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A predictive model of hospitalization cost after cerebral aneurysm clipping

Kimon Bekelis, M.D.^{1,*}, Symeon Missios, M.D.^{2,*}, Todd A. MacKenzie, Ph.D.^{3,4,5}, Nicos Labropoulos, Ph.D., D.I.C.⁶, and David W. Roberts, M.D.^{7,8}

¹Section of Neurosurgery, Dartmouth-Hitchcock Medical Center, Lebanon, NH

²Department of Neurosurgery, Cleveland Clinic, Cleveland, OH

³Department of Medicine, Dartmouth-Hitchcock Medical Center, Lebanon, NH

⁴Department of Community and Family Medicine, Dartmouth-Hitchcock Medical Center, Lebanon, NH

⁵The Dartmouth Institute for Health Policy and Clinical Practice, Lebanon, NH

⁶Section of Vascular Surgery, SUNY Stony Brook, Stony Brook, NY

⁷Geisel School of Medicine at Dartmouth, Hanover, NH

⁸Department of Neurology, Dartmouth-Hitchcock Medical Center, Lebanon, NH

Abstract

Background—Cost containment is the cornerstone of the Affordable Care Act. Although studies have compared the cost of cerebral aneurysm clipping (CAC) and coiling, they haven't focused on the identification of drivers of cost after CAC, or the prediction of its magnitude. The objective of the present study was to develop and validate a predictive model of hospitalization cost after CAC.

Methods—We performed a retrospective study involving CAC patients who were registered in the Nationwide Inpatient Sample (NIS) database from 2005–2010. The two cohorts of ruptured and unruptured aneurysms underwent 1:1 randomization to create derivation and validation subsamples. Regression techniques were used for the creation of a parsimonious predictive model.

Results—Of the 7,798 patients undergoing CAC, 4,505 (58%) presented with unruptured, and 3,293 (42%) with ruptured aneurysms. The median hospitalization cost was \$24,398 (Interquartile Range (IQR), \$17,079 – \$38,249), and \$73,694 (IQR, \$46,270 – \$115,128) for the two cohorts, respectively. Common drivers of cost identified in the multivariate analyses included: length of

Corresponding Author: Kimon Bekelis, M.D., Dartmouth-Hitchcock Medical Center, One Medical Center Dr., Lebanon, NH 03756, kbekelis@gmail.com, T: 603-650-5110, F: 603-650-4547.

*These authors contributed equally to this work and are co-primary authors

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stay, number of admission diagnoses and procedures, hospital size and region, and patient income. The models were validated in independent cohorts and demonstrated final R^2 very similar to the initial models. The predicted and observed values in the validation cohort demonstrated good correlation.

Conclusions—This national study identified significant drivers of hospitalization cost after CAC. The presented model can be utilized as an adjunct in the cost containment debate and the creation of data-driven policies.

Keywords

cerebral aneurysm; aneurysm clipping; stroke; drivers of cost; cost prediction; NIS

INTRODUCTION

In recent years regulatory bodies in the United States have increased the pressure for containment of healthcare spending.¹² In this context the development of Accountable Care Organizations and the implementation of bundled payment methods are changing the way we define value in healthcare.¹ Neurosurgical procedures are often high risk and are associated with significant hospitalization costs. Cerebral aneurysm clipping (CAC), especially in the setting of subarachnoid hemorrhage (SAH), is a prototypical such procedure, and will be in the spotlight for policy makers. The estimation of the hospitalization cost for each individual CAC patient, and the identification of modifiable drivers of cost could allow physicians to understand the economic aspects of CAC, and modify their practice accordingly. Future attempts at cost containment could focus on these factors, rather than follow an arbitrary path.

Several studies have compared the difference in the cost or charges of clipping and coiling.^{3–15} Some of them have been retrospective analyses of single institution experiences,^{6–8} demonstrating results with limited generalization, given their inherent selection bias. Other investigations have focused on patients from the ISAT study¹⁴ or other international centers,³¹⁰¹²¹³¹⁵ with restricted applicability to the US health care market. Multi-center studies based on US data⁴⁵⁸⁹¹¹ did not analyze modifiable drivers of cost or develop a model for cost approximation.

