Effect of Endovascular Services and Hospital Volume on Cerebral Aneurysm Treatment Outcomes

S. Claiborne Johnston, MD, MPH

Background and Purpose—Endovascular coil embolization and angioplasty for cerebral vasospasm are offered by some centers for the treatment of unruptured and ruptured cerebral aneurysms. Whether the availability of these therapies improves outcomes at these institutions has not been evaluated.

Methods—We assessed institutional factors in the outcomes of patients treated for cerebral aneurysms in the academic medical centers of the University Health Systems Consortium. In-hospital deaths (primary outcome), length of stay, and hospital charges were evaluated in multivariable models adjusted for age, sex, race, admission source, and admission status.

Results—There were 2623 unruptured and 9534 ruptured aneurysm cases treated at 70 centers in the University Health Systems Consortium hospital discharge database during 1994–1997. Patients treated at institutions that more frequently used coil embolization were less likely to die in the hospital (relative risks [RRs] for every 10% of endovascular-treated cases: ruptured aneurysms: RR, 0.91; 95% CI, 0.86 to 0.96; \( P = 0.001 \); unruptured aneurysms: RR, 0.84; 95% CI, 0.78 to 0.91; \( P < 0.001 \)). Patients treated at institutions that used angioplasty for vasospasm had a 16% reduction in risk of in-hospital death compared with patients treated at other institutions (RR, 0.84; 95% CI, 0.71 to 0.98; \( P = 0.03 \)). Hospital treatment volume was not independently associated with in-hospital death.

Conclusions—Patients treated for cerebral aneurysms at institutions offering endovascular services have lower rates of in-hospital mortality. Whether this is due to improved outcomes with endovascular therapy or is a marker for other aspects of multidisciplinary care cannot be answered in this analysis. (Stroke. 2000;31:111-117.)

Key Words: angioplasty ■ cerebral aneurysm ■ endovascular therapy ■ subarachnoid hemorrhage ■ surgical treatment

Endovascular coil embolization, a technique for treating cerebral aneurysms, has been used more and more frequently since its introduction in 1991.\(^1,2\) It is generally performed by neuroradiologists and provides an alternative to neurosurgical aneurysm clipping at some institutions. Current data comparing surgical clipping with endovascular coil embolization are largely limited to case series, as reviewed in 2 recent meta-analyses.\(^2,3\) In addition, a single large-cohort study from the University Health Systems Consortium (UHC) suggested better outcomes in patients with unruptured aneurysms treated by endovascular techniques, but this study could not rule out the possibility that the association was produced by selection of lower-risk aneurysms for coil embolization.\(^4\) Furthermore, combining neuroradiologists and vascular neurosurgeons in multidisciplinary services provides additional benefits by increasing treatment options, and this has not been evaluated.

For studies of ruptured aneurysm treatment, selection bias may be a particularly difficult problem. Prognosis after rupture is largely determined by preprocedural neurological condition, as demonstrated by Hunt and Hess,\(^5\) and this may be an important factor in determining how an aneurysm is treated, resulting in selection bias. Without randomization, any analysis directly comparing outcomes between treatments is suspect, even after risk adjustment, since differences in unknown or unmeasured risk factors may remain.

Changing the focus of the analysis to a comparison of institutions rather than individuals can bypass the issue of selection bias at the patient level.\(^6\) Consider a pool of patients at an institution that uses a new therapy. Patients selected for the new therapy would have received the old therapy if the new treatment were not available. If the new therapy is safer, patients who received it, regardless of how they were selected, will benefit, and overall outcomes at the institution will improve. Therefore, selection of treatment for individual patients should not bias the evaluation of institutional outcomes. Differences in institutional patient populations may still produce bias, but these differ-
ences are expected to be smaller and easier to identify and control.6

To utilize the advantage of group-level analysis in reducing selection bias, we evaluated institutional treatment in a cohort study of all ruptured and unruptured aneurysms treated in UHC hospitals. The UHC database includes 80 US academic medical centers with 2.1 million hospital discharges per year.7 Medical centers involved in education are more likely to use endovascular therapy but also may provide other advantageous services, such as devoted neurological intensive care.8 By restricting analysis to academic medical centers, we attempted to reduce this potential for confounding. Furthermore, 2 previous studies found that institutions treating more aneurysms had lower rates of in-hospital death,9,10 and therefore it was important to adjust for institutional volume as another potential confounder. A multivariable model was developed to adjust for individual and institutional risk factors while accounting for clustering of outcomes by hospital.

