Microvascular Decompression Surgery in the United States, 1996 to 2000: Mortality Rates, Morbidity Rates, and the Effects of Hospital and Surgeon Volumes

Steven N. Kalkanis, M.D.
Neurosurgical Service, Massachusetts General Hospital, and Department of Surgery, Harvard Medical School, Boston, Massachusetts

Emad N. Eskandar, M.D.
Neurosurgical Service, Massachusetts General Hospital, and Department of Surgery, Harvard Medical School, Boston, Massachusetts

Bob S. Carter, M.D., Ph.D.
Neurosurgical Service, Massachusetts General Hospital, and Department of Surgery, Harvard Medical School, Boston, Massachusetts

Fred G. Barker II, M.D.
Neurosurgical Service, Massachusetts General Hospital, and Department of Surgery, Harvard Medical School, Boston, Massachusetts

Reprint requests:
Fred G. Barker II, M.D., Brain Tumor Center, Massachusetts General Hospital, Cox 315, 32 Fruit Street, Boston, MA 02114.
Email: barker@helix.mgh.harvard.edu

Received, October 15, 2002.
Accepted, February 18, 2003.

OBJECTIVE: Microvascular decompression (MVD) is associated with low mortality and morbidity rates at specialized centers, but many MVD procedures are performed outside such centers. We studied short-term end points after MVD in a national hospital discharge database sample.

METHODS: A retrospective cohort study was performed by using the Nationwide Inpatient Sample, 1996 to 2000.

RESULTS: The sample included 1326 MVD procedures for treatment of trigeminal neuralgia, 237 for treatment of hemifacial spasm, and 27 for treatment of glossopharyngeal neuralgia, performed at 305 hospitals by 277 identified surgeons. The mortality rate was 0.3%, and the rate of discharge other than to home was 3.8%. Neurological complications were coded in 1.7% of cases, hematomas in 0.5%, and facial palsies in 0.6%, with 0.4% of patients requiring ventriculostomies and 0.7% postoperative ventilation. Trigeminal nerve section was also coded for 3.4% of patients with trigeminal neuralgia, more commonly among older patients ($P = 0.08$), among female patients ($P = 0.03$), and at teaching hospitals ($P = 0.02$). The median annual caseloads were 5 cases per hospital (range, 1–195 cases) and 3 cases per surgeon (range, 1–107 cases). With adjustment for age, sex, race, primary insurance, diagnosis (trigeminal neuralgia versus hemifacial spasm versus glossopharyngeal neuralgia), geographic region, admission type and source, and medical comorbidities, outcomes at discharge were superior at higher-volume hospitals ($P = 0.006$) and with higher-volume surgeons ($P = 0.02$). Complications were less frequent after surgery performed at high-volume hospitals ($P = 0.04$) or by high-volume surgeons ($P = 0.01$). The rate of discharge other than to home was 5.1% for the lowest-volume-quartile hospitals, compared with 1.6% for the highest-volume-quartile hospitals. Volume and mortality rate were not significantly related, but three of the four deaths in the series followed procedures performed by surgeons who had performed only one MVD procedure that year. Length of stay (median, 3 d) and hospital volume were not significantly related. Hospital charges were slightly higher at higher-volume hospitals ($P = 0.007$).

CONCLUSION: Although most MVD procedures in the United States are performed at low-volume centers, mortality rates remain low. Morbidity rates are significantly lower at high-volume hospitals and with high-volume surgeons.

KEY WORDS: Microvascular decompression, Mortality rate, Volume-outcome relationship

Neurosurgery 52:1251-1262, 2003 DOI: 10.1227/01.NEU.0000065129.25359.EE www.neurosurgery-online.com

There is increasing evidence that patient mortality and morbidity rates are lower when complex medical or surgical procedures are performed at high-volume centers or by high-volume physician providers. For example, in-hospital mortality rates are lower when complex cancer operations (5, 16), cardiovascular operations (6), or peripheral vascular operations (11) are performed at high-volume hospitals. Within neurosurgery, lower rates of adverse outcomes have been documented after surgical repair of intracranial aneurysms by high-volume surgeons (9) or at high-volume hospitals (1, 20, 34).

For many surgical procedures, the anticipated risks of the operation and perioperative care vary substantially among individual patients, in association with well-understood risk factors. For example, the risk of postoperative facial paresis after acoustic neuroma resection is strongly dependent on tumor size. Because such studies are observational in nature, imbalances in risk factors among patients treated by high- and low-volume providers (referred to as "case mixture") can bias the results of these studies if they are not properly measured and adjusted for. However, these risk factors are often not recorded in the large administrative databases that are used for volume-outcome studies.

Microvascular decompression (MVD) offers a relatively pure model of the volume-outcome relationship, for several reasons. First, preoperative morbidity rates are low, because syndromes treated with MVD rarely cause systemic debility. Alternative treatments that are less invasive than MVD, such as radiofrequency gasserian ganglion lesioning, radiosurgery, and botulinum toxin injection, are usually chosen for patients with significant medical comorbidity who might otherwise have been candidates for MVD. In-hospital mortality rates and rates of discharge other than to home are thus likely to represent adverse outcomes of care, rather than consequences of the presenting disease. Second, the severity and duration of syndromes treated with MVD are not known to be risk factors for death or morbidity after MVD procedures. Although vascular compression by a dolichoectatic vertebrobasilar system probably poses a slightly higher risk of cranial nerve morbidity (23), there is no known reason why such patients should preferentially present to lower-volume hospitals or surgeons. Third, posterior fossa microsurgery is often thought to be technically demanding. Limited exposure, deep working area, and the potential severity of adverse outcomes that can result from postoperative infarction or swelling are all characteristic of operations in the posterior fossa. The volume-outcome relationship is often studied in the context of technically demanding surgery, because relatively minor surgical errors more frequently result in measurable adverse outcomes.

We studied the volume-outcome relationship for MVD procedures performed in a representative sample of United States hospitals between 1996 and 2000. Specifically, we related the chance of adverse outcomes (in-hospital death, outcome at hospital discharge, complications of surgery, length of stay, and hospital charges) to annual hospital and surgeon caseloads of MVD procedures, as well as to other patient and provider characteristics.

