SNI
SURGICAL NEUROLOGY INTERNATIONAL
SNI: Neurovascular
OPEN ACCESS
For entire Editorial Board visit : http://www.surgicalneurologyint.com

Original Article

Association of travel distance and cerebral aneurysm treatment

Jian Guan, Michael Karsy, William T. Couldwell, Richard H. Schmidt, Philipp Taussky, Min S. Park

Department of Neurosurgery, Clinical Neurosciences Center, University of Utah, Salt Lake City, Utah, USA

E-mail: Jian Guan - jian.guan@hsc.utah.edu; Michael Karsy - Michael.karsy@hsc.utah.edu; William T. Couldwell - william.couldwell@hsc.utah.edu; Richard H. Schmidt - richard.schmidt@hsc.utah.edu; Philipp Taussky - phil.taussky@hsc.utah.edu; *Min S. Park - min.park@hsc.utah.edu
*Corresponding author

Received: 20 January 17 Accepted: 08 June 17 Published: 06 September 17

Abstract

Background: The management of cerebral aneurysms requires a significant level of expertise, and large areas of the country have limited access to such advanced neurosurgical care. The objective of this study was to examine the impact of longer travel distance on aneurysm management.

Methods: Adult patients treated for cerebral aneurysms from January 1, 2013 to January 1, 2016, were retrospectively identified. Demographic data, socioeconomic data, aneurysm characteristics, and postoperative outcomes were evaluated with univariate and multivariable analysis to determine factors that influenced treatment prior to or after rupture.

Results: Two hundred fifty aneurysms (87 ruptured) were treated during the study period. Patients treated after rupture were more likely than those treated before rupture to live in areas with lower median household income (62% vs. 45%, $P = 0.009$), to live further from the treatment center (68% vs. 40%, $P < 0.001$), and to have aneurysms in the anterior communicating artery, anterior cerebral artery, or posterior communicating artery ($P < 0.001$). On multivariable analysis, longer travel distance (OR 3.288, 95% CI 1.562–6.922, $P = 0.002$), lower income (1.899, 95% CI 1.003–3.596, $P = 0.049$), and aneurysm location ($P = 0.035$) remained significantly associated with treatment after rupture.

Conclusions: Patients who must travel further to receive advanced neurovascular care are more likely to receive treatment for their aneurysms only after they rupture. Further inquiry is needed to determine how to better provide neurosurgical treatment to patients living in underserved areas.

Key Words: Aneurysm clipping, cerebral aneurysm, endovascular treatment, flow diversion, travel distance

Access this article online
Website: www.surgicalneurologyint.com
DOI: 10.4103/sni.sni_28_17
Quick Response Code:

INTRODUCTION

Cerebral aneurysms are estimated to be present in more than 3% of the population,[38] suggesting that nearly 10 million individuals in the United States alone may harbor these lesions. Although a significant body of evidence suggests that only a minority of aneurysms eventually rupture,[1,30,32] aneurysmal subarachnoid hemorrhage remains a significant cause of morbidity

How to cite this article: Guan J, Karsy M, Couldwell WT, Schmidt RH, Taussky P, Park MS. Association of travel distance and cerebral aneurysm treatment. Surg Neurol Int 2017;8:210.
http://surgicalneurologyint.com/Association-of-travel-distance-and-cerebral-aneurysm-treatment/

and mortality.[7,12] The inherent complexities of the management of aneurysms—both ruptured and unruptured—combined with advancements in both imaging and treatment modalities mean that these patients are best treated at high-volume centers with deep subspecialty expertise.[37] The availability of such care; however, is limited by both a dearth of vascular and endovascular neurosurgeons[34] and a geographic maldistribution of practitioners, with the majority of counties in the United States having no neurosurgeons at all.[20]

The shortage of healthcare professionals is not limited to neurosurgery, and significant discussion is ongoing in both the medical literature[13,35,36,39,42] and the popular press[12,31] about how best to tackle this difficult issue. One of the results of this deficiency is the need for extended travel by some patients to obtain primary and specialty medical care. Although the impact of distance to care and management has been investigated in other subspecialties,[17,19,27] little research has been reported in the neurosurgical literature. In our study, we examined the association of distance to a quaternary neurovascular center and timing of cerebral aneurysm treatment.

