Neurointerventional Procedural Volume per Hospital in United States
Implications for Comprehensive Stroke Center Designation

Mikayel Grigoryan, MD; Saqib A. Chaudhry, MD; Ameer E. Hassan, DO; Fareed K. Suri, MD; Adnan I. Qureshi, MD

Background and Purpose—Availability of neurointerventional procedures is recommended as a necessary component of a comprehensive stroke center by various regulatory guidelines that also emphasize adequate procedural volumes. We studied the volumes of neurointerventional procedures performed in various hospitals across the United States with subsequent comparisons with rates of minimum procedural volumes recommended by various professional bodies or used in clinical trials to ensure adequate operator experience.

Methods—We reviewed the Nationwide Inpatient Sample database in the United States for the years 2005 to 2008. Using International Classification of Disease—Clinical Modification, 9th revision, and Medicare severity diagnosis-related group codes, we identified among hospitals that admit stroke patients those that met the minimum criteria for overall and individual procedural volumes specified in various guidelines. We then compared the characteristics between the high-volume hospitals that performed at least 100 cervicocerebral angiograms and met 1 other procedural criterion (n=79) and low-volume hospitals (n=958).

Results—Proportions of hospitals that met individual procedural volume criteria over the 4-year period according to procedure were: cervicocerebral angiography (7.0%–7.8%); endovascular acute ischemic stroke treatments (0.4%–2.6%); carotid angioplasty/stent placement (3.0%–5.3%); intracranial angioplasty/stent placement (0.3%–1.3%); and aneurysm embolization (1.3%–2.6%). There were significant trends for increasing numbers of all the endovascular procedures except intracranial angioplasty/stent placement over the course of 4 years. The high-volume hospitals were more likely to be urban teaching hospitals (70.9% versus 13.1%; P<0.001), had larger bed size (79.7% versus 26.9%; P<0.001), and had significantly higher rates of hemorrhagic stroke admissions and lower rates of transient ischemic attack admissions. Urban teaching location/status (OR, 8.92; CI, 4.3–18.2; P<0.001) and large bed size (OR, 4.40; CI, 2.0–9.5; P<0.001) remained as independent predictors of a high-volume hospital when adjusted for age, gender, risk factors, and stroke subtype.

Conclusions—There are very few hospitals in the United States that meet all the neurointerventional procedural volume criteria for all endovascular procedures recommended to ensure adequate operator experience. Our results support the creation of specialized regional centers for ensuring adequate procedural volume within treating hospitals. (Stroke. 2012;43:1309-1314.)

Key Words: angiography ■ aneurysm embolization ■ carotid stent ■ comprehensive stroke center ■ neurointerventional procedures ■ thrombectomy ■ thrombolysis

To improve the care for 800,000 persons who have a new or recurrent stroke,1 Brain Attack Coalition has proposed establishment of primary2 and comprehensive stroke centers3 to provide basic and advanced interventions, respectively. Primary stroke centers have been designated by the Joint Commission since 2003, in addition to certifications provided by various states. The designation of a comprehensive stroke center (CSC) is now being considered. A CSC is defined as a facility or system with the necessary personnel, infrastructure, expertise, and programs to diagnose and treat stroke patients who require a high intensity of medical and surgical care, specialized tests, or interventional therapies.3 Physicians with expertise in neurointerventional and vascular neurosurgical procedures were recommended as a necessary component of a CSC by various regulatory guidelines.

The varieties of procedures that are included under that category are diverse, and competency in 1 procedure does not automatically mean equivalent competency in others. On the basis of these considerations, hospitals are moving toward “procedure-specific credentialing.” This change in paradigm

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has necessitated development of well-defined criteria to ensure required training experience in each procedure\textsuperscript{4,5} independent of certification, fellowship, or membership in a specialty body or society.

Such criteria rely on procedural volume as an aggregate and for individual procedures to ascertain the appropriateness of training programs and as a prerequisite for acquiring and maintaining hospital procedural privileges.\textsuperscript{4,5} Existing guidelines have been proposed to identify adequate volumes required for specific neurointerventional procedures to ensure appropriate ongoing skills of both physicians and affiliated personnel.\textsuperscript{4} We sought to study the volumes of neurointerventional procedures performed in various hospitals in the United States and compare the rates to minimum procedural volumes recommended by various professional bodies or used in clinical trials to ensure adequate operator experience within CSC.