PATIENTS AND METHODS

We obtained the Nationwide Inpatient Sample (NIS) hospital discharge database for the years 1996 to 2000 from the Healthcare Cost and Utilization Project, Agency for Healthcare Research and Quality (Rockville, MD) (35). The NIS is a hospital discharge database that represents approximately 20% of all in-patient admissions to nonfederal hospitals in the United States. For these years, the NIS contains discharge data on 100% of discharges from a stratified random sample of nonfederal hospitals in 19 to 28 states. Hospitals are selected for inclusion in the database with the use of a stratified sampling technique that is intended to produce a representative 20% subsample of all United States nonfederal hospital discharges, so that conclusions drawn from the database can be confidently generalized to the entire United States medical community. Because the NIS contains data on all patients discharged from sampled hospitals during the year, regardless of age or payer, it can be used to determine the total annual volumes of specified procedures at individual hospitals. For many states, a code identifying the surgeon who performed the principal procedure is also included. An overview of the NIS is available at http://www.ahcpr.gov/data/hcup/nisintro.htm.

Inclusion and Exclusion Criteria and Definition of End Points

We defined MVD for treatment of trigeminal neuralgia (TN), hemifacial spasm (HFS), and glossopharyngeal neuralgia (GPN) as follows. MVD for treatment of TN was defined as an admission with a primary diagnosis code of 350.1 (TN) and a primary procedure *International Classification of Diseases, 9th Revision–Clinical Modification* (ICD-9-CM) code of 04.41 (decompression of trigeminal nerve root). MVD for treatment of HFS was defined as an admission with a primary diagnosis code of 351.8 (facial nerve disorders) and a primary procedure code of 04.42 (other cranial nerve decompression), and MVD for treatment of GPN was defined as an admission with a primary diagnosis code of 352.1 (GPN) and a primary procedure code of 04.42.

Two primary end points were examined in this study, i.e., in-hospital death and discharge to institutions other than home. In-hospital death was coded directly in the NIS database and was analyzed by using logistic regression. Because there were few deaths (four in the sample), we performed limited analyses of death, to avoid overfitting (10, 31); death was correlated only with age, hospital caseload adjusted for age, and surgeon caseload adjusted for age. Discharge to institutions other than home was coded on a four-level scale and was analyzed by using ordinal logistic regression, which allows use of the entire spectrum of outcomes, rather than simplifying to a single cutoff point, with resultant loss of information (27, 29, 36). Discharge was coded as death, discharge to a long-term care facility, discharge to another facility, or discharge home, as follows. NIS data distinguish discharge to long-term care facilities (such as skilled nursing facilities) from discharge to intermediate-term care facilities or other facilities for all states except California and Maryland; for those states, we coded these discharges (0.4% of the total) as discharge to another facility. We considered discharge home with home health care or home intravenous therapy (4.2% of discharges) as discharge home. Discharge to another acute-care hospital (0.4%) was counted as discharge to an institution other than home, not as discharge to a long-term care facility.

Length of stay and total hospital charges were coded in the NIS data. Length of stay and hospital charge analyses included only patients discharged alive from the hospital.

Length of stay and hospital charge data were highly positively skewed and were analyzed as logarithmic transforms.

Patient Characteristics

Patient age, sex, and race, median household income for the ZIP code of residence, primary payer (Medicare, Medicaid, private insurance, self-pay, no charge, or other), type of admission (emergency, urgent, or elective), and admission source (emergency ward, transfer from another hospital, transfer from a long-term care facility, or routine) were coded in the NIS data. Two cases (0.1%) with admission type of "other" were recoded as routine admissions. More than 5% of discharges had missing values for two variables used principally as stratification factors for other analyses, i.e., race (22% missing) and admission type (17% missing). When these variables were used as stratification factors, missing values for race and admission type were imputed as follows. Missing race was set to white. Missing admission type was set to emergency for admissions from the emergency ward, to urgent for admissions transferred from other hospitals, and to routine for admissions from other sources. To assess the effect of general medical comorbidity, the set of 30 medical comorbidity markers described by Elixhauser et al. (12), with exclusion of the two specific neurological comorbidity variables (paralysis and other neurological deficits) and three comorbidity variables likely to represent postoperative conditions (fluid and electrolyte disorders, blood loss anemia, and deficiency anemias), were calculated by using Agency for Healthcare Research and Quality software (www.ahcpr.gov/data/hcup/comorbid.htm) and were summed to yield a single comorbidity score, with possible values between 0 and 25.

We used ICD-9-CM Procedure Code 04.02 to identify patients who underwent trigeminal nerve section as well as MVD. We identified potential markers of specific adverse outcomes of care for MVD patients, i.e., postoperative neurological complications, including infarction or hemorrhage (ICD-9-CM Codes 997.00–997.09); hematoma complicating a procedure (Codes 998.1–998.13); mechanical ventilation (Codes 96.70–96.72); facial palsy (Code 351.0); trigeminal nerve disorder, otherwise unspecified (Code 350.8); performance of a ventriculostomy (Code 02.2); and physical therapy consultation (Codes 93.01–93.59).

Provider and Hospital Characteristics

Hospital region (Northeast, Midwest, South, or West), location (rural or urban), teaching status, and bed size (small, medium, or large) were coded in the NIS data. We derived hospital and surgeon volumes of MVDs for each year by counting the cases for each identified surgeon and hospital in the database. Because both hospital and physician volume variables were positively skewed, logarithmic transforms were used when measures of volume were entered into regression models.

Statistical Methods

Statistical methods included Fisher's exact test, Wilcoxon rank-sum test, Spearman rank correlation, and log-linear, ordinary, and proportional-odds ordinal logistic regressions (15, 17, 26). To correct for possible clustering of similar outcomes within hospitals, which could result in falsely inflated estimates of the statistical significance of regression coefficients, a sandwich variance-covariance matrix was estimated from the data by using methods attributable to Huber and White, with adjustment for clustering by hospital (15). Length of stay and hospital charges were analyzed as logarithmic transforms by using least-squares regression, corrected for clustering as described above. Calculations were performed by using Statistical Analysis System (Version 8.2; SAS Institute, Cary, NC) and S-plus (Version 3.3 for Windows; Insightful, Inc., Seattle, WA) software, with the Hmisc and Design modeling function software libraries attributable to Harrell (14, 15) and the LOCFIT local-likelihood regression library attributable to Loader (24, 25). All P values are two-tailed.

