Geographic variation and regional trends in adoption of endovascular techniques for cerebral aneurysms

Clinical article

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Object. Considerable evolution has occurred in treatment options for cerebral aneurysms. Development of endovascular techniques has produced a significant change in the treatment of ruptured and unruptured intracranial aneurysms. Adoption of endovascular techniques and increasing numbers of patients undergoing endovascular treatment may affect health care expenditures. Geographic assessment of growth in endovascular procedures has not been assessed.

Methods. The National Inpatient Sample (NIS) was queried for ICD-9 codes for clipping and coiling of ruptured and unruptured cerebral aneurysms from 2002 to 2008. Patients with ruptured and unruptured cerebral aneurysms were compared according to in-hospital deaths, hospital length of stay, total hospital cost, and selected procedure. Hospital costs were adjusted to bring all costs to 2008 equivalents. Regional variation over the course of the study was explored.

Results. The NIS recorded 12,588 ruptured cerebral aneurysm cases (7318 clipped and 5270 coiled aneurysms) compared with 11,606 unruptured aneurysm cases (5216 clipped and 6390 coiled aneurysms), representing approximately 121,000 aneurysms treated in the study period. Linear regression analysis found that the number of patients treated endovascularly increased over time, with the total number of endovascular patients increasing from 17.28% to 57.59% for ruptured aneurysms and from 29.70% to 62.73% for unruptured aneurysms ($p < 0.00001$). Patient age, elective status, and comorbidities increased the likelihood of endovascular treatment ($p < 0.00001$, $p < 0.00004$, and $p < 0.02$, respectively). In patients presenting with subarachnoid hemorrhage (SAH), endovascular treatments were more commonly chosen in urban and academic medical centers ($p = 0.009$ and $p = 0.05$, respectively). In-hospital deaths decreased over the study period in patients with both ruptured and unruptured aneurysms ($p < 0.00001$); presentation with SAH remained the single greatest predictor of death (OR 38.09, $p < 0.00001$). Geographic analysis showed growth in endovascular techniques concentrated in eastern and western coastal states, with substantial variation in adoption of endovascular techniques (range of percentage of endovascular patients [2008] 0%–92%). There were higher costs in patients treated endovascularly, but these differences were likely secondary to presenting diagnosis and site-of-service variations.

Conclusions. The NIS database reveals a significant increase in the use of endovascular techniques, with the majority of both ruptured and unruptured aneurysms treated endovascularly by 2008. Differences in hospital costs between open and endovascular techniques are likely secondary to patient and site-of-service factors. Presentation with SAH was the primary factor affecting hospital cost and a greater percentage of endovascular procedures completed at urban academic medical centers. There is substantial regional variation in the adoption of endovascular techniques.
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Key Words • **National Inpatient Sample** • **aneurysm** • **subarachnoid hemorrhage** • **regional variation** • **endovascular technique**

Since the first aneurysm clipping procedure was performed by Dandy in 1937, the treatment of cerebral aneurysms has undergone significant evolution. While the open exposure of clipping allowed for successful and reliable therapy, a desire to improve outcomes and to move toward less-invasive approaches spurred development of alternative therapies. Novel techniques ranging from stereotactic electrothrombosis to endovascular inflatable balloon occlusion were attempted with the goal of avoiding open craniotomy and brain retraction.[24,26] The advent of the detachable coil, approved by the FDA in 1995, provided an alternative to open surgical ligation.

Studies report comparable clinical outcomes with endovascular treatment of cerebral aneurysms in comparison with open surgical ligation. Endovascular approaches have been reported to provide decreased morbidity and death for both ruptured and unruptured aneurysms.[4,5,10–12,15,17–21] The popularity of endovascu-

Abbreviations used in this paper: AHRQ = Agency for Health Care Research and Quality; CHF = congestive heart failure; ISAT = International Subarachnoid Aneurysm Trial; LOS = length of stay; NIS = National Inpatient Sample; SAH = subarachnoid hemorrhage.

lar treatments has grown steadily since their introduction.[4–6,10,20] Andaluz and Zuccarello[1] reported that from 1993 to 2003, the number of aneurysm clipping procedures remained stable, whereas the number of endovascular procedures had doubled.

Increased focus on health care expenditures and cost effectiveness prompted multiple investigators to compare costs of endovascular coil embolization to open clipping of cerebral aneurysms.[3,11,13–16,25,28] Financial analysis of the ISAT revealed significantly greater costs associated with endovascular treatment.[22] Other reviews of administrative databases have found greater costs with coil embolization.[3,11,13,16] Hoh et al.,[14] reviewing an administrative database and attempting to control for patient and facility variables, reported greater charges with open aneurysm ligation, with clipping resulting in $15,325 more in total charges for patients with ruptured aneurysms as well as $11,263 more in total charges for unruptured cases.

Previous reports on health policy have focused on regional variations in health care spending and resource utilization. Fisher et al.[7] reported on regional variation in Medicare expenditures and noted that physician factors must play a predominant role in variation in health care expenditures. Limited research has been conducted on regional variation in adoption of new technology. Geographic heterogeneity in acceptance of new technologies may provide another potential explanation for regional variation in health care costs.

This study reviews the NIS database from 2002 to 2008 that is maintained by the AHRQ. The NIS database is the largest all-payer inpatient database in the US. The NIS was developed as part of the Healthcare Cost and Utilization Project, a federal-state-industry partnership sponsored by the AHRQ. As of 2008, the NIS contains all discharge data from 1056 hospitals located in 42 states, a stratified sample representing approximately 20% of US hospitals.