Subjects and Methods

Study Cohort

To develop a cohort of patients treated for ruptured and unruptured cerebral aneurysms at academic medical centers, we searched the UHC hospital discharge database from January 1994 through June 1997 for unruptured aneurysms and through December 1997 for ruptured aneurysms. A listing of the institutions contributing cases to the study is provided in the Appendix.

Development of the cohort of unruptured aneurysm patients has been previously described.4 Briefly, we included patients with a primary diagnosis of unruptured aneurysm (International Classification of Diseases, Ninth Revision [ICD-9] 437.3) and 1 of 2 procedure codes for aneurysm treatment (ICD-9 39.51 or 39.52). To validate the information in the UHC database, it was compared with a detailed medical record review for all patients treated at the largest volume center, the University of California at San Francisco (UCSF). We identified a potential source of bias: endovascular cases were more likely to return for follow-up coil embolization of the same aneurysms, and these admissions were relatively low risk and inexpensive. To eliminate this bias, we identified individual patients from medical record numbers (6-digit identity required), age, and race and combined all admissions for a given patient. In this way, we produced a single course of therapy for which hospital length of stay and charges were summed, and outcome was taken as the most adverse for all admissions.

In addition, we found that the ICD-9 code for endovascular treatment of an aneurysm was also used for surgical wrapping. Classifying patients by the predominant procedure performed by the operating physician eliminated this misclassification in the UCSF patients and presumably reduced it at other UHC institutions. The predominant procedure was defined by the ICD-9 procedure code used in a majority of a given physician’s cases. Using these strategies for reclassifying patients, we found that diagnoses, treatment variables, and outcomes were reliable compared with UCSF medical records, and all subsequent analyses were performed on this final, corrected cohort.

For ruptured aneurysms, we searched the UHC database for primary diagnosis of subarachnoid hemorrhage (ICD-9 430). To limit the cohort to ruptured aneurysms, we excluded patients with a secondary diagnosis of arteriovenous malformation or fistula (ICD-9 747.81), treatment diagnosis for arteriovenous malformation repair or radiosurgery (ICD-9 39.53 or 92.30), or secondary diagnosis of head trauma (ICD-9 800 to 803.9 and 850 to 854.9) in patients who did not receive aneurysm treatment. As for the unruptured aneurysms, all admissions for a given patient were combined, and procedure was classified as the predominant therapy of the operating physician based on other cases in the database.

Predictor Variables and Outcomes

Patient age, sex, race, admission source (transfer, emergency department, other), and admission status (emergent, urgent, elective) were included in all multivariable models. Institutional variables included yearly volume, percentage of cases treated by endovascular technologies, and institutional availability of angioplasty for vasospasm (identified as a single case of subarachnoid hemorrhage with treatment code ICD-9 39.50 during the study period). All institutional level variables were added into the multivariable models so that the independent contribution of each factor could be assessed.

In-hospital death was chosen as the primary outcome because it was important and likely to be correctly specified. A functional outcome measure was not available in the database, although discharge to home was previously shown to correlate with Rankin score at discharge.7 Secondary outcomes included discharge to home (expected for the majority of unruptured aneurysm cases, in whom pretreatment disability is unusual11,12), hospital charges as reported to UHC, and length of stay. Hospital length of stay and charges were analyzed only for patients surviving to discharge since institutions with higher mortality rates could appear to have shorter lengths of stay and lower charges otherwise.

Statistical Analysis

Choosing the values of continuous variables at which categories are defined can introduce a bias if choices are made during data analysis. To avoid this, all cut points were established a priori. Hospital treatment volume was divided into quartiles at the institutional level for univariate analysis and was treated as a continuous variable in multivariable analysis. In univariate analyses, use of endovascular techniques was evaluated by dividing institutions into those treating ≥10% or <10% of aneurysms with coil embolization; we assumed that those institutions treating ≥10% by endovascular techniques were using the technique as an acceptable treatment alternative. For multivariable analyses, the portion of cases treated by endovascular techniques was defined as a continuous variable. Institutional availability of angioplasty for vasospasm was treated as a binomial variable in all analyses.