RESULTS

There were 1326 admissions for MVD for treatment of TN, 237 admissions for MVD for treatment of HFS, and 27 admissions for MVD for treatment of GPN. Clinical characteristics of the 1590 patients are presented in *Table 1*. Most patients were white, with ages between 45 and 70 years, and there were more women than men. Most admissions were classified as routine, and admission through the emergency ward or as a transfer from another hospital was unusual. Calculated annual caseloads for all United States nonfederal hospitals during the study period were 1326 cases for TN, 245 cases for HFS, and 26 cases for GPN. There were no upward or downward trends in the annual number of cases during the study period and no trends in patient age with time. (The apparent excess of cases in the database for 1999 was attributable to the inclusion of one very high-volume institution that year alone.) Four patients died (0.3%), 17 were discharged to long-term care facilities (such as skilled nursing facilities) (1.1%), 39 were discharged to other facilities (such as rehabilitation hospitals) (2.5%), and 1530 were discharged home (96.2%).

Patient Characteristics and Outcomes

We tested five demographic variables as potential outcome predictors, i.e., age, sex, race, income in the ZIP code of the patient's residence (a surrogate measure for patient income), and primary payer for care. Age was a significant predictor of both death (odds ratio [OR], 2.1 per decade; 95% confidence interval [CI], 1.01–4.2; $P = 0.046$) and outcome at hospital discharge (OR, 2.4; 95% CI, 1.9–3.2; $P < 0.001$) (*Fig. 1*). Other demographic variables were analyzed only in relation to four-level outcomes at discharge. Sex, race, and income in the ZIP code of residence were not significant predictors of discharge outcome. The primary payer for care was associated with discharge outcome in univariate analyses, because of worse

TABLE 1. Clinical characteristics of 1590 patients who underwent microvascular decompression

Age (yr)	
Mean	57
Median	57
Interquartile range	47–68
Range	12–89
Female sex	1002 (63%)
Race (n = 1240)	
White	1036 (84%)
Black	64 (5%)
Hispanic	65 (5%)
Asian/Pacific Islands	43 (3%)
Native American	4 (0.3%)
Other	28 (2%)
Median household income for ZIP code of residence (n = 1492)	
< $25,000	142 (10%)
$25,000 to $34,999	476 (32%)
$35,000 to $44,999	407 (27%)
> $45,000	467 (31%)
Primary payer (n = 1581)	
Medicare	495 (31%)
Medicaid	60 (4%)
Private insurance	959 (61%)
Self-pay	21 (1%)
No charge	4 (0.2%)
Other	42 (3%)
Admission type (n = 1313)	
Emergency	61 (5%)
Urgent	105 (8%)
Routine	1145 (87%)
Admission source (n = 1566)	
Emergency ward	39 (2.5%)
Transfer from acute-care hospital	7 (0.4%)
Transfer from long-term care facility	27 (2%)
Routine	1493 (95%)
Year of treatment	
1996	240 (15%)
1997	259 (17%)
1998	231 (15%)
1999	526 (34%)
2000	334 (21%)
Diagnosis	
Trigeminal neuralgia	1326 (83%)
Hemifacial spasm	237 (15%)
Glossopharyngeal neuralgia	27 (2%)

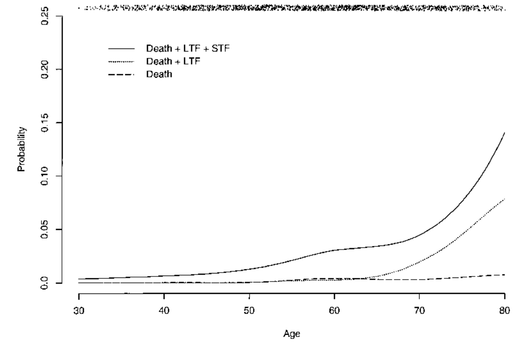

FIGURE 1. *Effects of age on the probability of death or discharge other than to home after MVD, plotted using local-likelihood fitting.* Dashed line, *death;* dotted line, *death or discharge to a long-term care facility* (LTF*);* solid line, *death or discharge to a long-term care facility or a short-term care facility* (STF*).* Bar along top, *scatterplot showing the age distribution of the sample; each* dot *represents one patient admission.*

outcomes among patients with Medicare insurance; with adjustment for age, however, there was no correlation between the primary payer for care and discharge outcome. All subsequent analyses were adjusted for age, sex, race, and primary payer, in addition to hospital geographic region and primary diagnosis (TN, HFS, or GPN).

Four variables related to acuity of patient presentation and patient medical comorbidity were tested as outcome predictors, i.e., admission type (described as emergency, urgent, or routine), admission source (routine outpatient versus other, such as through the emergency ward or transferred from an acute-care hospital or long-term care facility), whether or not the MVD procedure was performed on the first hospital day, and a summed score based on the presence of any of 25 common medical comorbidities. In models adjusted for the demographic variables outlined above and testing the four acuity/comorbidity variables as a group, the comorbidity score was a significant predictor of outcome (OR, 1.5 for worse outcome with each 1 point higher on the comorbidity scale; 95% CI, 1.1–2.0; $P = 0.004$), with a trend toward worse outcomes for patients with admission types other than routine outpatient (OR, 3.5; 95% CI, 0.8–15; $P = 0.1$). Age remained highly significant as an outcome predictor in this model.

Provider Characteristics and Outcomes

Surgery was performed at 305 hospitals in 27 states, by 277 identified surgeons. Hospitals and surgeons had widely varying annual caseloads of MVD procedures. As analyzed on a per-patient basis, the annual median caseload for hospital volume was 5 admissions (range, 1–195 admissions; 25th percentile, 2 admissions; 75th percentile, 19 admissions), and the median caseload for surgeon volume was 3 admissions (range, 1–107 admissions; 25th percentile, 1 admission; 75th percentile, 23 admissions). A total of 222 MVD operations (14%) were the only MVD procedures performed that year at that hospital, and 245 operations (29%) were the only MVD procedures performed that year by that surgeon.

We tested both hospital and surgeon annual caseloads of MVD procedures as outcome predictors. Both measures were highly significant outcome predictors, with larger annual caseloads for each being associated with better outcomes. We report ORs for the importance of hospital and surgeon caseloads for a 10-fold difference in caseloads, because this approximates the difference between the 25th and 75th percentiles for caseloads. In a multivariate analysis adjusted for the demographic and acuity/comorbidity variables described above, a 10-fold larger hospital caseload was associated with significantly better outcomes (OR, 0.50; 95% CI, 0.31–0.82; $P = 0.006$), as was a 10-fold larger surgeon caseload (OR, 0.30; 95% CI, 0.11–0.80; $P = 0.02$). Age and comorbidity remained significant predictors of outcome at discharge in the multivariate model ($P < 0.001$ for both). *Figure 2* presents the probability of discharge other than to home for operations at hospitals grouped by caseload into four quartiles and for surgeons similarly grouped. Discharge other than to home occurred after 5.1% of admissions (22 of 428 cases) for MVD at hospitals with annual caseloads of one or two admissions, compared with 1.6% of admissions (6 of 385 cases) at hospitals with annual caseloads of 20 admissions or more. The corresponding rates for surgeon caseloads were 6.1% of admissions (15 of 245 cases) for surgeons with annual caseloads of one case and 0.5% of admissions (1 of 208 cases) for surgeons with annual caseloads of 29 or more. The OR for worse outcome in a comparison of lowest- versus highest-volume-quartile hospitals was 3.4 (95% CI, 1.4–8.5), and that in a comparison of lowest- versus highest-volume-quartile surgeons was 14 (95% CI, 1.8–103). After adjustment for the annual hospital caseload, neither hospital teaching status ($P = 0.4$) nor hospital bed size ($P = 0.9$) was a significant additional predictor of outcome at hospital discharge.