The National Inpatient Sample (NIS)¹⁶ is an all-payer, hospital discharge database that represents approximately 20% of all inpatient admissions to nonfederal hospitals in the United States. It allows the unrestricted study of the patient population in question. Using this database, several socioeconomic variables, as well as patient and hospital level factors associated with increased cost after CAC were identified. Based on these data, a predictive model of cost after CAC was developed and validated in an independent cohort.

METHODS

National Inpatient Sample (NIS) Database

All patients undergoing CAC, who were registered in the National Inpatient Sample (NIS)¹⁶ Database (Healthcare Cost and Utilization Project, Agency for Healthcare Research and

Quality, Rockville, MD) between 2005 and 2010, were included in the analysis. The NIS is an all-payer prospective hospital discharge database that represents approximately 20% of all inpatient admissions to nonfederal hospitals in the US. More information about the NIS is available at <http://www.ahcpr.gov/data/hcup/nisintro.htm>.

Cohort Definition

In order to establish the cohort of patients, we used *International Classification of Disease-9-Current Modification* (ICD-9-CM) codes to identify patients in the registry who underwent clipping (ICD-9-CM code 39.51) for ruptured (ICD-9-CM code 430, excluding 094.87 for ruptured syphilitic aneurysm, 437.4 for cerebral arteritis, 747.81 for arteriovenous malformation, 800.0–801.9, 803.0–804.9, 850.0–854.1, and 873.0–873.9 for traumatic hemorrhage, 39.53 or 92.30 for treatment diagnosis for arteriovenous malformation repair or radio surgery) and unruptured (ICD-9-CM code 437.3) cerebral aneurysms between 2005 and 2010 (Figure 1).

Outcome Variable

The primary outcome variable was the total hospitalization cost after CAC. Cost data were obtained by conversion of the hospital charges using the group-average cost-to-charge ratio for each hospital in the database. Group-average cost-to-charge ratio and hospital charges are available in the NIS database. All costs were adjusted to their 2010 dollar value using the national consumer price index.

Exposure Variables

The association of the outcome with the pertinent exposure variables was examined in a multivariate analysis. Age was a continuous variable. Gender, race (African American, Hispanic, Asian, or other, with Caucasian being the reference value), insurance (private insurance, self-pay, Medicaid, with Medicare being the reference value), and income (defined as the median income based on zip code; income was divided into quartiles, with the lowest quartile being the reference value) were categorical variables.

The patient-level (Table S1) comorbidities (categorical variables) were diabetes mellitus (DM), tobacco exposure, hypertension, hyperlipidemia, peripheral vascular disease (PVD), congestive heart failure (CHF), coronary artery disease (CAD), history of prior ischemic stroke, obesity, chronic renal failure (CRF), history of a TIA event, seizure disorder and coagulopathy. The patient-level postoperative variables (categorical variables) were (Table S1): treated hydrocephalus, hyponatremia, postoperative complications, deep vein thrombosis (DVT), pulmonary embolism (PE), and acute renal failure (ARF). Lastly, hospitalization specific factors (continuous variables) were length-of-stay (LOS), and number of procedures performed (NPx), and number of admission diagnoses (NDx).

The hospital characteristics used in the analysis as categorical variables included hospital region (West, South, Midwest, with Northeast being the reference value), hospital location (urban teaching, urban non-teaching, with rural being the reference value), and hospital bed size (medium, large, with small being the reference value). More information of the

definitions of the various categories of hospital characteristics can be found at http://www.hcup-us.ahrq.gov/db/vars/nis_stratum/nisnote.jsp.

Statistical analysis

We created and separately analyzed two cohorts, one for ruptured and one for unruptured aneurysms. Continuous variables were presented with the mean and standard deviation, whereas categorical values were presented as percentages. Continuous variables were compared using t-tests and categorical variables were compared using Chi-square tests.