For univariate analyses, categorical variables were evaluated with Pearson’s χ² test; for treatment volumes, quartiles 1 and 4 were compared. We used the Wilcoxon rank sum test to compare hospital charges and lengths of stay since these variables were skewed13 (a few complicated patients remained in the hospital for long periods of time). To evaluate variability between institutions, the 10th to 90th percentile range of input variables and outcomes was determined at the institutional level.

In multivariable analysis, we were interested in assessing institutional factors in the individual risk of patients. Since predictor variables and outcomes are clustered by institution with correlation between patients at a given institution, logistic regression, which ignores correlation, would tend to overestimate the precision of model coefficients. Therefore, we used generalized estimating equations to account for correlation at the institutional level and provide more accurate CIs14; equal correlation between all intercenter observations (compound symmetry) was chosen as the covariance structure. Odds ratios were converted to relative risks [RRs] so that results could be more readily interpreted.15

For analysis of continuous variables in multivariable analysis, we also used generalized estimating equations. Lengths of stay and hospital charges were transformed by using their natural logs in the models. In this way a normal distribution could be approximated by reducing the positive skew in these data. We confirmed that normal distributions were approximated by comparing the actual distribution of model residuals with an idealized normal distribution using q-q plots. The Stata statistical package was used for all analyses (version 5.0, Stata Corporation).

The validation portion of this study was approved by the UCSF institutional review committee, and subjects gave informed consent.
Results

Univariate Analysis

During the study period, there were 9534 patients treated for ruptured aneurysms at 70 university hospitals and 2623 patients treated for unruptured aneurysms at 64 centers (Table 1). Institutions varied widely in the demographics of treated patients, in the use of endovascular techniques, and in the yearly volume of cases treated, as demonstrated by the broad 10th to 90th percentile intervals. Institutional outcomes, such as in-hospital deaths, discharges to home, length of stay, and hospital charges, were variable as well.

Treatment volumes were divided into quartiles by institution (for ruptured aneurysms: quartile 1, 0 to 16 cases per year; quartile 2, 17 to 31; quartile 3, 32 to 45; and quartile 4, >45; for unruptured aneurysms: quartile 1, 0 to 3 cases per year; quartile 2, 4 to 8; quartile 3, 9 to 14; and quartile 4, >14). In univariate analysis, greater institutional volume was associated with reduced risk of in-hospital death and briefer lengths of stay (Table 2). For ruptured aneurysms, patients in quartile 4 of volume were more likely to be discharged home but had greater hospital charges compared with quartile 1.

However, institutions with larger volumes tended to treat more patients transferred from other hospitals (quartile 1 versus quartile 4, 25% versus 45% transfers; \( P < 0.0001 \) by chi-squared test), and these patients tended to do better (transfers versus other sources of admission, 19% versus 26% in-hospital deaths; \( P < 0.0001 \)). When the analysis was stratified by source of admission, the benefit of treatment at a higher volume institution was no longer apparent (in-hospital deaths in quartile 1 versus quartile 4: for emergency department cases, 31% versus 28%; \( P = 0.33 \); for transfer cases, 19% versus 16%; \( P = 0.45 \)).

Use of endovascular therapies increased during the study period. Angioplasty for vasospasm was not performed in 1994 and occurred in 4.1% of cases in 1997 (\( P < 0.0001 \) by Fisher’s exact test). The use of coil embolization for ruptured aneurysms steadily increased from 2.0% of treated aneurysms in 1994 to 7.5% in 1997 (\( P < 0.0001 \)) but increased little for unruptured aneurysms, from 9% to 11% of cases (\( P = 0.27 \)).

Use of endovascular techniques was associated with fewer in-hospital deaths in univariate analysis (Table 2). The mortality difference persisted whether the cut point was set at offering the technique (\( P = 0.006 \)), 5% treated (\( P < 0.001 \)), or 20% treated (\( P < 0.001 \)). Coil embolization was used in \( \geq 10\% \) of cases at 4 institutions for ruptured aneurysms and 8 for unruptured aneurysms. Length of stay was shorter at institutions treating \( \geq 10\% \) of cases by endovascular coil embolization. Those institutions treating more cases by endovascular techniques had lower mean hospital charges for unruptured aneurysms but higher charges for ruptured aneurysms.