The differences in outcomes with high- and low-volume hospitals and surgeons varied according to patient age. *Figure 3* presents the probability of discharge other than to home as a function of age for the highest- and lowest-volume-quartile hospitals and surgeons. Older patients demonstrated a much greater difference between highest- and lowest-volume providers, with respect to the probability of discharge other than to home. The difference between highest- and lowest-volume surgeons was larger than the difference between highest- and lowest-volume hospitals for all patient ages.

We tested patient characteristics as potential predictors of care at high-volume hospitals (*Table 2*) or by high-volume surgeons. Older patients were less likely to be treated at a high-volume hospital ($P < 0.001$) or by a high-volume surgeon ($P = 0.002$). Race was a significant predictor of both hospital volume ($P = 0.02$) and surgeon volume ($P = 0.008$), with higher provider volumes for white patients and lower volumes for black patients. The primary payer for care was a significant predictor of both hospital and surgeon volumes ($P = 0.002$ for both), with highest provider volumes for those

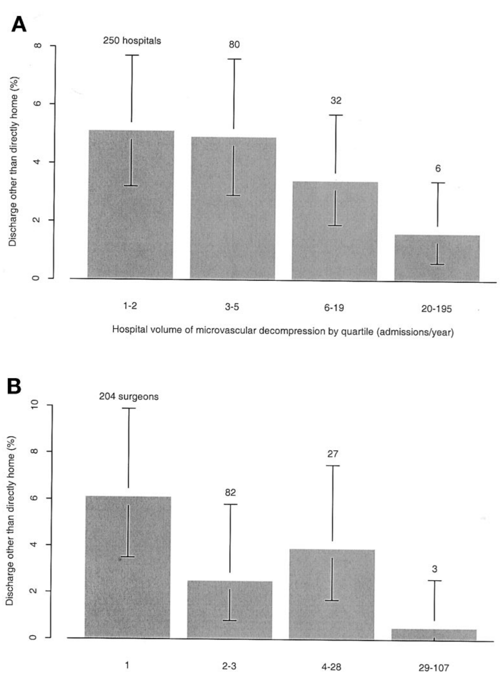

FIGURE 2. *Bar graph showing the probability of discharge other than to home as a function of hospital (A) and surgeon (B) volumes of MVD procedures, by quartile. The relationship between larger caseloads and better outcomes was significant in multivariate analyses for hospitals (P = 0.006) and surgeons (P = 0.02).*

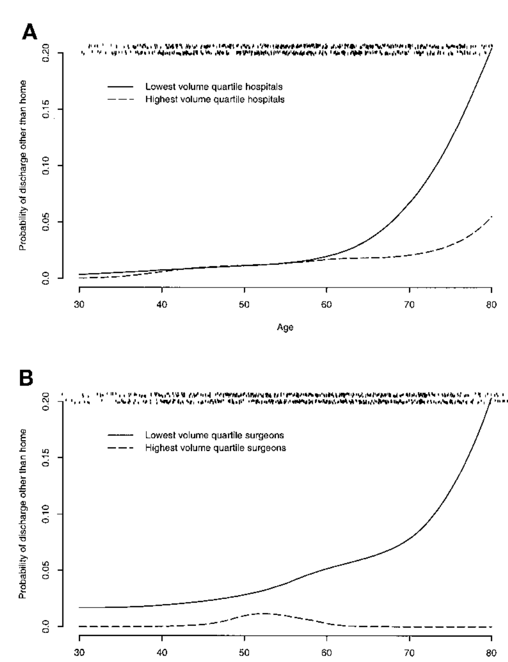

FIGURE 3. *Probability of discharge other than to home as a function of age for the highest- and lowest-volume quartiles of hospitals (A) and surgeons (B), plotted using local-likelihood fitting.* Bars along top, *scatterplots showing the age distribution of the sample; each* dot *represents one patient admission.*

TABLE 2. Patient characteristics in high- and low-volume hospitals

	Low-volume (1 or 2 cases/yr)	High-volume (≥20 cases/yr)
Age (yr) (median)	59	56
Female sex	260/428 (61%)	244/385 (63%)
Race		
White	262/319 (82%)	301/350 (86%)
Black	20/319 (6.3%)	13/350 (3.7%)
Primary payer		
Medicare	146/426 (34%)	95/383 (25%)
Medicaid	19/426 (4%)	13/383 (3%)
Private insurance	236/426 (55%)	269/383 (70%)
Median household income for ZIP code of residence		
< $25,000	55/408 (13%)	14/370 (4%)
$25,000 to $34,999	150/408 (37%)	98/370 (26%)
$35,000 to $44,999	103/408 (25%)	93/370 (25%)
> $45,000	100/408 (25%)	165/370 (45%)
Rural (versus urban) (hospital location used as proxy)	21/427 (5%)	0/385 (0%)
Admission type		
Emergency	21/373 (6%)	3/254 (1%)
Urgent	45/373 (12%)	6/254 (2%)
Routine	305/373 (82%)	245/254 (96%)
Admission source		
Emergency ward	13/417 (3%)	0/385 (0%)
Transfer from acute-care hospital	2/417 (0.5%)	1/385 (0.3%)
Transfer from long-term care facility	1/417 (0.2%)	0/385 (0%)
Routine	401/417 (96%)	384/385 (99.7%)
Diagnosis		
Trigeminal neuralgia	372/428 (87%)	285/385 (74%)
Hemifacial spasm	53/428 (12%)	89/385 (23%)
Glossopharyngeal neuralgia	3/428 (1%)	11/385 (3%)

with private insurance. Patients from higher-income areas of residence had higher-volume hospitals and surgeons ($P < 0.001$ for both). Diagnoses of HFS or GPN were more commonly treated at high-volume hospitals and by high-volume surgeons ($P < 0.001$ for both). Emergency or urgent admissions were more common for low-volume hospitals ($P < 0.001$) and surgeons ($P = 0.005$), and admissions other than routine outpatient were also more common for low-volume hospitals ($P = 0.06$) and surgeons ($P = 0.007$). Patients with more medical comorbidity tended to be treated at lower-volume hospitals ($P = 0.001$) and by lower-volume surgeons ($P = 0.002$).