Initial analysis of cost data revealed significant positive skewness and kurtosis and linear regression analysis using cost resulted in a heteroskedastic variance of errors. In order to achieve normality the data were transformed using the natural logarithm (ln) transformation. Other transformations attempted included square root, cube root, and inverse transformation. These were not eventually used because the ln transformation provided the best fit for the data. The ln transformation significantly improved the skewness and kurtosis of the distributions (skewness = 0.12, kurtosis = -0.049 for ruptured aneurysms, and skewness = 0.61, kurtosis = 0.54 for unruptured aneurysms). Normality was also assessed using histograms and Q-Q plots. The distributions of LOS, NDx, and NPx demonstrated significant positive skewness and kurtosis as well, and were also ln transformed before the analysis to achieve normality.

Each of our cohorts (ruptured and unruptured aneurysms) was then randomized (1:1 randomization, in order to create two 50% sub-samples) to a derivation and a validation cohort. Subsequently, patients with missing values were removed from each cohort using listwise deletion. A parsimonious model was then developed in the derivation cohort by performing a stepwise linear regression including all the variables discussed previously. Dummy variables were created for non-binary categorical variables. The level of significance used for retention in the model was 0.05. No collinearity was observed by assessing tolerance and variance inflation factor (VIF). The regression diagnostics performed were the coefficient of determination (R^2) and analysis of the residuals. Normality among the distribution of residuals was verified with histograms (Figure S1, S2, S6, and S7), and P-P plots (Figure S3, S4, S8, and S9). Further diagnostics included scatter plots of the standardized predicted values versus the standardized residuals, which revealed a random, symmetric distribution of values about zero (Figure S5 and S10), therefore suggesting a linear fit of data.

The model created in the derivation cohort was applied on the validation cohort and the R^2 was calculated and residual analysis was performed. The predicted values for the validation cohort were plotted against the observed values and goodness of fit was assessed. No heteroskedasticity was observed for both the ruptured and unruptured cohorts. For reporting purposes, we back transformed the data to demonstrate the percentage of the contribution of each variable to the cost value.

All probability values are the results of two-sided tests, and the level of significance was set at $P < 0.05$. Statistical analyses were performed using SPSS version 20 (IBM, Armonk, NY), XLSTAT version 2013.6.02 (Addinsoft, New York, NY).

RESULTS

Patient characteristics

In the selected study period there were 7,798 patients undergoing CAC who were registered in NIS. Of these patients, 4,505 (mean age was 54.2 years, 74.8% females) presented with unruptured aneurysms, and 3,293 (mean age was 53.3 years, 70.2% females) with subarachnoid hemorrhage (Table 1 and 2). Following 1:1 randomization and subsequent listwise deletion, derivation and validation cohorts were created for both unruptured and ruptured aneurysms. Randomization resulted in no significant differences in exposure factors between these two subgroups (Table 1 and 2).

Primary outcome

The mean and median hospitalization cost for patients undergoing CAC for unruptured cerebral aneurysms was \$32,872 (95% CI, \$32,068 – \$33,677) and \$24,398 (Interquartile Range (IQR), \$17,079 – \$38,249), respectively (Table 3). The mean and median hospitalization cost for patients undergoing CAC for subarachnoid hemorrhage was \$93,180 (95% CI, \$90,701 – \$95,660) and \$73,694 (IQR, \$46,270 – \$115,128), respectively (Table 3).