Using data from the NIS, this study focuses on trends in the US of open clipping versus endovascular coiling of both ruptured and unruptured aneurysms. Costs between procedures as well as geographical cost differences in hospitals were noted. We attempt to show the regional impact of the growing adoption of endovascular treatment for cerebral aneurysms by investigating trends in utilization and cost across the US.

Methods

Data Selection and Outcome Variables

The NIS databases were obtained from the AHRQ's Healthcare Cost and Utilization Project. This database represents approximately 20% of patient admissions every year at nonfederal hospitals. Results were investigated from 2002 through 2008, the last year with available data.

Hospitalization patient records were cross-matched by ICD-9 codes for SAH (430) or unruptured cerebral aneurysm (437.3) along with procedure codes for aneurysmal clipping (39.51) and coiling (39.79, 39.72, or 39.52) in the NIS database. Results were imported into a MySQL database for querying. Selection of these aneurysm codes has been previously validated.[12–14]

The NIS hospitalization data on adult patients (18 years of age or older) with SAH and unruptured aneurysms were compiled. The 2 cohorts (aneurysms presenting with SAH and presenting unruptured) were compared against one another for 4 primary end points—in-hospital death, hospital LOS, total hospital cost, and selected procedure. Hospital costs were adjusted to bring all costs to 2008 equivalents through application of an assumed 3% per year inflation factor.

We excluded patients who were listed with procedure codes for both clipping and coiling, and those who received diagnosis codes for both an unruptured aneurysm and SAH. Regression analysis was performed for fixed-effect variables including age, sex, race, number of procedures, number of diagnoses, nonelective procedure, and year of surgery. Patients who died in the hospital were excluded from the LOS estimation. We examined the choice of operation (clipping or coiling) in the context of patient demographics, comorbidities, and presenting diagnosis.

Hospital location by state was treated as a random effect; we analyzed the variability across states and plotted the geographic results. The standard errors of random effects were estimated (function se.ranef, the "arm" package in the R programming language) and the 95% CIs were calculated. States with a CI outside the population mean were noted and tabulated.

Statistical Analysis

Statistical analysis was performed using the lme4 package (version 0.999375–33) in the R programming language for statistical computing (version 2.11.0), both available under the GNU Public License (http://www.cran.r-project.org). The variables death and choice of treatment were used for logistic regression analysis. Length of stay was analyzed assuming a Poisson distribution accounting for overdispersion, with greater variance than expected in a Poisson variable. The total cost was analyzed using a linear regression in which LOS was treated as a fixed effect measured as cost per day. Random effect of state was modeled as a baseline effect on costs and a cost per day during LOS. All factors of interest were included and parsimonious models were found by systematically removing the least significant factor and recalculating the model.

Results

Clipping and Coiling Rates in SAH Versus Unruptured Aneurysms

We found 27,180 patients who presented with cerebral aneurysms. Of these patients, 1696 who had both ruptured and unruptured aneurysms were excluded. Additionally, 477 patients treated with both endovascular and clipping procedures and 813 who did not have SAH or an unruptured cerebral aneurysm as their primary diagnosis were omitted. These exclusions and omissions resulted in patient cohorts of 12,588 SAH cases (7318 clipped and 5270 coiled aneurysms) compared with 11,606 unruptured cerebral aneurysm cases (5216 clipped and 6390 coiled aneurysms). Assuming a representative cohort sample, the NIS offers a representative sample of more than 120,000 patients with aneurysms.

Linear mixed regression analysis of the selected procedure (clipping or coiling) for SAH and unruptured aneurysms found that the likelihood of a clipping procedure decreased over time for both patient populations, and the total number of patients receiving coil embolization increased from 17.28% to 57.59% (SAH cases) and 29.70% to 62.73% (unruptured aneurysm cases), respectively ($p < 0.0001$; Fig. 1).

Increasing age was associated with an increase in the rate of aneurysmal coiling versus clipping ($p < 0.00001$; Fig. 2). An increased likelihood of undergoing a coiling procedure was observed in patients who had peripheral vascular disease and more recent procedures ($p < 0.0001$). The odds of undergoing clipping were higher in patients with comorbidities such as hypertension, diabetes mellitus, and electrolyte abnormalities. In patients with SAH the association between age and coiling procedures was reduced. Comorbidities such as CHF, diabetes mellitus, electrolyte abnormalities, and whether the procedure was elective increased the likelihood of undergoing a coiling procedure. Other factors found to affect the choice of procedure are summarized in Table 1.

Geographic trends in operative procedure choice in 2002 compared with 2008 show large increases in the percentage of coiling procedures performed across the US, with major increases along the coastlines and throughout the Northeast corridor (Fig. 3). Although there are clear differences in reporting between the 2002 and 2008 hospital cohorts, geographic disparity in adoption of endovascular therapy and regional variation in choice of endovascular treatment over open surgical ligation are evident. There was a significant range in the percentage of patients treated with endovascular techniques in 2008, the most recent year with complete data available. States reported between 0% and 92% of patients with cerebral aneurysms who were treated endovascularly.