We performed limited analyses of mortality data, because there were only four in-hospital deaths in the group. With adjustment for patient age, hospital caseload was not a significant mortality predictor ($P = 0.4$) but surgeon caseload was ($P < 0.001$). Of the three deaths for which surgeon caseload data were available, all occurred after surgery performed by physicians for whom no other admissions for MVD were reported that year. *Figure 4* presents mortality rates according to hospital and surgeon caseloads, plotted by quartile.

Complications and Provider Volume

We identified several ICD-9-CM codes that corresponded to apparent complications of surgery or perioperative care, i.e., postoperative neurological complications, including infarction or hemorrhage (reported for 27 of 1590 patients, 1.7%); hematoma complicating a procedure (8 patients, 0.5%); mechanical ventilation (11 patients, 0.7%); facial palsy (10 patients, 0.6%); trigeminal nerve disorder, otherwise unspecified (0 patients); performance of a ventriculostomy (6 patients, 0.4%); and phys-

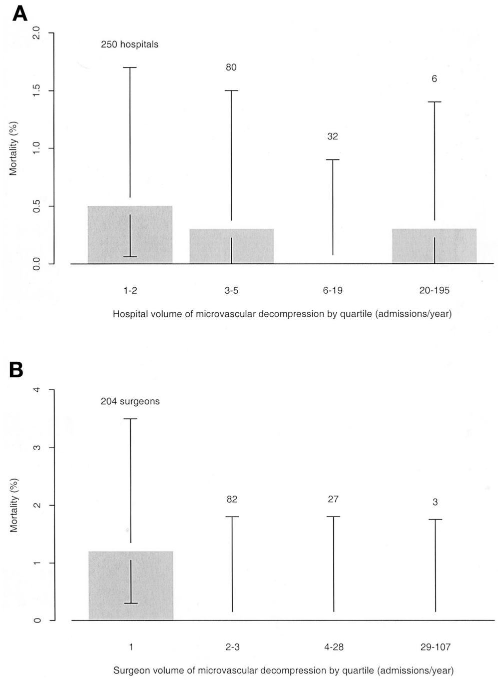

FIGURE 4. *Bar graph showing the probability of in-hospital death as a function of hospital (A) and surgeon (B) volumes of MVD procedures, by quartile. The relationship between larger caseloads and lower mortality rates was significant in multivariate analyses for surgeons (P < 0.001) but not for hospitals (P = 0.4).*

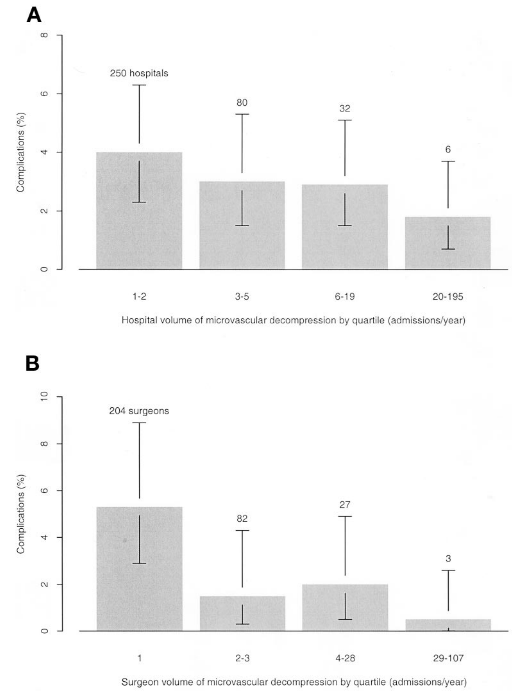

FIGURE 5. *Bar graph showing the probability of postoperative complications as a function of hospital (A) and surgeon (B) volumes of MVD procedures, by quartile (see text for definition of complications). The relationship between larger caseloads and lower complication rates was significant for both hospitals (P = 0.04) and surgeons (P = 0.01).*

ical therapy consultation (21 patients, 1.3%). One or more of these diagnoses, excluding physical therapy consultation, was coded for 47 patients (3.0%). The presence of one or more of these diagnoses was significantly correlated with worse outcome at hospital discharge (in a multivariate analysis adjusted for the variables described above; OR, 19; 95% CI, 7.4–46; $P <$ 0.001). Neither age ($P = 0.4$) nor primary diagnosis ($P = 0.8$) had any effect on complication probability in a multivariate model.

In multivariate models with correction for the variables described above, a complication was less likely to occur after surgery at a high-volume hospital or with a high-volume surgeon. ORs for occurrence of a complication were 0.59 for a 10-fold larger hospital caseload (95% CI, 0.35–0.98; $P = 0.04$) and 0.32 for a 10-fold larger surgeon caseload (95% CI, 0.13–0.77; $P = 0.01$). Compared with hospitals or surgeons in the highest-volume quartile, complications were approximately twice as frequent at lowest-volume hospitals (OR, 2.2; 95% CI, 0.9–5.4) and approximately 12 times as frequent with low-volume surgeons (OR, 11.6; 95% CI, 1.5–89). *Figure 5* and *Tables 3* and *4* present the probability of the occurrence of one or more of these five coded complications in relation to hospital and surgeon caseloads, by quartile. Hospital caseload was a significant predictor of neurological complications, and surgeon caseload was a significant predictor of neurological complications, hematoma-related complications, facial palsy, and ventriculostomy placement (*Tables 3* and *4*).

Length of Stay and Hospital Charges

The length of stay decreased significantly during the study period, from a median of 4 days in 1996 to 3 days in 2000 ($P =$ 0.002). With multivariate adjustment for the variables described above, as well as stratification by year of treatment, there was no significant relationship between length of stay and hospital volume, although there was a trend toward shorter stays at higher-volume hospitals ($P = 0.4$). Teaching hospitals had significantly shorter stays than did nonteaching hospitals ($P = 0.004$). There was no significant correlation between hospital bed size and length of stay, although there was a trend toward longer stays at larger hospitals ($P = 0.09$).