Multivariable Analysis

Multivariable analysis was used to evaluate the independent effects of institutional factors on patient outcomes after adjustment for individual-level characteristics, including age, sex, race, admission source (emergency department, transfer, other), and admission type (emergent, urgent, elective) (Table 3). For ruptured aneurysms, patients treated at institutions that used angioplasty for vasospasm had a 16% reduction in
risk of in-hospital death compared with patients treated at other institutions. This effect was independent of institutional volume and use of coil embolization. Ruptured aneurysm patients treated at institutions that more frequently used coil embolization were less likely to die in hospital, with a 9% reduction in risk for every 10% of cases treated by endovascular techniques. For unruptured aneurysms, there was a 16% reduction in odds of in-hospital death for every 10% of cases treated by endovascular techniques. For unruptured aneurysms, we had seen lower rates of treatment failure to treat ruptured aneurysms, we entered all variables into a multivariable model. Subarachnoid hemorrhage patients were more likely to receive aneurysm treatment at institutions that treated a greater portion of cases by endovascular techniques (5% more likely to be treated for every variable for treatment modality into the model of ruptured aneurysm patients, we found no association between the procedure performed and in-hospital death at the individual level ($P=0.23$).

Forty-three percent of patients did not receive aneurysm treatment after subarachnoid hemorrhage. To determine which institutional and patient-level factors were associated with failure to treat ruptured aneurysms, we entered all factors into a multivariable model. Subarachnoid hemorrhage patients were more likely to receive aneurysm treatment at institutions that treated a greater portion of cases by endovascular techniques (5% more likely to be treated for every variable for treatment modality into the model of ruptured aneurysm patients, we found no association between the procedure performed and in-hospital death at the individual level ($P=0.23$).

Forty-three percent of patients did not receive aneurysm treatment after subarachnoid hemorrhage. To determine which institutional and patient-level factors were associated with failure to treat ruptured aneurysms, we entered all factors into a multivariable model. Subarachnoid hemorrhage patients were more likely to receive aneurysm treatment at institutions that treated a greater portion of cases by endovascular techniques (5% more likely to be treated for every variable for treatment modality into the model of ruptured aneurysm patients, we found no association between the procedure performed and in-hospital death at the individual level ($P=0.23$).

Forty-three percent of patients did not receive aneurysm treatment after subarachnoid hemorrhage. To determine which institutional and patient-level factors were associated with failure to treat ruptured aneurysms, we entered all factors into a multivariable model. Subarachnoid hemorrhage patients were more likely to receive aneurysm treatment at institutions that treated a greater portion of cases by endovascular techniques (5% more likely to be treated for every variable for treatment modality into the model of ruptured aneurysm patients, we found no association between the procedure performed and in-hospital death at the individual level ($P=0.23$).
10% of endovascular-treated cases; 95% CI, 3% to 8%; \( P < 0.001 \) and at those institutions with greater treatment volumes (4% more likely to be treated for every 10 cases treated per year; 95% CI, 0% to 8%; \( P = 0.04 \)). Offering angioplasty for vasospasm was not associated with whether a patient received aneurysm treatment after subarachnoid hemorrhage (\( P = 0.97 \)).

Institutional treatment volume was not an independent predictor of in-hospital death for either ruptured or unruptured aneurysms (Table 3). Even in a multivariable model with other institutional factors removed, treatment volume was not a significant predictor of in-hospital death for unruptured aneurysms after adjustment for individual-level factors (3% decrease in risk for every 10 cases per year; 95% CI, 19% decrease to 15% increase), although a trend was apparent for ruptured aneurysms (3% decrease; 95% CI, 0% to 6% decrease; \( P = 0.06 \)). When a cut point of 5 cases per year was used for volume in multivariable analysis, a level found to distinguish mortality rates in a prior study,\(^{10} \) there was a trend toward fewer in-hospital deaths in institutions treating \( \geq 5 \) cases per year compared with others, but the difference did not reach statistical significance (RR for in-hospital death in high versus low volume for ruptured aneurysms, 0.78; 95% CI, 0.56 to 1.19; \( P = 0.24 \); for unruptured aneurysms: RR, 0.71; 95% CI, 0.34 to 1.55; \( P = 0.39 \)). Small numbers of ruptured (n = 67) and unruptured (n = 236) aneurysms at institutions treating \( < 5 \) cases per year accounts for broad CIs. The 20 highest-volume neurosurgeons were at institutions treating \( < 5 \% \) of cases by coil embolization.