Regionally, the greatest increase in utilization of endovascular techniques in the US was found along the western coastline and in the northeast. The percentage of coiling procedures compared with clipping procedures has steadily increased in these areas. National ORs suggest that Arizona and Iowa have substantially higher likelihoods of clipping versus coiling procedures (OR 8.086, 95% CI 3.517–18.586, and OR 7.180, 95% CI 4.178–12.344, respectively). Missouri, Oklahoma, Virginia, California, New York, and Tennessee also demonstrated greater rates of clipping versus endovascular treatment (Table 2). States with greater likelihoods of endovascular treatment included Arkansas, Indiana, Kansas, Michigan, New Hampshire, and Texas. Geographic changes in ORs per year in coiling procedures reveal significant declines in the likelihood of clipping procedures in Arizona, Iowa, Missouri, Oklahoma, South Carolina, Virginia, and Wisconsin (Table 3). Of the 20 states east of the Mississippi River in which 2008 NIS data were available, 13 (65%) featured endovascular treatment incidences of 50% or greater. Sixteen states in the remainder of the nation had appropriate representation in the 2008 NIS sample and 6 (37.5%) of these featured greater than 50% incorporation of endovascular approaches.

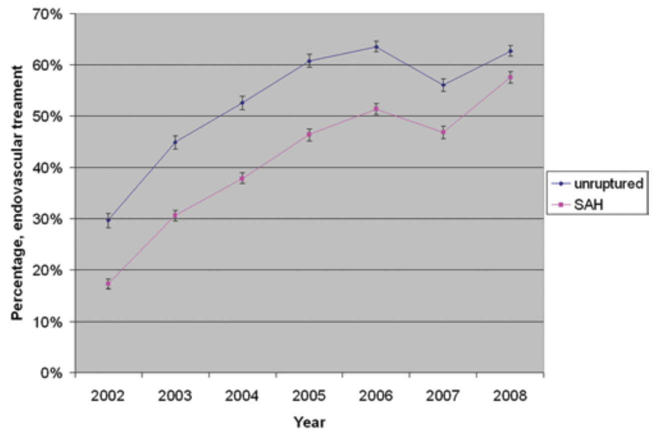

Fig. 1. Line graph showing the increase in endovascular therapies in both ruptured and unruptured cerebral aneurysms from 2002 to 2008, based on assessment of the AHRQ NIS database.

Patients Presenting With SAH

Patients presenting with SAH had a higher likelihood of comorbidities such as anemia, coagulopathy, CHF, and electrolyte abnormalities. African American, Hispanic, and Asian patients were more likely to present with SAH. Demographic data on patients presenting with SAH are reviewed in Table 4. From 2002 to 2008, the incidence of patients presenting with SAH declined from 60.04% to 45.17% ($p < 0.00007$; Fig. 4). Geographic variation in patient presentation is also reviewed in Table 4; there were few geographic outliers with regard to presentation with SAH (5 states).

Fixed-Effects Analysis of In-Hospital Mortality Rates

The rate of in-hospital deaths declined for patients with either SAH or unruptured cerebral aneurysms over the time period, from 15.75% to 13.56% and from 1.90%

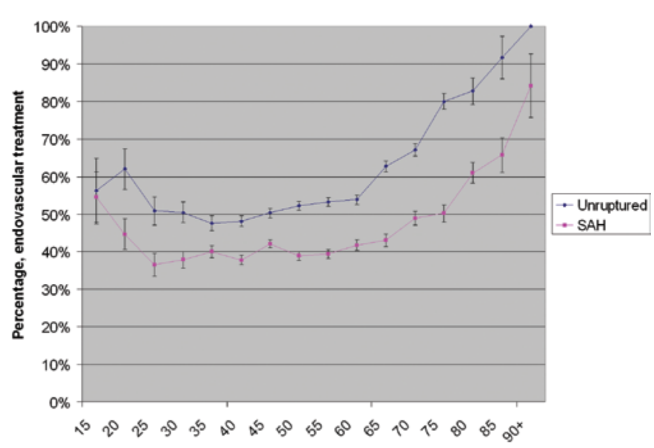

Fig. 2. Line graph showing the relationship between advancing patient age (in years) and choice of endovascular therapy in ruptured and unruptured cerebral aneurysms from 2002 to 2008, based on assessment of the AHRQ NIS database.

TABLE 1: Factors affecting procedure choice (endovascular vs open surgery) for patients presenting with SAH and unruptured cerebral aneurysms*

Variable	OR (95% CI)	p Value
age	1.024 (1.020–1.028)	<0.00001
elective procedure	0.774 (0.686–0.910)	<0.00004
hypertension	0.860 (0.802–0.921)	<0.00002
diabetes mellitus	0.442 (0.218–0.896)	0.024
electrolyte abnormality	0.398 (0.326–0.486)	<0.00001
peripheral vascular disease	1.362 (1.145–1.620)	0.001
yr of procedure	1.258 (1.154–1.372)	<0.00001
patients presenting w/ SAH		
age	0.987 (0.982–0.992)	<0.00001
CHF	1.827 (1.190–2.805)	0.006
diabetes mellitus	2.501 (1.025–6.103)	0.045
electrolyte abnormality	2.607 (2.090–3.253)	<0.00001
elective procedure	1.935 (1.574–2.380)	<0.00001

* The ORs reflect the likelihood of endovascular treatment compared with surgical clipping.

to 0.39%, respectively (p < 0.00001). Odds ratios for fixed effects on in-hospital mortality rates with respect to coiling versus clipping procedures were analyzed using parsimonious models including age, year of procedure, SAH, and number of procedures and diagnoses (Table 5). The greatest single predictor of in-hospital death was presentation with SAH (OR 38.06, 95% CI 21.84–66.41; p < 0.00001). A coiling procedure increased the odds of death overall, but this is likely confounded by the large increase in death within the SAH patient population (p = 0.0001). Analysis of geographic random effects found no significant differences in in-hospital mortality rates.