MATERIALS AND METHODS

Patient cohort

After obtaining approval from the institutional review board with a waiver of informed consent, we queried a clinical database to obtain information about patients 18 years and older who underwent treatment for cerebral aneurysm between January 1, 2013, and January 1, 2016. Patients were excluded if geographic, demographic, or socioeconomic data were unavailable. All endovascular procedures were performed by one of two endovascular neurosurgeons, and all open surgical procedures were performed by one of four neurosurgeons. All procedures were performed at a quaternary referral center that provides care to the American Intermountain West—a geographic region comprising the states of Utah, Nevada, and parts of Idaho, Arizona, Colorado, Montana, and New Mexico and serving a population of more than 3 million.[22]

Data collection

Demographic, geographic, socioeconomic, aneurysm-related, and postoperative information was collected on all patients. Demographic data included age, race/ethnicity (dichotomized into Caucasian and non-Caucasian), sex, marital status, and insurance type (divided into private, Medicaid/self-pay, and Medicare). Each patient's ZIP code was collected. The U.S. Census data (http://www.census.gov/) were used to determine the median household income for each patient's ZIP code. These were subsequently dichotomized based on the median value for the cohort ($56,011). Travel distance for each patient was also calculated from the patient's ZIP code to our medical center utilizing Google maps (http://maps.google.com) and dichotomized based on the median travel distance (89.9 miles). The concentration of general family practice physicians (FPPs) in each patient's home county was also obtained via the National Provider Identifier database (https://www.cms.gov/Regulations-and-Guidance/HIPAA-Administrative-Simplification/NationalProvIdentStand/DataDissemination.html) and was dichotomized based on the median FPP-to-patient ratio (1 physician to 3034 patients). Information on active tobacco use and hypertension was also collected.

Aneurysm-related data included rupture status at time of treatment, treatment modality, aneurysm size (dichotomized based on a cutoff size of 7 mm), and aneurysm location. Treatment modality was dichotomized into open clipping or endovascular (consisting of coiling with or without stent assistance and flow diversion). Aneurysm location was divided into seven categories based on those used in previous papers.[1] Each patient also had a Charlson Comorbidity Index (CCI) score calculated based on published criteria.[11] Postoperative data collected on each patient included length of hospitalization and final discharge destination.

Mapping of aneurysm distribution was performed using ArcGIS (ESRI 2011. ArcGIS Online: Release 10.3. Redlands, CA: Environmental Systems Research Institute, http://www.arcgis.com).

Statistical analysis

Continuous variables were analyzed using Student's *t*-test, and categorical variables were analyzed using Chi-squared analysis. Univariate and multivariable analysis were first performed to compare patients with ruptured aneurysms and those with unruptured aneurysms (i.e., to assess timing of treatment). Variables were selected for this multivariable model based on factors that reached a $P < 0.2$ on univariate analysis. Univariate analysis was then used to compare patients who lived less than or greater than the median hospital travel distance. In all analyses, $P < 0.05$ was considered statistically significant. All statistical analyses were performed using SPSS V20.0 (IBM Corporation, Armonk, NY).

RESULTS

Demographic characteristics of patients in the ruptured and unruptured treatment groups were largely similar, with no significant differences between the groups in age, sex, marital status, race/ethnicity, CCI, or insurance type [Table 1]. The rate of smoking in the ruptured group was slightly higher than in the unruptured group (37% vs. 26%, $P = 0.087$), but this difference was not statistically significant. The rate of hypertension was similar in both groups. Patients treated

