overall hospital cost and have no direct effect on neurologic outcome. Because postoperative outcome is related to the characteristics of the AVM itself (12), quantitating the benefit of embolization in terms of standardized outcome scores or for cost-benefit analysis will require large numbers of patients and will need to be segmented by preoperative risk class.

Conclusion

We found that higher preoperative surgical risk grades are associated with greater hospital resource utilization (independent of the use of embolization), both in cost and days spent in the hospital, and that preoperative embolization added to the overall cost of care. More information, including cost and outcome data pooled from a variety of institutions, will be needed before decisions on the use of embolization can be based on cost-benefit considerations.

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References

1. Brown RD Jr, Wiebers DO, Torner JC, O'Fallon WM. **Frequency of intracranial hemorrhage as a presenting symptom and subtype analysis: a population-based study of intracranial vascular malformations in Olmsted County, Minnesota.** *J Neurosurg* 1996;85:29–32
2. Ostfeld AM. **A review of stroke epidemiology.** *Epidemiol Rev* 1980;2:136–152
3. Brown RD Jr, Wiebers DO, Forbes G, et al. **The natural history of unruptured intracranial arteriovenous malformations.** *J Neurosurg* 1988;68:352–357
4. Graf CJ, Perret GE, Torner JC. **Bleeding from cerebral arteriovenous malformations as part of their natural history.** *J Neurosurg* 1983;58:331–337
5. Ondra SL, Troupp H, George ED, Schwab K. **The natural history of symptomatic arteriovenous malformations of the brain: a 24-year follow-up assessment.** *J Neurosurg* 1990;73:387–391
6. DeMeritt JS, Pile-Spellman J, Mast H, et al. **Outcome analysis of preoperative embolization with *N*-butyl cyanoacrylate in cerebral arteriovenous malformations.** *AJNR Am J Neuroradiol* 1995;16:1801–1807
7. Jafar JJ, Davis AJ, Berenstein A, Choi IS, Kupersmith MJ. **The effect of embolization with N-butyl cyanoacrylate prior to surgical resection of cerebral arteriovenous malformations.** *J Neurosurg* 1993;78:60–69
8. Pasqualin A, Scienza R, Cioffi F, et al. **Treatment of cerebral arteriovenous malformations with a combination of preoperative embolization and surgery.** *Neurosurgery* 1991;29:358–368
9. Spetzler RF, Martin NA, Carter LP, Flom RA, Raudzens PA, Wilkinson E. **Surgical management of large AVM's by staged embolization and operative excision.** *J Neurosurg* 1987;67:17–28
10. Vinuela F, Dion JE, Duckwiler G, et al. **Combined endovascular embolization and surgery in the management of cerebral arteriovenous malformations: experience with 101 cases.** *J Neurosurg* 1991;75:856–864
11. Jordan JE, Marks MP, Lane B, Steinberg GK. **Cost-effectiveness of endovascular therapy in the surgical management of cerebral arteriovenous malformations.** *AJNR Am J Neuroradiol* 1996;17:247–254
12. Hamilton MG, Spetzler RF. **The prospective application of a grading system for arteriovenous malformations.** *Neurosurgery* 1994;34:2–6
13. van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJ, van Gijn J. **Interobserver agreement for the assessment of handicap in stroke patients.** *Stroke* 1988;19:604–607
14. Hartmann A, Hofmeister C, Sciacca RR, et al. **Determinants of neurologic outcome after surgery for brain arteriovenous malformation.** Paper presented at the annual meeting of the American Academy of Neurology, Toronto, April 1999
15. Nelson M, Bonsor G, Lamb JT. **Cost implications of different policies for the treatment of arteriovenous malformations of the brain.** *Neuroradiology* 1991;33(Suppl):203–205