Multivariable analyses were repeated limiting the cohort to surgically treated patients. Use of coil embolization was the only institutional predictor of in-hospital death among surgically treated ruptured aneurysm patients, with a 12% decrease in surgical mortality risk for every 10% of cases treated by coil embolization (95% CI, 7% to 18% decrease; \( P < 0.001 \)). For unruptured aneurysms, the protective effect of use of endovascular therapy was smaller and did not reach statistical significance (8% decrease in odds of death for every 10% of endovascular-treated cases; 95% CI, 24% decrease to 11% increase; \( P = 0.38 \)).

Hospital charges and length of stay were evaluated in multivariable analysis after adjustment for individual patient characteristics. Institutional factors were not associated with hospital charges, although there was a trend for greater charges in hospitals treating more cases (4% increase for every 10 cases treated per year; \( P = 0.10 \)). Length of stay was shorter at institutions treating more aneurysms by endovascular techniques (9% decrease for every 10% of ruptured aneurysms cases treated by endovascular techniques; \( P = 0.03 \); 6% decrease for unruptured aneurysms; \( P = 0.003 \)). Increasing treatment volume was also associated with briefer lengths of stay for unruptured aneurysms (6% decrease for every 10 cases per year; \( P = 0.006 \)).

**Discussion**

In a prior study at the individual level, coil embolization for unruptured aneurysms was shown to be associated with lower rates of mortality and discharge to nursing homes in the UHC database.\(^{4} \) Although this may indicate that coil embolization is safer, it is also possible that the lowest-risk patients were referred for coil embolization of unruptured aneurysms at a given institution and that this accounted for their better outcomes. Our present analysis at the institutional level argues against this hypothesis. Those institutions that used coil embolization more frequently had better overall outcomes for unruptured aneurysms, and the effect was large, with a 16% risk reduction of in-hospital death for every 10% of unruptured aneurysms treated by coil embolization. In the model, an institution using coil embolization to treat 30% of unruptured aneurysms would be expected to have 40% fewer in-hospital deaths compared with an institution not offering the technique. This institution-level analysis supports the conclusion that coil embolization is safer for treatment of unruptured aneurysms: it shows that selection biases within institutions are not responsible for the differences in outcomes between modalities since, overall, patients did better at institutions using coil embolization more frequently. Increased referral of low-risk patients to institutions using endovascular therapy could also explain these findings but seems unlikely to account for the large effect seen.

For ruptured aneurysms, institutional use of coil embolization was also associated with better outcomes, with a 9% risk reduction of in-hospital mortality for every 10% of cases treated with coil embolization. An institution using coil embolization in 30% of cases would be expected to have 25% fewer in-hospital deaths compared with one never using the technique. Compared with patients with unruptured aneurysms, there is much more variability in condition and prognosis on arrival, and the potential for selection bias within a given institution is great. Some institutions reserve coil embolization for high-risk subarachnoid hemorrhage cases,\(^{16,17} \) while the opposite is true at other institutions,\(^{19} \) and this type of selection bias obstructs a direct comparison of the 2 treatment modalities. However, an analysis at the institutional level may still be valid since the outcomes for all the patients treated at a given institution are compared with other institutions, and selection bias within an institution is not an issue. If use of coil embolization is limited to high-risk patients, overall institutional outcomes may improve since these patients might not be treated otherwise or might have done worse if treated surgically.

In fact, we found that the outcomes of surgical cases improve dramatically as a larger proportion of cases are treated by endovascular techniques, suggesting that the patients at highest surgical risk are being sent for coil embolization. An alternative explanation is that neurosurgeons are more skilled at institutions that use endovascular therapy more frequently, but this seems unlikely since the highest-volume neurosurgeons were at institutions that rarely performed coil embolization. It is also possible that use of coil embolization is a marker for some other important aspect of care or of the treated patient pool, but this factor would need to be independent of hospital volume, angioplasty for vasospasm, and admission source since these variables were present in the multivariable model. Therefore, it appears that centers offering coil embolization have lower mortality for surgically clipped patients and lower mortality overall, prob-
ably by allowing physicians to choose the most favorable approach for a given patient.