Table 1: Univariate analysis of ruptured versus unruptured aneurysm groups

Variable	Unruptured (*n*=163)	Ruptured (*n*=87)	*P**
Female patients	119 (73)	59 (68)	0.388
Mean age in years±SD	55.2±12.5	54.1±12.9	0.501
Married	104 (64)	52 (60)	0.531
Race/ethnicity			
Caucasian	134 (82)	70 (81)	0.734
Non-caucasian	29 (18)	17 (20)	
Payor type			
Private	89 (55)	44 (51)	0.280
Medicaid/self pay	26 (16)	21 (24)	
Medicare	48 (29)	22 (25)	
Charlson comorbidity index ± SD	1.87±1.5	1.66±1.8	0.317
Hypertension	80 (49)	39 (45)	0.521
Tobacco use	43 (26)	32 (37)	0.087
Lower income	73 (45)	54 (62)	0.009
Shorter travel distance	98 (60)	28 (32)	<0.001
Lower family practice physician concentration	97 (60)	41 (47)	0.061
Aneurysm location			
Internal carotid artery	54 (33)	16 (18)	<0.001
AComm/ACA	31 (19)	37 (43)	
MCA	29 (18)	12 (14)	
PComm	10 (6)	9 (10)	
Basilar tip	8 (5)	5 (5)	
Other posterior circulation	18 (11)	8 (9)	
Cavernous carotid	13 (8)	0 (0)	
Smaller aneurysm size	80 (49)	53 (61)	0.074
Endovascular treatment	99 (61)	34 (39)	0.001
Length of stay (days) ± SD	4.0±5.6	18.5±7.9	<0.001
Discharge destination			
Home	140 (86)	32 (37)	<0.001
Home health	6 (4)	1 (1)	
Inpatient rehabilitation	12 (7)	30 (35)	
Skilled nursing facility	4 (3)	7 (8)	
LTAC	1 (1)	6 (7)	
Death	0 (0)	11 (13)	

AComm: Anterior communicating artery, ACA: Anterior cerebral artery, MCA: Middle cerebral artery, PComm: Posterior communicating artery, LTAC: Long-term acute care facility. Results are reported as number of patients (%) unless otherwise indicated. **P*<0.05 was considered significant.

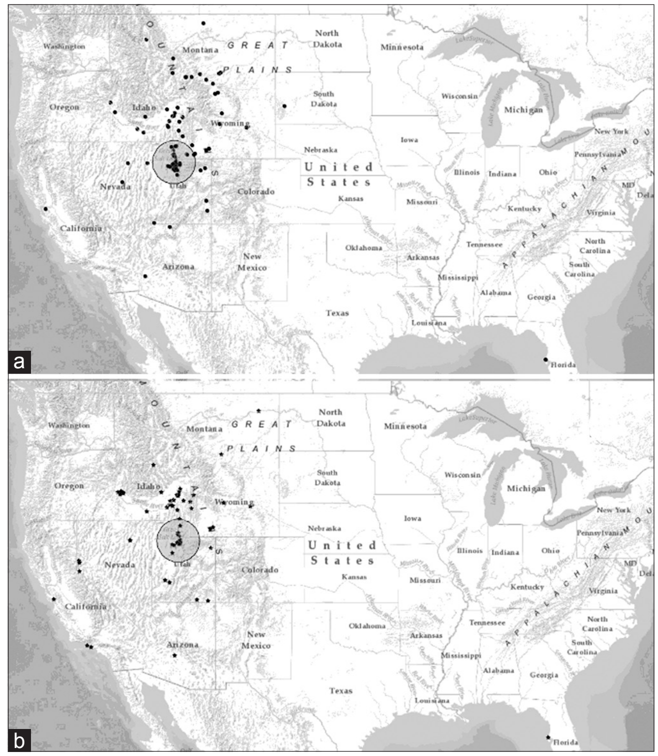

Figure 1: Maps showing unruptured (a) versus ruptured (b) aneurysm distribution. Circle in both figures denotes median travel distance for all patients. Some of these patients happened to be in the area on vacation/travels rather than referred specifically to us

after the aneurysm had ruptured were significantly more likely to fall into the longer travel distance group (68% vs. 40%, $P < 0.001$, Figure 1). Patients who were treated for ruptured aneurysm were also significantly more likely to be from areas with lower median household income (62% vs. 45%, $P = 0.009$).