Length of Stay

Patients with SAH and unruptured cerebral aneurysms had median LOS calculated for both clipping and coiling procedures. In patients with SAH, median LOS was 16 days regardless of treatment. In patients with unruptured cerebral aneurysms, median LOS declined by 1 day, from 5 to 4 days in the clipping group and from 2 to 1 day in the coiling group, over the years 2002 to 2008. Quasi-Poisson regression analysis was performed to evaluate the fixed effects of age, SAH, number of diagnoses and procedures, race, and year of procedure (Table 6). Subarachnoid hemorrhage significantly increased LOS, while endovascular treatment decreased LOS. Age, number of diagnoses including comorbidities (such as hypertension, CHF, and electrolyte disturbances), and number of procedures performed each increased the likelihood of longer median LOS in all patients with aneurysms. Other factors are reviewed in Table 6. Geographic random effect analysis found a lower median LOS in patients living in the states of California, Colorado, Michigan, and Missouri, whereas patients in Connecticut, Tennessee, Texas, and Virginia had a longer median LOS (Table 6).

Institutional Variation in Total Treatment Cost

Variation in total hospital costs for patients with cerebral aneurysms was analyzed based on institutional category using NIS facility distinctions (rural, urban and private, or urban and academic). While yearly fluctuations in hospital charges were found, there were evident general trends toward greater expenditures over time. Total median costs for treatment of unruptured cerebral aneurysms steadily increased from $43,884.56 in 2002 to $69,622.61 in 2008 in urban and private centers, and from $41,116.35 in 2002 to $68,325.96 in 2008 in urban and academic centers. In patients with SAH, rural total cost increased from a median of $79,705.22 in 2002 to $144,458.69 in 2008. Costs steadily increased at urban and private institutions from $118,785.88 in 2002 to $234,039.66 in 2008, and at urban and academic centers from $115,940.04 in 2002 to $197,174.20 in 2008.

Factors Affecting Total Hospital Charges

Fixed-effects analysis was performed on variables including comorbidities, race, number of procedures, year of procedure, coil embolization, and death on total cost for patients with unruptured cerebral aneurysms or SAH. Patients with neurological disease and coagulopathy showed increases in total cost by $103,821.99 and $26,556.74, respectively (p < 0.001), whereas peripheral vascular disease lowered total costs by $9500.95. Presentation with SAH increased overall hospital costs by $7187, a difference that was not statistically significant (p = 0.24).

Assessing the raw data from the NIS database, endovascular treatment increased total hospital costs by more than $25,000 (p < 0.001; Table 7). Death increased total hospital charges by $28,471.88 (p = 0.003), which likely arises from the resources demanded of patients presenting with SAH. Elective treatment lowered costs by $6234.75 (p = 0.001), regardless of all other factors. The year the procedure was performed increased hospital charges by $4326.68 (p < 0.001), reflecting trends in rising health care costs outpacing the inflation correction used in the analysis. Individual factors contributing to an increase or decrease in hospital costs are reviewed in Table 7.

Stratifying patients by diagnosis revealed clear parallel increases in total hospital charges, with the greatest contributor to increased cost demonstrated as presentation with SAH. The cost curves for both endovascular and open surgical treatments increased over time, with no significant differences between the 2 cohorts (Fig. 4). While overall assessment of the cohort showed greater charges in endovascularly treated patients, analysis of patients with SAH receiving clipping or coiling revealed coiling to be cost effective, lowering hospital charges by $19,578.84 (p < 0.001). Multiple procedures performed on patients with SAH were associated with an increase in cost of $3709.30 (p < 0.001). The total cost for treating patients with SAH also increased by $2625.76 (p < 0.001) over the 6-year period (Table 7).