Total hospital charges increased significantly during the study period, from a median of $15,600 in 1996 to $20,100 in 2000. With multivariate adjustment for the variables described above, as well as stratification by year of treatment, total hospital charges were significantly higher at higher-volume institutions (22% higher for a 10-fold larger caseload; 95% CI, 5.5–41%; $P = 0.007$). There was no significant relationship between hospital charges and either hospital teaching status ($P = 0.2$) or hospital bed size ($P = 0.3$).

Concurrent Trigeminal Nerve Section

Some surgeons prefer to combine a partial trigeminal sensory rhizotomy with MVD for treatment of TN, particularly when vascular compression of the trigeminal nerve root entry

TABLE 3. Complications of microvascular decompression in relation to annual hospital caseloads

	No. of cases				P value[a]
	1 or 2 admissions/yr	3–5 admissions/yr	6–19 admissions/yr	≥20 admissions/yr	
Neurological complications	9/428 (2.1%)	9/370 (2.4%)	6/407 (1.5%)	3/385 (0.8%)	0.04
Hematoma	2/428 (0.5%)	2/370 (0.5%)	3/407 (0.7%)	1/385 (0.2%)	0.3
Mechanical ventilation	7/428 (1.6%)	1/370 (0.3%)	0/407 (0.0%)	3/385 (0.8%)	0.2
Facial palsy	4/428 (0.9%)	1/370 (0.3%)	3/407 (0.7%)	2/385 (0.5%)	0.8
Ventriculostomy	2/428 (0.5%)	1/370 (0.3%)	2/407 (0.5%)	1/385 (0.2%)	0.3
Physical therapy consultation	7/428 (1.6%)	4/370 (1.1%)	5/407 (1.2%)	5/385 (1.3%)	0.8

[a] P value calculated for each complication type separately, in multivariate models including demographic, acuity, and comorbidity variables.

TABLE 4. Complications of microvascular decompression in relation to annual surgeon caseloads

	No. of cases				P value[a]
	1 admission/yr	2 or 3 admissions/yr	4–28 admissions/yr	≥29 admissions/yr	
Neurological complications	9/245 (3.7%)	3/199 (1.5%)	2/205 (1.0%)	0/208 (0.0%)	0.02
Hematoma	2/245 (0.8%)	0/199 (0.0%)	0/205 (0.0%)	0/208 (0.0%)	<0.001
Mechanical ventilation	3/245 (1.2%)	0/199 (0.0%)	0/205 (0.0%)	1/208 (0.5%)	0.9
Facial palsy	2/245 (0.8%)	0/199 (0.0%)	2/205 (1.0%)	0/208 (0.0%)	0.04
Ventriculostomy	3/245 (1.2%)	0/199 (0.0%)	0/205 (0.0%)	0/208 (0.0%)	<0.001
Physical therapy consultation	6/245 (2.4%)	2/199 (1.0%)	4/205 (2.0%)	2/208 (1.0%)	0.7

[a] P value calculated for each complication type separately, in multivariate models including demographic, acuity, and comorbidity variables.

zone is less impressive during surgery (4, 8, 21, 42, 43). Trigeminal nerve section was coded during the index admission for 45 of 1326 patients with TN (3.4%). Trigeminal nerve section was not significantly associated with either outcome at hospital discharge ($P = 0.8$) or a coded complication ($P = 0.2$). In a multivariate model, trigeminal nerve section was more common among older patients ($P = 0.08$), among female patients ($P = 0.03$), and at teaching hospitals ($P = 0.02$). Neither hospital caseload ($P = 0.8$) nor surgeon caseload ($P = 0.9$) was significantly associated with the probability of trigeminal nerve section.

DISCUSSION

We studied 1590 admissions for MVD procedures performed at United States nonfederal hospitals between 1996 and 2000, using a database that represents a 20% stratified random sample of all hospital admissions during that period. The in-hospital mortality rate was 0.3%, and a total of 3.8% of patients either died or were not discharged directly home. One or more of five common postoperative complications were coded for 3.0% of patients. Care provided by higher-volume hospitals and surgeons was followed by lower mortality rates, better outcomes at hospital discharge, and fewer complications of care. These benefits were more commonly experienced by patients who were younger, healthier, and white, who had private insurance, and who resided in wealthier areas. Hospital charges for higher-volume care were significantly higher.

MVD for treatment of TN, HFS, and GPN was introduced in the late 1960s and was largely popularized by Jannetta and coauthors (2, 3, 18, 19, 28, 32). For TN and HFS, which are the primary diagnoses for most MVD procedures (98% of the cases in this series), less-invasive alternative treatments for patients with medically intractable conditions are widely available. TN can be treated with percutaneous surgical procedures, such as radiofrequency lesioning of the gasserian ganglion, glycerol rhizolysis, or balloon microcompression, as well as with radiosurgical lesioning of the trigeminal nerve root. HFS can be treated with botulinum toxin injections into the affected facial musculature. These less-invasive treatments are widely perceived as being safer than posterior fossa microsurgery, a perception that is almost certainly correct.

However, MVD offers significant advantages, compared with alternative treatments, for both TN and HFS. For TN, MVD offers rates of success (free of pain, without medication) that are superior or at least equal to those of other reported treatments, with substantially lower rates of facial numbness. For HFS, MVD offers total relief from spasm for most patients, without further treatment, whereas botulinum toxin injections are often only modestly effective in abolishing spasm and require lifelong treatments, repeated several times each year. Many patients are willing to submit to a slightly higher treatment risk to obtain these benefits, but the perceived magnitude of the risk is of paramount importance in their decision. Dr. William Sweet, a passionate advocate of percutaneous thermal rhizotomy for treatment of TN, commented that "when I have finished giving an account of the comparative features of the percutaneous versus open procedures, in all but a few instances, the patient says, 'I'll take the one where almost nobody has died yet' " (39, p 871).

One important question is, "how many die?" In early reports, the postoperative mortality rate for MVD was approximately 1% (37). Taha and Tew (41) reported an aggregate mortality rate of 0.6% for several large series of MVD procedures for treatment of TN that were described in the 1980s and early 1990s. On the basis of a 1985 poll of heads of major neurosurgical services, Sweet reported that "the incidence of mortality and major morbidity was far higher among most less-experienced surgeons" (37, p 177). Although large series of MVD procedures with low or zero mortality rates have been reported (7, 13, 28), the results achieved at hospitals that are not specialized centers for MVD remain unknown, as does the overall proportion of MVD surgery that is performed at lower-volume hospitals.