Aneurysm location differed significantly between the ruptured and unruptured groups ($P < 0.001$). Ruptured aneurysms were significantly more likely to arise from the anterior communicating artery, anterior cerebral artery, or posterior communicating artery, whereas those treated prior to rupture were more likely to arise from the internal carotid artery. Ruptured aneurysms were also significantly more likely to be treated with open clipping than were unruptured aneurysms (61% vs. 39%, $P < 0.001$).

Patients treated for ruptured aneurysms had significantly longer hospital stays than those treated for unruptured aneurysms (18.5 ± 7.9 days vs. 4.0 ± 5.6 days, $P < 0.001$) and were significantly less likely to discharge home ($P < 0.001$). Variables selected for the multivariable model included tobacco use, aneurysm size, aneurysm location, median household income, travel distance, and local FPP concentration. Discharge destination, treatment modality, and length of stay met criteria, but were not included in our model as we thought that it was unlikely these variables had an impact on aneurysm treatment timing. In our multivariable model, aneurysm location ($P < 0.035$, Table 2), lower income ($P = 0.049$), and longer travel distance ($P = 0.002$) were significantly associated with aneurysm treatment after rupture.

Patients who were "far" from our medical center were similar in all assessed demographic factors when compared with the "close" group, including age, sex, race/ethnicity, and marital status [Table 3]. CCI values for both groups were also not significantly different, nor were rates of tobacco use and hypertension. Patients in the "far" group were more likely to be from a region with a lower median household income ($P < 0.001$) and from an area with

Table 2: Multivariable analysis of ruptured versus unruptured aneurysm groups

Variable	B	e^B	95% C.I. for e^B	P*
Aneurysm location				0.035
Internal carotid artery (ref)	n/a	n/a	n/a	n/a
AComm/ACA	1.320	3.743	1.699-8.242	0.001
MCA	0.432	1.541	0.603-3.937	0.366
PComm	1.183	3.265	1.054-10.118	0.040
Basilar tip	1.018	2.769	0.704-10.883	0.145
Other posterior circulation	0.251	1.285	0.446-3.701	0.642
Cavernous carotid	-20.063	<0.001	n/a	0.999
Lower income	0.641	1.899	1.003-3.596	0.049
Smaller aneurysm size	0.575	1.776	0.961-3.282	0.067
Tobacco use	-0.303	0.739	0.396-1.378	0.341
Longer travel distance	1.190	3.288	1.562-6.922	0.002
Higher family practice physician concentration	0.303	1.354	0.652-2.809	0.303

CI: Confidence interval, AComm: Anterior communicating artery, ACA: Anterior cerebral artery, MCA: Middle cerebral artery, PComm: Posterior communicating artery. *$P<0.05$ was considered significant.

better FPP coverage ($P < 0.001$). Aneurysm size, location, and treatment modality were not significantly different when comparing patients in the "close" and "far" groups, although "far" patients were significantly more likely to be treated after aneurysm rupture ($P < 0.001$). "Far" patients were also more likely to have a longer length of hospitalization after treatment ($P < 0.001$) and were less likely to discharge home ($P = 0.050$)

DISCUSSION

Aneurysmal subarachnoid hemorrhage is a devastating pathology that can result in permanent disability even in survivors.[25,33] The cost of management after rupture is also dramatically greater, with one study showing that charges to treat ruptured aneurysms were two to three times in excess of those for aneurysms treated prior to hemorrhage.[21] Despite the obvious benefits of treating aneurysms prior to rupture, the complexity of their natural history[14] and the need for advanced imaging to detect and monitor them often makes early treatment difficult because of the need for ready access to subspecialized care. It is perhaps unsurprising, therefore, that patients in vulnerable demographic and socioeconomic groups have been shown to be more likely to be treated for aneurysms only after subarachnoid hemorrhage[9] and have worse outcomes than their peers.[24]

The need to travel long distances to obtain medical care is a common problem in the United States.[4,29] This problem is likely especially problematic for patients seeking neurosurgical care, with estimates suggesting that for every 100,000 people in the US, there are fewer than two practicing neurosurgeons.[20] Such figures likely underestimate the problem with regard to specific subspecialties such as