Geographical Variation in Total Treatment Cost and Trends in Treatment Cost

Geographic random effect impact on total hospital

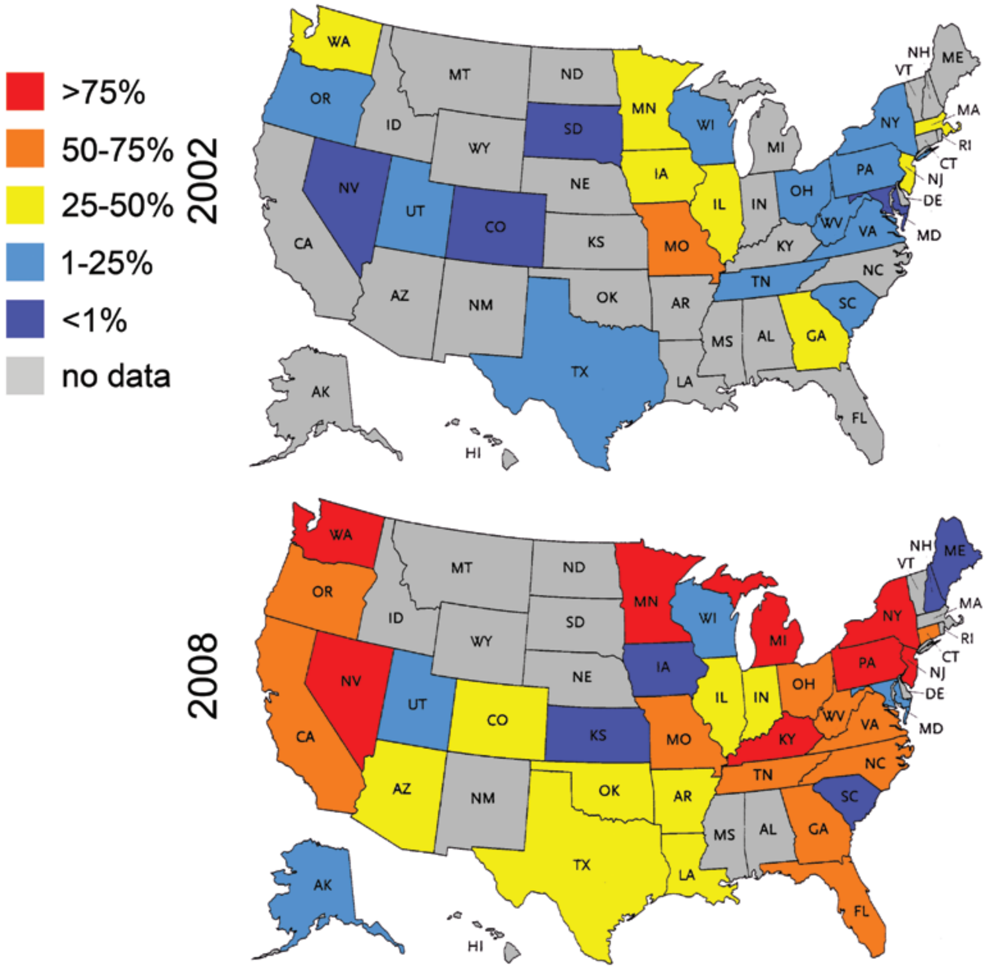

FIG. 3. Maps illustrating the geographic disparity in adoption of endovascular techniques. Color-coding illustrates the percentage of aneurysms (ruptured and unruptured) treated endovascularly. There was a substantial increase in endovascular therapy between 2002 and 2008, with specific increases concentrated along the eastern portion of the US and along the Pacific Coast.

cost was modeled as both a cost per day and a net "admission cost," which was a sum added to other hospital expenditures. States whose costs diverged from the national mean were identified if the 95% CI of the random effects did not reach zero. Methodological issues in the use of NIS data may entail regional sampling differences, a potential source of bias. Examination of the random effects on cost by state revealed that Pennsylvania and California were consistently more expensive per hospital admission and per day. Arizona, Iowa, New York, and Tennessee were less expensive per admission and per day. Geographic outliers in total costs and daily costs are reviewed in Table 8.

Discussion

Financial Impact of Endovascular Therapy

Few studies have compared the cost of endovascular treatment to open surgery for patients with aneurysms in the US.[13,14,22] Maud et al.[22] estimated the cost of initial hospitalization, disability, angiography, retreatment, and rebleeding for patients with SAH using utilization data from the Premier Perspective Comparative Data-

TABLE 2: United States trends in likelihood of endovascular versus open surgical treatment of cerebral aneurysms from 2002 to 2008*

State	OR (95% CI)
Arizona	8.086 (3.517–18.586)
California	1.381 (1.136–1.677)
Iowa	7.180 (4.178–12.344)
Missouri	4.797 (3.692–6.231)
New York	1.578 (1.261–1.975)
Oklahoma	3.359 (0.894–12.629)
Tennessee	1.575 (1.210–2.049)
Virginia	3.161 (2.167–4.612)
Arkansas	0.409 (0.194–0.862)
Indiana	0.066 (0.020–0.216)
Kansas	0.172 (0.058–0.512)
Michigan	0.258 (0.129–0.519)
New Hampshire	0.135 (0.041–0.443)
Texas	0.652 (0.520–0.818)

* The ORs reflect the likelihood of surgical clipping.

TABLE 3: Year-to-year geographic changes in the likelihood of endovascular versus open surgical treatment of cerebral aneurysms from 2002 to 2008*

State	OR (95% CI)
Arizona	0.684 (0.580–0.807)
Iowa	0.753 (0.620–0.914)
Missouri	0.873 (0.813–0.937)
Oklahoma	0.690 (0.536–0.888)
South Carolina	0.727 (0.617–0.856)
Virginia	0.898 (0.819–0.984)
Wisconsin	0.805 (0.701–0.925)
Indiana	1.400 (1.152–1.699)
Michigan	1.434 (1.228–1.674)
New Hampshire	1.372 (1.066–1.767)
Texas	1.066 (1.002–1.133)
New Jersey	1.169 (1.042–1.310)
New York	1.057 (1.002–1.114)

* The ORs reflect the likelihood of surgical clipping.

base. They applied these values to data obtained from the ISAT to calculate and compare US cost estimates for patients treated with either endovascular coiling or surgical clipping. The average 1-year total cost per patient with a ruptured intracranial aneurysm treated by coiling was $45,493, whereas the average 1-year cost per patient treated by clipping was significantly lower at $41,769. They concluded that although coiling had better outcomes at 1 year, it resulted in higher costs directly related to a higher incidence of retreatment.[22]

An analysis of a single institution by Hoh et al.[13] evaluated the difference in LOS and total hospital costs in open and endovascular treatment of cerebral aneurysms. From 2005 to 2007, database records of patients presenting with cerebral aneurysms were compared with those treated with surgical clipping and those with endovascular coiling. For patients with unruptured aneurysms, clipping was associated with an increased LOS but lower total hospital costs. Patients with ruptured aneurysms treated with clipping had a lower total hospital cost compared with those treated with endovascular coiling as well.