The use of angioplasty for vasospasm was independently associated with lower rates of in-hospital death. The association was strong, with a 16% reduction in risk of in-hospital death at institutions offering the technique compared with others. Although results of cerebral angioplasty have been promising, since the technique was only performed in 2% of cases, it cannot account for improved outcomes by itself. Rather, availability of angioplasty is likely a marker for aggressive and attentive multidisciplinary care or for more skilled neurointerventional radiologists.

We cannot confirm that institutional treatment volume is an important independent predictor of in-hospital death in cerebral aneurysm treatment, as described in prior reports. Although higher-volume institutions appeared to have better outcomes in univariate analysis, the effect disappeared after correction for patient characteristics. Higher-volume institutions treated more patients transferred from other facilities, and transferred patients tended to do better than admissions from other sources. This potential source of confounding has been recognized previously for subarachnoid hemorrhage cases treated in Rochester, Minnesota, and may be due to a reluctance to transfer cases with very poor prognoses. The influence of transferred cases on patient mix was not evaluated in prior publications and may account for some of the impact of treatment volume they reported.

Our analysis was limited to academic medical centers, and this also may have affected our ability to detect an institutional volume effect. It is possible that elevated standards of care at academic centers obscure differences between institutions that manage many and few aneurysms. The International Cooperative Study did not find a volume-mortality association, and it also was limited to academic centers.

There were few very-low-volume institutions in this cohort, and the prior study of Medicare patients showed the strongest effect with annual treatment volumes <5/y compared with others. We did not have power to find an effect with these very small treatment volumes. Additionally, we used a method of multivariable analysis that accounts for the clustering of observations by hospital. This method produces more accurate but conservative CIs, reducing power despite large sample sizes. We suspect that a volume effect would be confirmed with a cross section of institutions including community hospitals, but the effect may not be as large as previously suggested.

Our results suggest that multidisciplinary, specialized neurovascular services offering endovascular therapies are associated with reduced in-hospital mortality and, presumably, better outcomes overall. Regardless of who is being treated by endovascular techniques at a given institution, arrival at a hospital that uses these therapies appears beneficial. This study supports a multidisciplinary approach to cerebral aneurysms, combining the expertise of neurosurgeons and neurointerventional radiologists. Transfer of patients with cerebral aneurysms to specialized centers offering endovascular therapies may be warranted.

Appendix

The following institutions, in alphabetical order by state, contributed aneurysm cases to the database:

- University of Alabama, University of Southern Alabama; University of Arizona; University of Arkansas; University of California at Davis, University of California at Irvine, University of California at Los Angeles, University of California at San Diego, University of California at San Francisco, Stanford; University of Colorado; University of Connecticut, Yale; Georgetown University; Howard University; University of Florida; Emory University; Medical College of Georgia; Loyola University, University of Chicago, University of Illinois at Chicago; Indiana University; University of Iowa; University of Kansas; University of Kentucky; University of Massachusetts; University of Michigan; Fairview University, Minnesota; University of Missouri, St Louis University; University of Nebraska; Robert Wood Johnson University; Columbia-Presbyterian Medical Center, New York University, State University of New York at Brooklyn, State University of New York at Syracuse, State University of New York at Stony Brook; Eastern Carolina University, University of North Carolina, Wake Forest University; Medical College of Ohio, Ohio State University, University of Cincinnati, Case Western Reserve; University of Oklahoma; Oregon Health Sciences University; Allegheny University, University of Pennsylvania, Pennsylvania State University, University of Pittsburgh, Thomas Jefferson University, Lehigh Valley Hospital; Medical University of South Carolina; Vanderbilt University; Memorial Hermann Hospital, University of Texas at Galveston; University of Utah; Medical College of Virginia, University of Virginia; University of Washington; West Virginia University; Froedtert Memorial Hospital, University of Wisconsin.

Acknowledgments

This study was supported by a grant from the National Institutes of Health/National Institute of Neurological Disorders and Stroke (K08 NS 02042–01) and by a research fellowship to Dr Johnston from the National Stroke Association. The efforts of Andrew Brown, MD, MPH, in gathering the cohort were greatly appreciated.

References


Effect of Endovascular Services and Hospital Volume on Cerebral Aneurysm Treatment Outcomes
S. Claiborne Johnston

Stroke. 2000;31:111-117
doi: 10.1161/01.STR.31.1.111

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/31/1/111