Table 3: Univariate analysis of travel distance

	Close (*n*=126)	Far (*n*=124)	P*
Female patients	90 (71)	88 (71)	0.936
Mean age in years±SD	54.1±12.6	55.6±12.7	0.352
Married	72 (57)	84 (68)	0.084
Race/ethnicity			
Caucasian	98 (78)	106 (86)	0.116
Non-caucasian	28 (22)	18 (15)	
Payor type			
Private	67 (53)	66 (53)	0.994
Medicaid/self pay	24 (19)	23 (19)	
Medicare	35 (28)	35 (28)	
Charlson comorbidity index±SD	1.67±1.4	1.93±1.8	0.205
Hypertension	62 (49)	57 (46)	0.608
Tobacco use	32 (25)	43 (35)	0.109
Lower income	43 (34)	84 (68)	<0.001
Treatment after rupture	28 (22)	59 (48)	<0.001
Lower family practice physician concentration	106 (84)	32 (26)	<0.001
Aneurysm location			
Internal carotid artery	40 (32)	30 (24)	0.437
AComm/ACA	27 (21)	41 (33)	
MCA	23 (18)	18 (15)	
PComm	10 (8)	9 (7)	
Basilar tip	7 (6)	6 (5)	
Other posterior circulation	14 (11)	12 (10)	
Cavernous carotid	5 (4)	8 (7)	
Smaller aneurysm size	71 (56)	62 (50)	0.314
Endovascular treatment	59 (47)	58 (47)	0.994
Length of stay (days) ± SD	6.6±7.6	11.5±10.5	<0.001
Discharge destination			
Home	96 (76)	76 (61)	0.050
Home health	3 (2.4)	4 (3.2)	
Inpatient rehabilitation	15 (12)	27 (22)	
Skilled nursing facility	7 (6)	4 (3)	
LTAC	1 (1)	6 (5)	
Death	4 (3)	7 (6)	

AComm: Anterior communicating artery, ACA: Anterior cerebral artery, MCA: Middle cerebral artery, PComm: Posterior communicating artery, LTAC: Long-term acute care facility. Results are reported as number of patients (%) unless otherwise indicated. *$P<0.05$ was considered significant

vascular neurosurgery, as only a minority of the neurosurgical workforce specializes in these pathologies.[34]

Our study suggests that patients who must travel significant distances to receive neurosurgical care for cerebral aneurysms are more than three times as likely to be treated for a ruptured aneurysm as those who live in closer proximity to a comprehensive neurovascular center. This difference is independent of other factors including socioeconomic status, aneurysm characteristics, and other demographic variables. Patients in our cohort who lived further from our center actually tended to have more ready access to primary care physicians, as indicated by a lower average FPP-to-patient ratio (1 FPP to 2572 patients in the longer distance group vs. 1 FPP to 3433 patients in the shorter distance group), possibly because of a higher population density in urban areas. With regard to timing of cerebral aneurysm treatment; however, there was no significant benefit to living in a region with a higher concentration of primary care physicians. Prior studies have supported the idea that a simple increase in physician number is not sufficient to improve patient outcomes[40] and that such gains require an approach that maximizes both the quality of care and its proper utilization.

There are several possible explanations for our study's findings. Patients who live further away from a cerebrovascular care center may simply be less likely to be evaluated for a cerebrovascular lesion. The most common symptom leading to discovery of unruptured cerebral aneurysms within our cohort was headache, with the majority of patients being initially evaluated by a family practitioner or a neurologist. In practices where cerebrovascular lesions are rarely encountered, vessel imaging may not be available or commonly employed in the evaluation of such a nonspecific finding. Patients living further away from a treatment center may also defer elective aneurysm treatment for logistical reasons—an unwillingness or inability to travel dozens if not hundreds of miles for the initial intervention and then for any required follow-up. Patients in our cohort who were from areas with lower median household income were also more likely to be treated after aneurysm rupture than electively, a finding which has previously been described,[9] although our analysis of patient income must be tempered by the fact that ZIP code–level median income was analyzed, not individual patient income. It is likely that patients who fall into both categories—geographically isolated from neurosurgical care and without the resources to support travel to obtain such care—would be especially vulnerable to poorer management. This idea is supported by the superior outcomes associated with cerebral aneurysm management at high-volume centers.[26,43]

The location of the aneurysm in the circulation also significantly affected the chance of treatment after rupture in our cohort, with both posterior communicating artery lesions and anterior communicating artery lesions more than three times as likely as internal cerebral artery aneurysms to receive intervention only after hemorrhage. The dangers of posterior communicating artery aneurysms are well documented and accepted.[38] Despite a fairly robust volume of evidence suggesting the increased rupture risk of anterior communicating artery aneurysms,[6,15,18] the behavior of these lesions is less widely appreciated.