TABLE 4: Comparison of demographics in patients presenting with SAH*

Variable	OR (95% CI)	p Value
age	0.991 (0.988–0.995)	<0.00001
anemia	2.143 (1.779–2.582)	<0.00001
CHF	2.368 (1.776–3.158)	<0.00001
coagulopathy	1.803 (1.267–2.566)	0.0011
diabetes mellitus	0.839 (0.709–0.991)	0.04
electrolyte abnormalities	5.102 (4.436–5.868)	<0.00001
renal failure	0.617 (0.404–0.946)	0.03
African American	1.432 (1.239–1.654)	<0.00001
Hispanic	1.322 (1.125–1.553)	0.0007
Asian	2.047 (1.502–2.790)	<0.00001
yr of presentation	0.891 (0.853–0.930)	<0.00001
geographic outliers		
California	1.436 (1.094–1.884)	
New Jersey	1.977 (1.142–3.421)	
Utah	2.178 (1.156–4.105)	
New York	0.609 (0.454–0.815)	
Iowa	0.408 (0.254–0.656)	

* The ORs reflect the likelihood of presenting with SAH.

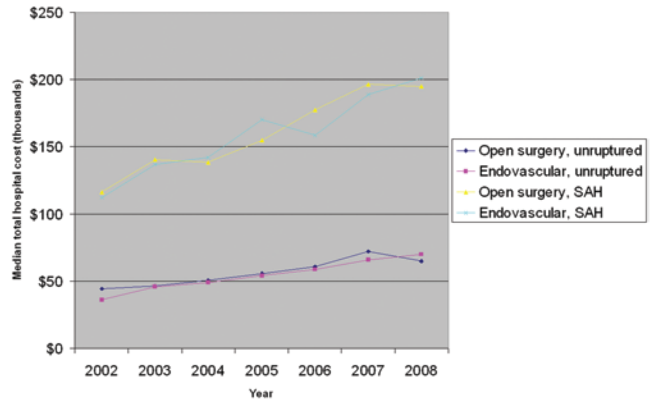

Fig. 4. Line graph demonstrating the relationship between hospital charges, patient presenting diagnosis (ruptured vs unruptured cerebral aneurysm), and choice of treatment (endovascular vs open surgery). Endovascular and open treatments had very similar hospital charges, with the primary disparity arising from differences in patient presentation.

An NIS database analysis conducted by Hoh et al.[14] examined the total hospital cost and LOS for patients with unruptured and ruptured aneurysms. This study used NIS data from 2002 to 2006. After adjusting for the effects of patient- and hospital-specific factors, clipping was associated with significantly longer LOS and significantly higher total hospital costs for patients with ruptured and unruptured aneurysms. Surgical clipping was associated with an average of 1.2-times more days in hospitalization for ruptured aneurysms and an average of 1.8-times more days in hospitalization for those with unruptured aneurysms. In addition, clipping resulted in $15,325 more in total charges for patients with ruptured aneurysms as well as $11,263 more in total charges for patients with unruptured aneurysms.

Trends and Geographic Variations in Health Care Expenditures

Medicare spending, after adjusting for inflation, has risen annually by 3.5% per year from 1992 to 2006. Cost increases have not been uniform, and considerable differences have been noted across regions. A report by Fisher et al.[7] notes that in large Eastern metropolitan areas such as Miami, Florida; Long Island, New York; and Boston, Massachusetts, increases in Medicare spending have averaged up to 5.0% per year. Other similar areas, such as Salem, Oregon, and San Francisco, California, have much lower rates of health care cost inflation with rates of approximately 2.3% to 2.4%.

An explanation for this discrepancy in health care spending is not evident. High cost areas in the country

TABLE 5: Fixed effects from random effect analysis on in-hospital death (coiling vs clipping)*

Variable	OR (95% CI)	p Value
age	1.025 (1.021–1.029)	<0.00001
SAH	38.09 (21.841–66.412)	<0.00001
no. of diagnoses	1.186 (1.110–1.266)	<0.00001
no. of procedures	1.345 (1.257–1.438)	<0.00001
yr of procedure	0.661 (0.584–0.747)	<0.00001
coiled aneurysm	1.318 (1.148–1.514)	0.0001

* The ORs reflect the likelihood of patient death during admission.

TABLE 6: Factors and geographic outliers in median hospital LOS

Variable	Multiplier* (95% CI)	p Value
age (per year)	1.002 (1.001–1.004)	0.005
SAH	2.751 (2.380–3.181)	<0.001
yr of procedure	0.952 (0.941–0.964)	<0.0001
no. of procedures	1.126 (1.107–1.146)	<0.00001
hypertension	1.002 (1.001–1.004)	<0.00001
electrolyte abnormality	1.223 (1.041–1.436)	0.007
CHF	1.335 (1.012–1.761)	0.02
endovascular Tx	0.518 (0.467–0.576)	<0.00001
no. of diagnoses	1.067 (1.051–1.083)	<0.00001
African American	1.111 (1.043–1.182)	0.0005
Hispanic	1.117 (1.044–1.195)	0.0007
geographic outliers		
California	0.861 (0.818–0.907)	
Colorado	0.826 (0.711–0.960)	
Connecticut	1.167 (1.019–1.336)	
Michigan	0.809 (0.681–0.960)	
Missouri	0.867 (0.787–0.955)	
Tennessee	1.140 (1.051–1.237)	
Texas	1.072 (1.002–1.147)	
Virginia	1.161 (1.041–1.296)	

* The multiplier value refers to the effect of the given variable on the mean LOS.

are also associated with high growth and also slight differences in the malpractice environment. Previous reports note that regional differences in health care costs could only explain approximately 10% of state variations in Medicare expenditures.[2,7] Physician behavior may explain some cost discrepancies. In higher spending regions, primary care physicians are reported to be more likely to recommend discretionary services such as referrals to treat general diseases, and all physicians were more aggressive with admissions to ICUs.[27] In regions with more physicians and hospital beds, data show that patients make more visits to physicians and experience more hospitalizations.[8,9] The local health care environment profoundly influences health care resource capacity and access, and thus may impact clinical decision making.