### Materials and Methods

We analyzed the data from Nationwide Inpatient Sample, the largest all-payer inpatient care database in the United States, for the years 2005 to 2008. NIS represents \( \sim 20\% \) stratified random sample of all patients admitted at nonfederal hospitals, including those managed by city and state governments and for-profit and not-for-profit organizations. They encompass academic (teaching) and nonacademic institutions. Five hospital characteristics, geographic region, ownership, location (urban or rural), teaching status, and bed size, are used for stratification in an attempt to create a sample that is maximally representative of hospitalizations in the United States. Actual Nationwide Inpatient Sample-reported numbers rather than extrapolated national estimates were used in the current analysis.

Using the appropriate The International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes (430–437), we first identified all the hospitals that admitted patients with acute stroke as a primary diagnosis. After that, we used various ICD-9-CM and Medicare severity diagnosis-related group codes to determine the annual numbers of individual neurointerventional procedures performed per hospital. The procedures studied included the following: cervicocerebral angiogram (ICD-9-CM procedure code 88.40–88.49); endovascular acute ischemic stroke treatments (Medicare severity diagnosis-related group codes 23, 24, excluding craniotomy code 01.12); carotid angioplasty and stent placement (ICD-9 code 00.63); intracranial angioplasty and stent placement (ICD-9 codes 0.62 or 0.65); and endovascular treatment of intracranial aneurysms and arteriovenous malformations (ICD-9 code 39.71–39.79). Because there are a few surgical procedures important for the management of stroke patients with direct relationship to endovascular procedures, we also have included in the analysis carotid endarterectomy (ICD-9-CM procedure codes 38.10–38.19) and surgical treatment of intracranial aneurysm (ICD-9 code 39.51). We then identified the hospitals performing the recommended numbers of these procedures annually according to the established guidelines when applicable or recommendations by various organizations. Table 1 provides the annual number required for each procedure and the sources of data that support the use of the threshold. We deliberately reduced the number of intracranial angioplasty/stent placement from 25 to 10, because there were no hospitals performing this procedure at recommended volume. Hospitals fulfilling all the procedural criteria were designated as those who had adequate procedural volume for adequate operator experience within CSC.

Additional analysis included identification of hospitals performing at least 100 cervicocerebral angiograms per year in addition to meeting at least 1 other procedural volume criterion (high-volume) and comparing the characteristics with hospitals that do not meet these criteria (low-volume) in terms of hospital teaching status, patient demographics, insurance status, stroke admissions, and discharge data. Nationwide Inpatient Sample defines a hospital as a teaching hospital if it has an Accreditation Council for Graduate Medical Education-approved residency training program, is a member of the Council of Teaching Hospitals, or has a ratio of full-time equivalent interns and residents to beds of 0.25 or higher.

Comparisons were performed using Fisher exact probability test and probability values were noted. Multivariable logistic regression analysis was performed on the patient level to determine independent predictors of admission to a high-volume hospital. The regression model was adjusted for hospital clustering. The analyses were performed using the SAS software version 9.1 (SAS Institute, Cary, NC).

### Results

Data from 1035 hospitals in 2005, 1028 hospitals in 2006, 1024 hospitals in 2007, and 1038 hospitals in 2008 across the United States were analyzed. Total annual numbers for each neurointerventional/neurosurgical procedure are provided in Table 2. The numbers for carotid endarterectomy and carotid angioplasty and stent placement as well as surgical treatment of aneurysms were relatively stable throughout 4 years, whereas the numbers of all endovascular procedures except intracranial angioplasty and stent placements demonstrated significant increasing trends over the course of 4 years.

The proportions of hospitals performing recommended numbers of neurointerventional procedures are presented in Table 3. To better-illustrate the actual distribution volumes, we arbitrarily divided them in 3 groups by volume for each of the procedures. Only 2 hospitals met all the procedural criteria in 2005, 5 hospitals met all the procedural criteria in 2006, 2 hospitals met all the procedural criteria in 2007, and 7 hospitals met all the procedural criteria in 2008. The proportions of hospitals that met individual procedural volume criteria according to procedure were: cervicocerebral angiography (7.0%–7.8%); endovascular acute ischemic stroke treatments (0.4%–2.6%); carotid angioplasty/stent placement (3.0%–5.3%); intracranial angioplasty/stent placement (0.3%–1.3%); and aneurysm embolization (1.3%–2.6%). For surgical procedures, these numbers were 27.3% to 35.1%.
28.7% for carotid endarterectomy and 3.1% to 4.0% for surgical treatment of intracranial aneurysm treatment.