Our study has several limitations. The first is its retrospective nature, which increases its vulnerability to confounders. One possible confounder is aneurysm treatment at other facilities—specifically the possibility that elective aneurysms are preferentially treated locally, while patients with subarachnoid hemorrhage are referred to high-volume centers. The literature, however, does not appear to support this, with the most recent national data suggesting that a similar percentage of unruptured and ruptured aneurysms are treated at low-volume centers.[8] A second possible confounder is a differing baseline rupture risk between patients living near or far from our center. Patients in the two distance groups were similar with regard to multiple variables known to influence aneurysm rupture risk including age, sex, tobacco use, and hypertension, but other known risk factors could not be assessed,[10] and therefore may influence our results. Significant among these is the dichotomization of tobacco use into "users" and "non-users," when in fact heavy tobacco use has been shown to increase aneurysm rupture risk significantly more than light use.[28]

Socioeconomic status has been demonstrated time and again to be associated with a variety of healthcare quality measures,[5,31,41] and any study investigating differences in outcomes among groups of patients must take such differences into consideration. Without access to individual income data, we utilized ZIP code–based median household income as a surrogate for socioeconomic status.[16] This methodology for analyzing income increases the risk of misrepresenting actual individual patient socioeconomic status because of heterogeneity within ZIP codes and inherent differences in ZIP codes due to a number of variables (urban vs. rural, geographical factors, etc.). Although this approach has been validated multiple times in the literature as an acceptable surrogate for socioeconomic studies,[2,3,23] the risk remains that our analysis of socioeconomic status may be biased as a result. Ideally, future studies would have access to individual patient and family income data and would preferably compare matched cohorts to more definitively examine the influence of travel distance on cerebral aneurysm treatment in isolation.

We examined a relatively small cohort of patients at a single center, thus limiting our power and the generalizability of our findings. The latter may especially be true given the nature of how healthcare providers are distributed throughout the nation. We were unable to assess the absolute incidence of unruptured aneurysms present in the population from which our hospital draws, nor do we have access to information on what proportion of these aneurysms are detected in each location. As a result, we are unable to make firm conclusions as to what impact travel distance has on rates of aneurysm diagnosis or rates of referral—only that of the cases referred to our center requiring treatment, a higher proportion of those from distant locations are treated following rupture. Finally, we did not examine specific characteristics of patients within the ruptured aneurysm group, such as time from rupture to presentation, presenting acuity (i.e., Hunt and Hess grade, World Federation of Neurological Surgeons grade), and rate of loss to follow-up. Subsequent studies examining these factors would undoubtedly be informative.