A primary assumption in ascribing regional variations in health care costs to physician behavior is uniform availability of technology. Fisher et al.[7] note that variation in availability of clinical technology does not explain cost variation nationwide, noting further that all US residents have access to the same technology. It has not been demonstrated that all US citizens have uniform access to new technologies.

Results of the Present Study

Our findings demonstrate an increase in percentage of cerebral aneurysms treated endovascularly from 2002 to 2008 for both SAH (17.28% to 57.59%) and unruptured aneurysms (29.70% to 62.73%; $p < 0.0001$; Fig. 1). Geographic trends across the US with the greatest increase in endovascular coiling were predominantly east of the Mississippi River and along the west coast (Fig. 3). In the cohort of states east of the Mississippi River in which 2008 NIS data were available, 65% had predominant use of endovascular techniques in treatment of cerebral aneurysm patients, while only 37.5% of states with adequate data in the remainder of the nation featured greater than 50% use of endovascular approaches. While there has been steady growth of endovascular techniques nationwide, the pattern of this growth is not uniform and significant regional variations are evident.

Length of stay remained constant for SAH from 2002 to 2008 for patients treated with either clipping or coiling, while patients with unruptured aneurysms saw LOS decrease by an average of 1 day. Patients who underwent aneurysmal coiling procedures for either SAH or unruptured aneurysms experienced significantly shorter LOSs overall compared with those who underwent clipping procedures.

While presentation with SAH did not, in isolation, increase hospital costs in a statistically significant fashion, many sequelae of SAH captured by the NIS database may be associated with increased health care expenditures. Subarachnoid hemorrhage was strongly correlated with in-hospital death, which increased the total hospital cost by more than $28,000 ($p < 0.003$). High-grade SAH may be modeled in the NIS by capture of patients presenting with neurological deficits; presence of neurological comorbidities in our analysis correlated with an increase in total hospital charges of $103,822 ($p < 0.00001$).

Based on this assessment of NIS data, patient presentation and site of clinical service have greater impact on overall hospital charges than choice of endovascular or open surgical treatment of cerebral aneurysms. This likely explains previous disagreements in the literature with regard to economic impact of endovascular therapy, and may explain the relative cost savings offered by choice of endovascular treatment in patients presenting with SAH.[6,13,14,16,22,25]

Geographic Variation and Trends in the Treatment of Cerebral Aneurysms

There are significant regional differences in the incorporation of endovascular treatment of cerebral aneurysms. While the overall percentage of patients with an-

TABLE 7: Factors affecting total hospital costs*

Variable	Estimate ($)	SEM ($)	p Value
death	28,471.88	9,622.46	0.003
elective procedure	−6,234.75	1,909.99	0.001
no. of procedures	5,180.70	435.24	<0.00001
yr of procedure	4,326.68	418.11	<0.00001
endovascular Tx	25,410.78	3,311.40	<0.00001
coagulopathy	26,556.74	4,649.85	<0.00001
neurological disorder	103,821.99	13,370.63	<0.00001
urban, academic clinical setting	10,643.54	13,371.63	0.0006
peripheral vascular disease	−9,500.95	4,107.97	0.021
patients presenting w/ SAH			
endovascular Tx	−19,578.84	2,767.41	<0.00001
age	−461.84	87.08	<0.00001
CHF	15,867.86	6,840.37	0.020
hypertension	−5,186.56	2,258.39	0.022
electrolyte abnormalities	−9,595.71	3,732.95	0.010
neurological disease	−40,217.90	13,435.95	0.003
death	−19,275.42	9,818.59	0.05
no. of procedures	3,709.30	492.17	<0.00001
yr of procedure	2,625.76	570.28	<0.00001
endovascularly treated patients			
coagulopathy	−17,972.43	6,850.23	0.009
neurological deficit	−15,861.32	5,790.36	0.006
peripheral vascular disease	15,305.78	5,510.77	0.005
renal failure	−23,257.77	9,291.74	0.012
death	14,701.86	4,219.69	<0.00001

* $ = US dollars.

eurysms treated endovascularly grew from 2002 to 2008, the pattern of growth was not uniform. A greater number of states with a high incidence of endovascular treatment are concentrated east of the Mississippi River and along the Pacific Coast. Considerably lower percentages of aneurysms were treated endovascularly in the Midwest and the South. Patient presentation (SAH vs unruptured aneurysm) and death did not correlate with geographic location, indicating the difference in use of endovascular techniques is not based on patient factors.

These data may suggest that access to endovascular therapy may be lower in some areas, or that some regions are less receptive to transition to endovascular approaches. These differences do not conform to general population distributions, with some very large states showing evidence of low incorporation of endovascular treatment. In patients presenting with SAH, endovascular treatments increase in incidence with transition from rural to urban settings (p = 0.009) and increase further when comparing urban private and urban academic facilities (p = 0.05). Urban academic facilities overall have the highest costs recorded for patients with cerebral aneurysms (p = 0.0006).