Model derivation

Several factors were included in our parsimonious model after stepwise linear regression (Table 4). For unruptured aneurysms, hospitals in the West (20.6% more, in comparison to the Northeast), large bedsize (6.5% more, in comparison to small bedsize), urban teaching and non-teaching hospitals (17.8% and 20.1% more, in comparison to rural hospitals), African-Americans (5.8% more, in comparison to small bedsize), history of ischemic stroke (16.1% more), and higher income (8.7% more for the highest income quartile, in comparison to the lowest quartile) were associated with increased hospitalization cost. A 1% increase in LOS, number of procedures, and the number of admission diagnoses was associated with a 0.4%, 0.3%, and 0.1% increase in cost respectively. On the contrary, hospitals in the Midwest or the South (6.9% and 26.4% less, in comparison to hospitals in the Northeast), self-pay (9.0% less, in comparison to coverage by Medicare), and tobacco exposure (7.9% less) were associated with decreased cost. Our model could explain a significant portion of the variance in cost with an R^2 of 0.72.

For unruptured aneurysms (Table 4), hospitals in the West (22.9% more, in comparison to the Northeast), large bedsize (6.4% more, in comparison to small bedsize), postoperative complications (5.2% more), seizures (19.2% more), and higher income (10.5% more for the highest income quartile, in comparison to the lowest quartile) were associated with increased hospitalization cost. A 1% increase in LOS, number of procedures, and the number of admission diagnoses was associated with a 0.6%, 0.3%, and 0.1% increase in cost respectively. On the contrary, hospitals in the Midwest and the South (5.4% and 24.3% less, in comparison to hospitals in the Northeast), self-pay (9.2% less, in comparison to coverage by Medicare), hyperlipidemia (6% less), and urban-non teaching hospitals (10.1% less, in comparison to rural hospitals) were associated with decreased cost. Our model could explain a significant portion of the variance in cost with an R^2 of 0.63.

Model validation

The models were validated in a random cohort of patients, and the final R^2 did not differ more than 5% from the initial values (0.68 and 0.60 for ruptured and unruptured aneurysms, respectively). There was very good association of the predicted values with the observed values in the validation cohorts of both ruptured (Figure 2A) and unruptured (Figure 2B) aneurysms ($P < 0.001$).

DISCUSSION

In this study of NIS, the largest all-payer national database, we were able to identify several drivers of hospitalization cost after CAC. Based on these factors, we developed a predictive model of cost after CAC, and validated it in an independent cohort. Cost containment is the cornerstone of the Affordable Care Act.¹ A major component of the overall economic burden of healthcare is the initial hospitalization cost,¹⁷ especially in the setting of expensive, high-risk procedures, such as CAC. Several value-based incentives are being put in place,¹⁸ but their application in subspecialty areas such as neurosurgery is still vague, given the limited literature on identifiable targets. Although some studies have compared the cost of clipping to that of coiling, there has been no particular focus on specific drivers of hospitalization cost, or the prediction of its magnitude.

To address this, we identified drivers of cost for clipping of ruptured and unruptured cerebral aneurysms. The major contributor to the observed variation in cost was length of stay, after controlling for patient and hospital characteristics. This association is particularly reflected in SAH patients, where the necessity to hospitalize most patients for at least 2 weeks, results in a markedly increased cost of CAC in comparison to patients with unruptured aneurysms. The proposed model quantified the magnitude of the contribution of LOS to the cost of a neurosurgical procedure for the first time. Although LOS is a major target for cost containment, the focus should be only on excessively lengthy hospitalizations not justified by patient comorbidities. The comorbidities associated with increased LOS, in the setting of CAC, have been identified in prior studies,¹⁹ and should be taken into account to avoid penalizing the care of sicker patients. Other important contributors to increased LOS, and subsequently higher hospitalization costs are patient safety indicators, and hospital acquired conditions.²⁰²¹ These metrics of healthcare quality are tracked by several regulatory bodies and can impact the cost and outcomes of aneurysm care regardless of the quality of the operation.²⁰²¹ Any effort on minimizing LOS and cost should take into account factors associated with these events.