For further analysis, we designated “high-volume” hospitals as those that performed at least 100 cervicocerebral angiograms and met at least 1 other procedural criterion (n=79) and compared them with the remaining “low-volume” hospitals (n=958). The results are shown in Table 4. The high-volume hospital group had significantly higher proportion of urban teaching hospitals ($P<0.001$) and hospitals with large bed size ($P<0.001$). In multivariable analysis,
Table 4. Comparison of Characteristics Between High-Volume Versus Low-Volume Hospitals* (Nationwide Inpatient Sample 2005–2008)

<table>
<thead>
<tr>
<th></th>
<th>Low-Volume Hospitals</th>
<th>High-Volume Hospitals</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall N</td>
<td>959</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>N (%)</td>
<td>N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital teaching status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teaching</td>
<td>126 (13.1)</td>
<td>56 (70.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hospital location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural hospital</td>
<td>411 (42.9)</td>
<td>3 (3.8)</td>
<td></td>
</tr>
<tr>
<td>Urban nonteaching</td>
<td>427 (44.5)</td>
<td>21 (26.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Urban teaching</td>
<td>118 (12.3)</td>
<td>55 (69.6)</td>
<td></td>
</tr>
<tr>
<td>Information missing</td>
<td>3 (0.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital bed size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>459 (47.9)</td>
<td>3 (3.9)</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>239 (24.9)</td>
<td>13 (16.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Large</td>
<td>258 (26.9)</td>
<td>63 (79.7)</td>
<td></td>
</tr>
<tr>
<td>Information missing</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospital location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>115 (12.0)</td>
<td>14 (17.7)</td>
<td>NS</td>
</tr>
<tr>
<td>Midwest</td>
<td>291 (30.3)</td>
<td>13 (16.5)</td>
<td>0.009</td>
</tr>
<tr>
<td>South</td>
<td>373 (38.9)</td>
<td>38 (48.1)</td>
<td>NS</td>
</tr>
<tr>
<td>West</td>
<td>180 (18.8)</td>
<td>14 (17.7)</td>
<td>NS</td>
</tr>
<tr>
<td>Ischemic stroke admissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>124 (6.4)</td>
<td>61,966 (63.9)</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Intracranial hemorrhage admissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12,942 (6.2)</td>
<td>12,434 (12.9)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Subarachnoid hemorrhage admissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6733 (3.2)</td>
<td>5089 (5.3)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Transient ischemic attack or unspecified ischemia admissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64,658 (31.1)</td>
<td>24,279 (24.9)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

*High-volume hospitals were defined by performance of at least 100 cervico-cerebral angiograms and meeting of at least 1 other procedural criterion.

Discussion

Several studies have suggested that higher procedural volumes for endovascular procedures are associated with lower rates of periprocedural complication.6,7 Our results demonstrate that few hospitals in the United States meet all the neurointerventional procedural volume criteria for all endovascular procedures recommended within CSC. If high-volume hospitals were defined as those who performed at least 100 cervico-cerebral angiograms and met at least 1 other procedural criterion, then <1 out 10 hospitals met the criteria. These numbers are similar to the European data by Leys at al8,9 who showed that <10% of European hospitals admitting acute stroke patients have optimal facilities and only 4.9% met criteria for CSC. Although there is some evidence that the numbers of certain endovascular procedures are increasing, such increase is unlikely to substantially change the current estimates. We also observed that high-volume hospitals are more likely to be urban teaching hospitals and have large bed capacity. The purpose of our analysis was not to determine what procedural volume is adequate for performance of particular procedures but rather to provide the consequences of implementation of criteria available through best available evidence on a national scale.