The geographic disparity in use of endovascular therapies may illustrate significant regional variation in both the availability and utilization of new technologies. Over the time period studied, endovascular therapies may be considered to have matured, with publication of the ISAT trial, training of more practitioners in endovascular techniques, and wider acceptance of endovascular therapy by the neurosurgical community.[23] The heterogeneity of adoption of endovascular techniques may question the assumption that all US residents have access to the same medical technologies. Geographic variation in technology availability and accessibility may occur; uniform access to endovascular therapies is not evident from this assessment.

This assessment found significant geographic variation in hospital costs for treatment of cerebral aneurysms. Total hospital costs for both SAH and unruptured aneurysms were found to be significantly lower at rural hospitals compared with both private and academic urban hospitals. By state, Pennsylvania and California had the highest costs per admission. There were other outlier states with significant differences from median hospital cost values (Table 8).

Sources for Bias

Despite the size of the NIS, it remains merely a retrospective database. None of the patients whose data are summarized in the database were randomized, and no effort was made to ensure equal numbers of patients were included in each group of studied categories. Not all states participate in the NIS, and not all hospitals in each state participate in the NIS. The data sample is limited to the hospitals that report and is a reflection of their operative trends. While it may be assumed that this is a representative cross-section of the US health care market, sampling error may occur. This assessment assumes the accuracy of hospital coding data.

Regional variations from states with limited representation in the NIS may skew geographical data. States with no hospitals participating in the NIS assessment are necessarily omitted from the analysis. The database relies on accuracy and standardization of reporting from individual hospitals; regional variation in reporting methodology could occur.

The very large study sample values presented in the NIS and other administrative database studies increase the likelihood of achieving statistical significance with nonsensical relationships. For instance, in this assessment of the NIS database we found that the Asian patients undergoing clipping procedures were significantly less expensive than non-Asians or Asians treated endovascularly (p = 0.04). The clinical relevance of this finding is questionable. With NIS and other database studies, appropriate study design and critical assessment of results are necessary to provide database relationships with context, meaning, and relevance.

Conclusions

This review of cerebral aneurysm data from the NIS database reveals significant growth in endovascular techniques from 2002 to 2008. By 2008, the majority of both ruptured and unruptured aneurysms were treated

TABLE 8: Geographic analysis of total hospital charges and per-day charges

State	Charge (95% CI)*
total admission cost	
Arkansas	−20,548.28 (−29,507.93 to −11,588.63)
Arizona	−2,043.14 (−22,608.63 to −1,477.65)
California	36,279.54 (32,451.23 to 40,107.85)
Florida	10,641.94 (6,852.55 to 14,431.32)
Iowa	−11,771.90 (−22,091.84 to −1,451.97)
Massachusetts	8,595.81 (2,566.53 to 14,625.08)
New York	−9,654.48 (−13,396.72 to −5,912.24)
Pennsylvania	48,067.86 (36,187.22 to 59,948.50)
South Carolina	9,383.19 (−2,459.45 to 21,225.83)
Tennessee	−8,366.77 (−13,232.79 to −3,500.76)
Texas	12,665.71 (8,126.84 to 17,204.58)
per-day cost	
Arkansas	−1,724.61 (−2,303.90 to −1,145.33)
Arizona	24,53.58 (1,851.08 to 3,056.08)
California	5,062.59 (4,845.07 to 5,280.10)
Colorado	4,725.20 (4,213.27 to 5,237.13)
Connecticut	−1,134.42 (−1,531.96 to −736.88)
Florida	−900.23 (−1,092.51 to −707.94)
Hawaii	−2,927.36 (−5,128.87 to −725.86)
Iowa	−2,221.19 (−2,948.11 to −1,494.27)
Indiana	−2,428.26 (−2,961.34 to −1,895.17)
Kentucky	−947.49 (−1,857.70 to −37.29)
Maryland	−4,972.41 (−5,687.12 to −4,257.71)
Michigan	−2,031.44 (−2,619.04 to −1,443.84)
Nebraska	8,733.43 (7,129.34 to 10,337.53)
New Jersey	2,243.15 (1,696.76 to 2,789.54)
Nevada	4,289.64 (3,346.27 to 5,233.01)
New York	−1,861.29 (−2,040.36 to −1,682.23)
Oregon	−3,034.20 (−4,090.16 to −1,978.25)
Pennsylvania	15,529.05 (14,222.85 to 16,835.26)
Rhode Island	−1,882.74 (−2,654.69 to −1,110.80)
Tennessee	−531.74 (−822.92 to −240.56)
Texas	−1,086.84 (−1,298.00 to −875.68)
Virginia	−2,685.11 (−3,017.33 to −2,352.89)
Vermont	−4,257.05 (−5,151.66 to −3,362.44)
Wisconsin	−2,143.59 (−2,796.75 to −1,490.43)

* Charges given in US dollars.

endovascularly. The greatest impact on patient mortality was presentation with SAH. Differences in hospital costs between open and endovascular techniques are likely secondary to the presenting diagnosis of the patient and site-of-service factors. Presentation with SAH indirectly had a significant impact on hospital cost, and a greater percentage of endovascular procedures were completed at urban academic medical centers. There is substantial regional variation in adoption of endovascular techniques. These variations may question previous assumptions with regard to the uniformity of availability of technology in the US health care system. Geographical differences in the implementation of new technology may affect overall regional health care expenditures.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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