The contribution of several other variables was quantified in both cohorts. Complicated patients, with numerous admission diagnoses, and multiple procedures were associated with increased cost. Location of the hospital was crucial in determining the cost after CAC. The effect of region on healthcare spending is widely recognized across medical specialties.²²²³ Minimizing regional disparities could contribute to reduced spending.²²²³ In regards to CAC it appears that the Northeast was associated with significantly higher hospitalization cost in comparison to the Midwest and South. From a policy perspective, our study does not indicate whether it is possible to reduce spending without affecting patient outcomes. However, if the United States as a whole could safely achieve spending levels comparable to

those of the lowest-cost regions, significant savings could be achieved. Further research in that direction is needed. Additionally, we observed that larger hospitals, in urban areas were associated with higher cost. This could be related to more complex patients hospitalized in these institutions, since they typically function as referral centers. Higher income was associated with higher cost, possibly secondary to the fact that this population has insurance that covers most of the charges claimed by the hospital. As expected, uninsured patients were associated with less cost, given the limited resources they have to cover the hospital charges.

The proposed predictive model for hospitalization cost after CAC was created and validated in a statistically rigorous way. Particular attention was given to normalizing the distribution of the primary outcome and the continuous exposure variables in order to minimize errors in our regression analysis. In addition, residual analysis confirmed the linear fit of data. The diagnostics demonstrated that in both cohorts a significant portion of the cost variation could be explained by the variables included in our regression model. The model demonstrated good predictive ability in an independent validation cohort, with the predicted and observed values demonstrating good correlation.

Although our model cannot account for the full extent of cost variation, since it is limited by the data available through NIS, this is a first step in the direction of the trend in healthcare economics at a national level. It quantifies the contribution and relative importance of several drivers of cost (some of which have been identified before in other areas of medicine) for the first time. Although, most of the factors are not modifiable at the level of the independent practitioner, further studies of these low cost generating targets can help us identify successful models that can be replicated at the national level. This predictive model can be utilized as an adjunct in the cost containment debate and the creation of data-driven policies. Our model can fuel further studies in the field and provide elements for the design of prospective investigations.

The present study has limitations common to administrative databases. First, indication bias and residual confounding could account for some of the observed associations. The 1:1 randomization of the cohorts and the validation of the model in an independent cohort aimed to minimize this bias. Second, several coding inaccuracies can affect our estimates, as in other studies involving the NIS. However, coding for SAH has shown nearly perfect association with medical record review²⁴. Third, the NIS during the years studied did not include hospitals from all states¹⁶. However, the creation of the 20% sample is done in such a way by HCUP that the hospitals included are still diverse with respect to size, region, and academic status. Fourth, the NIS does not provide any clinical information on the structure, size, or location of the aneurysms, which are important factors to be considered in cerebrovascular neurosurgery. Fifth, we are lacking disease severity in SAH patients. To the extent that this is correlated with the number of procedures and admission diagnoses, we have partially controlled for that confounder. Sixth, some data categories were not available for all patients. To avoid the introduction of further bias we excluded those patients from any analysis. Seventh, causality is very hard to establish based on ecologic data. Our target was different though, and was focused on the identification of drivers of cost and the creation of a predictive model for it.

Conclusions

The Nationwide Inpatient Sample (NIS) is a prospective all-payer, hospital discharge database that contains a representative sample of all inpatient admissions to nonfederal hospitals in the United States. By using this, several socioeconomic variables, as well as patient and hospital level factors associated with increased cost after CAC were identified. Based on these data, a predictive model of cost after CAC was developed and validated in an independent cohort. Although the generalization of these predictions should be done with caution, the model can be utilized as an adjunct in the cost containment debate and the creation of data-driven policies. This can fuel further studies in the field and provide elements for the design of prospective investigations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Cohort selection for the study

Figure 2. Scatter plots demonstrating the association of the observed ln cost in the validation cohort and the predicted values of ln cost by the parsimonious model for unruptured (A) and ruptured aneurysms (B)