CONCLUSIONS

In this single-institution cohort, patients living further from our medical center were more likely to undergo treatment for their cerebral aneurysm emergently after rupture than electively. Further studies are needed to better define this association and to determine strategies to provide advanced neurosurgical care to remote regions of the country.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. The International Study of Unruptured Intracranial Aneurysms Investigators. Unruptured intracranial aneurysms-risk of rupture and risks of surgical intervention. N Engl J Med 1998;339(24):1725-1733.
2. Agarwal S, Menon V, Jaber WA. Outcomes after acute ischemic stroke in the United States: Does residential ZIP code matter? J Am Heart Assoc 2015;4:e001629.
3. Alter DA, Naylor CD, Austin P, Tu JV. Effects of socioeconomic status on access to invasive cardiac procedures and on mortality after acute myocardial infarction. N Engl J Med 1999;341:1359-67.
4. Attar MA, Hanrahan K, Lang SW, Gates MR, Bratton SL. Pregnant mothers out of the perinatal regionalization's reach. J Perinatol 2006;26:210-4.
5. Becker G, Newsom E. Socioeconomic status and dissatisfaction with health care among chronically ill African Americans. Am J Public Health 2003;93:742-8.
6. Bijlenga P, Ebeling C, Jaegersberg M, Summers P, Rogers A, Waterworth A, *et al*. Risk of rupture of small anterior communicating artery aneurysms is similar to posterior circulation aneurysms. Stroke 2013;44:3018-26.
7. Bonita R, Thomson S. Subarachnoid hemorrhage: Epidemiology, diagnosis, management, and outcome. Stroke 1985;16:591-4.
8. Brinjikji W, Lanzino G, Kallmes DF, Cloft HJ. Cerebral aneurysm treatment is beginning to shift to low volume centers. J Neurointerv Surg 2014;6:349-52.
9. Brinjikji W, Rabinstein AA, Lanzino G, Cloft HJ. Racial and ethnic disparities in the treatment of unruptured intracranial aneurysms: A study of the Nationwide Inpatient Sample 2001-2009. Stroke 2012;43:3200-6.
10. Chalouhi N, Hoh BL, Hasan D. Review of cerebral aneurysm formation, growth, and rupture. Stroke 2013;44:3613-22.
11. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis 1987;40:373-83.
12. Dusick JR, Gonzalez NR. Management of arterial vasospasm following aneurysmal subarachnoid hemorrhage. Semin Neurol 2013;33:488-97.
13. Dyer B, Strong T. How to tackle America's physician shortage. Fortune. August 10, 2015.
14. Etminan N, Brown RD, Jr., Beseoglu K, Juvela S, Raymond J, Morita A, *et al*. The unruptured intracranial aneurysm treatment score: A multidisciplinary consensus. Neurology 2015;85:881-9.
15. Froelich JJ, Neilson S, Peters-Wilke J, Dubey A, Thani N, Erasmus A, *et al*. Size and location of ruptured intracranial aneurysms: A 5-Year Clinical Survey. World Neurosurg 2016;91:260-5.
16. Geronimus AT, Bound J. Use of census-based aggregate variables to proxy for socioeconomic group: Evidence from national samples. Am J Epidemiol 1998;148:475-86.
17. Goldberg DS, French B, Forde KA, Groeneveld PW, Bittermann T, Backus L, *et al*. Association of distance from a transplant center with access to waitlist placement, receipt of liver transplantation, and survival among US veterans. JAMA 2014;311:1234-43.
18. Gross BA, Lai PM, Du R. Impact of aneurysm location on hemorrhage risk. Clin Neurol Neurosurg 2014;123:78-82.
19. Haddad AQ, Singla N, Gupta N, Raj GV, Sagalowsky AI, Margulis V, *et al*. Association of distance to treatment facility on quality and survival outcomes after radical cystectomy for bladder cancer. Urology 2015;85:876-82.
20. Health Policy Research Institute. The Surgical Workforce in the United States: Profile and Recent Trends. Chicago: American College of Surgeons and Association of American Medical Colleges; 2010; Available from: http://www.acshpri.org/documents/ACSHPRI_Surgical_Workforce_in_US_apr2010.pdf. [Last accessed on 2016 Mar 10].
21. Hoh BL, Chi YY, Lawson MF, Mocco J, Barker FG, 2nd. Length of stay and total hospital charges of clipping versus coiling for ruptured and unruptured adult cerebral aneurysms in the Nationwide Inpatient Sample database 2002 to 2006. Stroke 2010;41:337-42.