The determination of procedural volume adequate within a hospital to maintain competence of operators is not explicitly defined. Such volume requirements are further complicated by number and experience of operators within the hospital. We assumed that each hospital has a minimum of 1 neurointerventionalist and for procedures without any hospital-based requirement available through previous clinical trials or guidelines, the criteria used for training purposes (annual requirement for neurointerventionalist within the year before graduation) will be the best substitute. For comprehensive stroke centers, many of which have training programs, such volume requirements are appropriate. In other settings, using such criteria avoids underestimating the number of procedures required for maintenance of competence, but a smaller number maybe adequate.

Data analysis from interventional cardiology literature, including National Heart, Lung, and Blood Institute Percutaneous Transluminal Coronary Angioplasty15,11 and Palmaz-Shatz4 stent registries confirm the presence of a learning curve for endovascular procedures and indicate that the complication frequency continues to decline with increasing operator experience. Similar phenomenon was demonstrated for neurointerventional procedures, such as carotid angioplasty and stent placement13 and aneurysm embolization.14 Institutions should pay particular attention to this issue and monitor the case volumes of neurointerventionalists and effect on patient outcomes. It is possible that experienced neurointerventionalists do not require the same yearly procedural volumes for maintaining their skills. Recently, alternative training techniques such as simulation models and virtual reality training have become available for a variety of endovascular procedures5,16 and should be fully explored as an option to enhance skills of neurointerventionalists in the face of limited availability of endovascular procedures. Another major contributing factor to the overall low number of high-volume hospitals remains the undertreatment of acute stroke patients. Data suggest that despite increase in intravenous alteplase administration nationally in recent years, the overall rates of its use remain low.
The absolute numbers of several neurointerventional procedures have increased significantly over the analyzed period. The increasing proportion of carotid angioplasty and stent placement within the time period included in the analysis may be secondary to SAPPHIRE study results and reimbursement for surgical patients at high risk by Medicare and other insurance payers. In our comparative analysis, high-volume hospitals had significantly higher rates of hemorrhagic stroke admissions (both intracerebral hemorrhage and subarachnoid hemorrhage) and significantly lower rates of transient ischemic attack admissions, which probably accounts for the significantly higher rates of deaths in high-volume hospitals. Such differences in proportion of intracerebral hemorrhage and subarachnoid hemorrhage admissions, severity of neurological deficits, and presence of comorbid conditions result in higher mortality among those admitted to specialized stroke centers compared with those admitted to other hospitals.

Whereas the designation of a CSC is still being considered, a set of metrics has been recently proposed by the American Heart Association/American Stroke Association to monitor the quality of care provided by CSC, which includes a number of suggestions targeting quality improvements for neurointerventional procedures. The results of our study would support inclusion of neurointerventional procedural volume as an additional metric for CSC designation. The low number of high-volume hospitals also implies the need for creating a more efficient triage system of providing timely care to all the patients. Such triage may be based on selected transfers to CSC or primary admissions only to CSC for stroke patients. Finally, given the discrepancy between the large number of hospitals hiring physicians seeking neurointerventional training and hospitals able to provide adequate comprehensive neurointerventional procedures, our results would suggest a more appropriate balance in number of trainees, current hiring, and procedural volume.

The present study has a number of limitations. We used the data from the Nationwide Inpatient Sample, a large data set used in previous stroke studies with standardized design, to provide a representative estimate of the total hospitalizations in the United States. However, the database depends on the accuracy of diagnoses and procedures listed on discharge summaries. We used all available sources of identifying patients undergoing neurointerventional procedures because some of them (ie, endovascular treatment of acute ischemic stroke) do not have separate ICD-9 procedure codes, and the frequency of such procedures was determined using Medicare severity diagnosis-related group codes. We think that the yield of such an approach may be higher but the exact impact on accuracy of diagnosis is unknown. The results are estimated per hospital and do not account for systems that may provide adequate procedural volume through multiple hospitals using common practitioners.

Our results demonstrate that there are only few hospitals in the United States that perform adequate numbers of all the neurointerventional procedures recommended for a CSC. Although it is encouraging that the numbers of certain neurointerventional procedures are increasing over the past years, in our opinion the present data strongly support the creation of specialized regional centers for ensuring adequate procedural volume within treating hospitals.

Disclosures
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References
16. Van Herzeel I, Aggarwal R, Choong A, Brightwell R, Verommen FE, Cheshire NJ. Virtual reality simulation objectively differentiates level of
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