Table 1

Patient and hospital characteristics for patients with unruptured aneurysms

		All Patients		Model Cohort		Validation Cohort		P-Value
Sample size		4505		2318		2187		
		Mean	SD	Mean	SD	Mean	SD	
Age		54.17	11.85	54.26	11.79	54.08	11.92	0.606
Length of Stay		6.63	6.74	6.74	6.93	6.51	6.54	0.252
Number of Procedures		6.33	3.84	6.34	3.80	6.32	3.89	0.817
Number of Diagnoses		2.81	2.23	2.84	2.25	2.79	2.22	0.426
		N	%	N	%	N	%	
Sex	F	3368	74.76	1716	74.03	1652	75.54	0.258
	M	1137	25.24	602	25.97	535	24.46	
Region	Northeast	989	21.95	524	22.61	465	21.26	0.292
	Midwest	658	14.61	336	14.50	322	14.72	0.861
	South	1948	43.24	979	42.23	969	44.31	0.170
	West	910	20.20	479	20.66	431	19.71	0.446
Payer	Medicare	1127	25.02	598	25.80	529	24.19	0.225
	Medicaid	524	11.63	256	11.04	268	12.25	0.223
	Private payer	2464	54.69	1266	54.62	1198	54.78	0.937
	Self-payer	167	3.71	76	3.28	91	4.16	0.137
	Other	223	4.95	122	5.26	101	4.62	0.353
Race	Caucasian	3429	76.12	1757	75.80	1672	76.45	0.632
	African-American	453	10.06	238	10.27	215	9.83	0.662
	Hispanic	404	8.97	215	9.28	189	8.64	0.489
	Asian	82	1.82	33	1.42	49	2.24	0.053
	Other	137	3.04	75	3.24	62	2.83	0.487
Location	Rural	94	2.09	52	2.24	42	1.92	0.513
	Urban, nonteaching	498	11.05	245	10.57	253	11.57	0.307
	Urban, teaching	3913	86.86	2021	87.19	1892	86.51	0.531
Bedsize	Small	224	4.97	118	5.09	106	4.85	0.758

		All Patients		Model Cohort		Validation Cohort		P-Value
Sample size		4505		2318		2187		
		Mean	SD	Mean	SD	Mean	SD	
	Medium	627	13.92	320	13.81	307	14.04	0.855
	Large	3654	81.11	1880	81.10	1774	81.12	0.977
Quartiles of income	First quartile	1106	24.55	539	23.25	567	25.93	0.040
	Second quartile	1209	26.84	605	26.10	604	27.62	0.265
	Third quartile	1208	26.81	654	28.21	554	25.33	0.032
	Fourth quartile	982	21.80	520	22.43	462	21.12	0.304
		N	%	N	%	N	%	
Postoperative complications		582	12.92	323	13.93	259	11.84	0.041
Comorbidities								
	Stroke	170	3.77	94	4.06	76	3.48	0.346
	TIA	38	0.84	22	0.95	16	0.73	0.526
	Diabetes	445	9.88	235	10.14	210	9.60	0.581
	Obesity	224	4.97	118	5.09	106	4.85	0.758
	Coagulopathy	63	1.40	31	1.34	32	1.46	0.816
	Hyperlipidemia	943	20.93	475	20.49	468	21.40	0.477
	Chronic Renal Disease	35	0.78	18	0.78	17	0.78	0.868
	Alcohol abuse	125	2.77	61	2.63	64	2.93	0.609
	CAD	226	5.02	113	4.87	113	5.17	0.704
	COPD	1907	42.33	958	41.33	949	43.39	0.170
	CHF	106	2.35	64	2.76	42	1.92	0.078
	Hypertension	2529	56.14	1292	55.74	1237	56.56	0.598
	Peripheral Vascular Disease	137	3.04	64	2.76	73	3.34	0.298
	Hydrocephalus	94	2.09	53	2.29	41	1.87	0.389
	Hyponatremia	189	4.20	104	4.49	85	3.89	0.353
	Seizures	101	2.24	49	2.11	52	2.38	0.619
	Pulmonary embolism	89	1.98	45	1.94	44	2.01	0.950
	DVT	31	0.69	20	0.86	11	0.50	0.201