22. Krannich R. A sociodemographic portrait of the intermountain west. In: Krannich R, Luloff A, Field D, editors. People, places and landscapes: Social change in high amenity rural areas. Dordrecht, Netherlands: Springer; 2011. p. 27-43.
23. Krieger N. Overcoming the absence of socioeconomic data in medical records: Validation and application of a census-based methodology. Am J Public Health 1992;82:703-10.
24. Lai PM, Dasenbrock H, Lin N, Du R. The impact of insurance status on the outcomes after aneurysmal subarachnoid hemorrhage. PLoS One 2013;8:e78047.
25. Latimer SF, Wilson FC, McCusker CG, Caldwell SB, Rennie I. Subarachnoid haemorrhage (SAH): Long-term cognitive outcome in patients treated with surgical clipping or endovascular coiling. Disabil Rehabil 2013;35:845-50.
26. Leake CB, Brinjikji W, Kallmes DF, Cloft HJ. Increasing treatment of ruptured cerebral aneurysms at high-volume centers in the United States. J Neurosurg 2011;115:1179-83.
27. Lin CC, Bruinooge SS, Kirkwood MK, Olsen C, Jemal A, Bajorin D, *et al*. Association between geographic access to cancer care, insurance, and receipt of chemotherapy: Geographic distribution of oncologists and travel distance. J Clin Oncol 2015;33:3177-85.
28. Longstreth WT, Jr., Nelson LM, Koepsell TD, van Belle G. Cigarette smoking, alcohol use, and subarachnoid hemorrhage. Stroke 1992;23:1242-9.
29. Mayer ML, Beil HA, von Allmen D. Distance to care and relative supply among pediatric surgical subspecialties. J Pediatr Surg 2009;44:483-95.
30. Morita A, Kirino T, Hashi K, Aoki N, Fukuhara S, Hashimoto N, *et al*. The natural course of unruptured cerebral aneurysms in a Japanese cohort. N Engl J Med 2012;366:2474-82.
31. Mukherjee D, Kosztowski T, Zaidi HA, Jallo G, Carson BS, Chang DC, *et al*. Disparities in access to pediatric neurooncological surgery in the United States. Pediatrics 2009;124:e688-96.
32. Murayama Y, Takao H, Ishibashi T, Saguchi T, Ebara M, Yuki I, *et al*. Risk analysis of unruptured intracranial aneurysms: Prospective 10-year cohort study. Stroke 2016;47:365-71.
33. Park J, Woo H, Kang DH, Kim Y. Critical age affecting 1-year functional outcome in elderly patients aged ≥70 years with aneurysmal subarachnoid hemorrhage. Acta Neurochir (Wien) 2014;156:1655-61.
34. Rosman J, Slane S, Dery B, Vogelbaum MA, Cohen-Gadol AA, Couldwell WT. Is there a shortage of neurosurgeons in the United States? Neurosurgery 2013;73:354-5; discussion 365-6.
35. Steinbrook R. Easing the shortage in adult primary care--is it all about money? N Engl J Med 2009;360:2696-9.
36. The Editorial Board. Bottlenecks in training doctors. The New York Times. July 20, 2014.
37. Thompson BG, Brown RD, Jr., Amin-Hanjani S, Broderick JP, Cockroft KM, Connolly ES, Jr., *et al*. Guidelines for the Management of Patients With Unruptured Intracranial Aneurysms: A Guideline for Healthcare Professionals From the American Heart Association/American Stroke Association. Stroke 2015;46:2368-400.

38. Vlak MH, Algra A, Brandenburg R, Rinkel GJ. Prevalence of unruptured intracranial aneurysms, with emphasis on sex, age, comorbidity, country, and time period: A systematic review and meta-analysis. Lancet Neurol 2011;10:626-36.
39. Voelker R. Experts say projected surgeon shortage a "looming crisis" for patient care. JAMA 2009;302:1520-1.
40. Watson DE, McGrail KM. More doctors or better care? Healthc Policy 2009;5:26-31.
41. Weissman JS, Stern R, Fielding SL, Epstein AM. Delayed access to health care: Risk factors, reasons, and consequences. Ann Intern Med 1991;114:325-31.
42. Williams K, Schneider B, Lajos P, Marin M, Faries P. Supply and demand: Will we have enough vascular surgeons by 2030? Vascular 2016;24:414-20.
43. Zacharia BE, Bruce SS, Carpenter AM, Hickman ZL, Vaughan KA, Richards C, *et al*. Variability in outcome after elective cerebral aneurysm repair in high-volume academic medical centers. Stroke 2014;45:1447-52.