Our study demonstrated that a significant proportion of MVD procedures performed in the United States between 1996 and 2000 were performed at lower-volume hospitals and by lower-volume surgeons. We observed that 14% of MVD operations were performed at hospitals that reported no other MVD procedures that year and 29% of operations were performed by surgeons who reported no other MVD procedures that year. The median annual provider volume of MVD procedures was low, i.e., five cases/yr for hospital caseload and three cases/yr for surgeon caseload. Despite these low volumes, the in-hospital mortality rate for MVD procedures for the entire patient group was low (0.3%). Most patients (96.2%) were discharged directly home, and rates of coded serious complications were low.

Although adverse events and outcomes were infrequent, a relationship between higher provider volumes of care and better outcomes was apparent in our data. Specifically, higher-volume providers (hospitals and surgeons) demonstrated lower in-hospital mortality rates, fewer complications, and better outcomes at hospital discharge, as measured with a four-level scale (dead, discharged to a long-term care facility, discharged to another facility, or discharged directly home), especially for older patients (*Fig. 5*). Most of these relationships were statistically significant after multivariate adjustment for factors such as age, acuity of presentation, and important medical comorbidities. This adjustment was necessary because of imbalances in the case mixture between high- and low-volume hospitals and surgeons with respect to these factors, which were also correlated with adverse outcomes. Unmeasured imbalances in other risk factors between patients treated by high- and low-volume providers could have biased our results, but there are few established risk factors for adverse outcomes for MVD surgery. Reoperations pose higher risks to cranial nerves than do first craniotomies for MVD (22), but only one patient demonstrated a procedure code corresponding to reopening of the craniotomy site, and this might have represented a reexploration during hospitalization. A dolichoectatic vertebrobasilar system as the source of compression has been suggested to be a risk factor for cranial nerve complications after MVD (23). Our database did not contain information on the nature of the vessel causing neurovascular compression. Of the risk factors for vertebrobasilar dolichoectasia as a cause of TN that were identified by Linskey et al. (23), older age was more common at lower-volume hospitals, but associated hypertension was not related to hospital or surgeon caseload in our patient group (data not shown) and the combination of TN and HFS (tic convulsif) was treated at hospitals with annual MVD caseloads of five cases or more in seven of the nine cases we identified in our data. These considerations, combined with the rarity of vertebrobasilar dolichoectatic compression as a cause of TN or HFS, make it unlikely that an imbalance in the distribution of such cases between high- and low-volume providers could have strongly influenced our conclusions.

We observed that the difference in outcomes between high- and low-volume providers was greater for the oldest patients in the series (*Fig. 3*). For patients more than 65 years of age, the difference in outcomes was substantial; 13% of such patients who underwent surgery at the lowest-volume-quartile hospitals were not discharged directly home, compared with 2% of those who underwent surgery at the highest-volume-quartile hospitals. Why the volume-outcome effect should vary with age is not known. Older patients may have less functional reserve for adapting to mild cerebellar or vestibular injuries or poorer support systems after discharge, with greater anticipated difficulty coping with relatively mild deficits. If support at home for older patients treated at lower-volume hospitals was perceived as being poorer than that for similar patients treated at higher-volume hospitals (e.g., because of poorer socioeconomic status), then this could have biased our study in the direction of the effect we observed.

There have been few prior studies of the volume-outcome relationship in MVD surgery. In the mid-1980s, Sweet distributed a questionnaire to 49 neurosurgical services, requesting information regarding how many MVDs had been performed and what complications had occurred. He judged from the replies that major complications at low-volume hospitals were more frequent than would be expected from literature reports from specialized centers (38, 40). Other studies demonstrated a "learning curve" for MVD surgery, at the level of the individual surgeon (7) and institution (2, 28, 30, 33). Those studies demonstrated decreases in the rates of complications (usually hearing loss) as individuals or institutions gained greater experience with MVD, which reinforces our conclusions.

An important goal for volume-outcome studies is to determine the processes of care that differ between high- and low-volume providers. Ideally, by adopting processes favored by high-volume centers, low-volume providers could improve outcomes. We did identify some procedures whose frequencies differed between high- and low-volume centers, but these seemed likely to be responses to complications of care at the low-volume centers. For example, codes indicating computed tomographic or magnetic resonance imaging assessments of the brain were more common at low-volume hospitals (data not shown), as were codes corresponding to lumbar puncture or decompression of the spinal canal (presumably lumbar drainage to treat cerebrospinal fluid [CSF] leaks; data not shown). One potential difference between providers is the use of intraoperative hearing monitoring, which has been noted by several groups to correlate with lower complication rates (2, 28, 33). We could not examine hearing monitoring use because there is no ICD-9-CM code for the procedure.

An examination of the secondary diagnoses for patients who died revealed that all had experienced either a postoperative neurological complication, with or without infarction, or a hematoma complicating the procedure. These complications are usually associated with cerebellar retraction or occlusion or kinking of a cerebral vessel. Jannetta and coauthors (28) emphasized the importance of avoiding cerebellar retraction through proper exposure and CSF drainage from the basal cisterns; avoidance of vascular trauma or kinking is axiomatic.

We were unable to assess some adverse outcomes of MVD because of deficiencies or ambiguity in ICD-9-CM coding. Although there are ICD-9-CM codes for CSF otorrhea and rhinorrhea (nine patients in the series), there is no code for CSF leakage through a surgical incision. There is no code for unilateral hearing loss; only two patients demonstrated sensorineural hearing loss codes, and hearing loss codes do not indicate laterality or the presence of the deficit at the time of hospital admission. Facial numbness corresponds most closely to "trigeminal nerve disorder, unspecified," but no patients in the group demonstrated the code for this diagnosis or corneal anesthesia or hypesthesia. Other important measures of MVD success, such as relief of TN, HFS, or GPN, were not addressed in our study because this information is not contained in the NIS database.

Some differences between patients treated by high- and low-volume providers in our cohort seemed to correspond to acuity of presentation, such as emergency or urgent admission or admission as a transfer from another hospital. Urgent presentation was more common at low-volume facilities. However, other differences between patients of high- and low-volume providers, such as race, insurance, and income in the area of residence, may indicate a lack of ready access to high-volume care for some populations. Alternatively, some patients may choose low-volume institutions or surgeons for other reasons, such as proximity to home or familiarity with the hospital or surgeon. Further research will be necessary to determine whether the imbalances we observed represent unequal access to quality care or conscious choices based on factors other than provider volume.

CONCLUSIONS

In a series of MVD procedures representative of the United States medical community between 1996 and 2000, we observed that death and serious complications resulting from MVD were infrequent and that outcomes at hospital discharge were generally favorable. However, important differences in adverse outcomes between high- and low-volume providers did exist, with patients of high-volume providers experiencing lower mortality and morbidity rates and fewer complications. The difference in outcomes at hospital discharge was most important for older patients.

We studied the safety of MVD, rather than its efficacy in relieving symptoms, because of the limitations of our data source. Some differences between patients of high- and low-volume providers, such as race, insurance status, and median income in the area of residence, suggest a lack of free access to high-quality MVD care for some populations. These important topics require further research. However, our findings should be of interest to patients seeking high-quality MVD care and to physicians responsible for advising them.

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COMMENTS

This contribution by Kalkanis et al. is very welcome, because it offers a candid rigorous analysis of the effects of hospital and surgeon volumes on the rates of complications after microvascular decompression (MVD) of the nerves in the posterior fossa. The study included 1590 patients who underwent MVD procedures performed by 277 surgeons between 1996 and 2000, in 305 hospitals in the United States. The surgical procedure examined (i.e., standard decompression of Cranial Nerve V, VII, or IX, which does not present great variations in difficulty) and the system for evaluation of the related mortality and morbidity rates (data obtained from the hospital discharge database and not from published articles) provide the perfect model for this type of investigation. The results of the rigorous precise elaboration of the data are generally as expected, namely, that complications are less frequent among patients treated at high-volume hospitals and by high-volume surgeons. With more expert and proficient surgeons and higher levels of hospital care, results are better; we have always thought this. Overall, the results presented are interesting not only because they support what we believed but also because the data can be examined from different points of view. In my opinion, what needs to be emphasized is the present high level of safety of MVD procedures in the United States; 1590 treated patients exhibited a 0.3% mortality rate, a 3% morbidity rate, and a median length of stay in the hospital of less than 4 days, with 96.2% of patients being discharged directly home. Excellent overall outcomes such as these, which were obtained even with the contributions of 245 surgeons with one annual MVD operation, indicate the extremely high standard of care provided by the neurosurgical community in the United States. This report is very important, and the authors provide data that contribute to a general overview of the quality of care. On the basis of these findings, the results reported for some published MVD series could appear almost too good to be true.

Albino Bricolo
Verona, Italy

The report is an important one. As with other technical procedures, including cardiovascular surgery and vascular surgery (1), volume is correlated with outcomes. This is especially important in an era in which the population has begun to age and, as observed for cardiovascular surgery, there is a trend toward increasing numbers of patients in the seventh, eighth, and ninth decades of life undergoing procedures. This is based on both quality of life issues and increased lifespan. It can be anticipated that similar issues will arise with the treatment of trigeminal neuralgia. As Barker et al. (2) correctly pointed out, percutaneous procedures are perceived as being safer and stereotactic radiosurgery has been proposed for patients who are older or less able to tolerate anesthesia. At the Peter J. Jannetta Cranial Nerve Disorder Clinic, our experience has been that the age of the patient is the least important factor in the preoperative evaluation, when considered in conjunction with medical comorbidities, vascular abnormalities, and blood dyscrasias, as expected. This report supports the concept that patients can be expected to fare well in the appropriate setting.

In addition, we think this report allows individual surgeons to correlate their own results, examine their own complication rates, assess hospital resources, and measure themselves against a standard. This is especially important in an era in which all surgeons strive to maintain the quality of their care and services and search for areas of improvement. This article contributes to that effort.

Kenneth F. Casey
Peter J. Jannetta
Pittsburgh, Pennsylvania

1. Bardach NS, Zhao S, Gress DR, Lawton MT, Johnston SC: Association between subarachnoid hemorrhage outcomes and number of cases treated at California hospitals. **Stroke** 33:1851–1856, 2002.
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In recent years, patients have commonly asked their physicians, "how many of this procedure have you performed in the last year?" I suspect that most neurosurgeons probably do not know the exact number of each type of operation they perform, so they tend to provide an optimistic estimate if the procedure being discussed is either interesting or well reimbursed. Aside from the issue of honest disclosure to individual patients, the important question is whether centralized care for relatively rare disorders or procedures benefits society by providing more effective care to a greater proportion of the population. I strongly think that it does.

This study by Kalkanis et al. compared patient outcomes after MVD operations performed at high-volume hospitals and by high-volume surgeons, compared with low-volume hospitals and surgeons. With the use of a nationwide database for the years 1996 to 2000, the rates of hospital discharges to locations other than home were determined to be significantly lower for hospitals that performed more than 20 MVD procedures annually (1.6%) and for surgeons who performed more than 29 MVD procedures annually (0.5%). Moreover, complications that could be detected with this method (stroke, facial palsy, ventriculostomy, and physical therapy consultation) were twice as frequent at the lowest-volume hospitals and 12 times more common with low-volume surgeons. Recognizing the limitations of their work, the authors concluded that, although the majority of MVD procedures are performed at low-volume centers, outcomes are better at high-volume hospitals and with high-volume surgeons. On the basis of my experience, I completely agree with those conclusions. The authors have provided a thoughtful and significant contribution to the literature on trigeminal neuralgia.

Bruce E. Pollock
Rochester, Minnesota

The authors demonstrate that the mortality associated with MVD is significantly lower when performed by high-volume surgeons and that morbidity is lower for high-volume surgeons and high-volume hospitals. Overall mortality was low (0.3%). Specifically, a significant risk of neurological complications, hematoma, facial palsy, and ventriculostomy was demonstrated when low- and high-volume surgeons were compared. The article effectively demonstrates a difference between low- and high-volume surgeons and hospitals, which is an intuitive conclusion as well. The effect of this difference on patient decision making can only be guessed at, but I suspect it would be entirely in the manner of presentation. On the basis of the data reported in this article, the risk of death could be expressed as 0.3%, which is low for major brain surgery. As presented in the article, this figure pertains only to in-hospital deaths. A better mortality rate to use to inform patients of the mortality risk might be the risk of death within 30 days after surgery. The risk of neurological complications could be expressed either as between 0 and 3.7% or as, for example, "12 times higher" in comparing one surgeon with another on the basis of the experience level of each surgeon. The way in which each patient—or each primary care physician, for that matter—would probably make the decision is unique to each individual. The problem with studies of this sort is that medicine has been and remains an individual-dependent service, and these studies can study only trends or tendencies. Large teaching hospitals can have low-quality surgeons on staff, just as small hospitals may have good surgeons. Overall, this article is a valuable contribution to the literature on MVD, but the fundamental problems with trying to apply generalized information to specific surgeons and hospitals must be recognized.

Kim J. Burchiel
Portland, Oregon