		All Patients		Model Cohort		Validation Cohort		P-Value
Sample size		4505		2318		2187		
		Mean	SD	Mean	SD	Mean	SD	
	Acute Renal Failure	30	0.67	17	0.73	13	0.59	0.697

SD: standard deviation; F: female; M: male; TIA: transient ischemic attack; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; CHF: congestive heart failure; DVT: deep vein thrombosis

Income quartiles were created with equal number of patients per quartile

Table 2

Patient and hospital characteristics for patients with ruptured aneurysms

		All Patients		Model Cohort		Validation Cohort		P-Value
N		3293		1679		1614		
		Mean	SD	Mean	SD	Mean	SD	
Age		53.26	13.10	53.65	12.95	52.85	13.25	0.080
Length of Stay		20.21	15.97	20.21	16.00	20.21	15.95	0.990
Number of Procedures		6.71	3.78	6.70	3.85	6.72	3.71	0.966
Number of Diagnoses		9.03	4.49	9.03	4.51	9.03	4.47	0.878
		N	%	N	%	N	%	
Sex	F	2311	70.24	1170	69.73	1141	70.74	0.527
	M	980	29.76	508	30.27	472	29.26	
Region	Northeast	644	19.56	332	19.79	312	19.34	0.782
	Midwest	419	12.72	207	12.34	212	13.14	0.521
	South	1279	38.84	658	39.21	621	38.50	0.701
	West	949	28.82	481	28.67	468	29.01	0.855
Payer	Medicare	638	19.37	341	20.32	297	18.41	0.180
	Medicaid	557	16.91	259	15.44	298	18.47	0.023
	Private payer	1495	45.40	773	46.07	722	44.76	0.473
	Self-payer	374	11.36	189	11.26	185	11.47	0.896
	Other	227	6.89	116	6.91	111	6.88	0.974
	White	1889	57.36	992	59.12	897	55.61	0.046
Race	Black	557	16.91	294	17.52	263	16.31	0.377
	Hispanic	552	16.76	262	15.61	290	17.98	0.077
	Asian	135	4.10	59	3.52	76	4.71	0.101
	Other	158	4.80	71	4.23	87	5.39	0.140
Location	Rural	49	1.49	25	1.49	24	1.49	0.889
	Urban, nonteaching	384	11.66	179	10.67	205	12.71	0.077
	Urban, teaching	2858	86.79	1474	87.84	1384	85.80	0.093
Bedsize	Small	82	2.49	40	2.38	42	2.60	0.770

	All Patients	Model Cohort		Validation Cohort		P-Value
		1679	SD	Mean	SD	
N	3293			1614		
	Mean					
	SD					
Medium	503	234	13.95	269	16.68	0.033
Large	2706	1404	83.67	1302	80.72	0.030
Quartiles of income	First quartile	1015	30.82	517	30.81	0.999
	Second quartile	815	24.75	434	25.86	0.147
	Third quartile	780	23.69	390	23.24	0.555
	Fourth quartile	681	20.68	337	20.08	0.403
	N		%	N	%	
Postoperative complications	588	281	16.75	307	19.03	0.096
Comorbidities						
TIA	412	197	11.74	215	13.33	0.185
Stroke	246	115	6.85	131	8.12	0.188
Diabetes	344	186	11.08	158	9.80	0.249
Obesity	163	81	4.83	82	5.08	0.796
Coagulopathy	129	65	3.87	64	3.97	0.961
Hyperlipidemia	410	233	13.89	177	10.97	0.013
Chronic Renal Disease	20	13	0.77	7	0.43	0.302
Alcohol abuse	197	103	6.14	94	5.83	0.763
CAD	349	187	11.14	162	10.04	0.333
COPD	1074	552	32.90	522	32.36	0.772
CHF	179	92	5.48	87	5.39	0.971
Hypertension	1872	972	57.93	900	55.80	0.231
Peripheral Vascular Disease	150	75	4.47	75	4.65	0.870
Hydrocephalus	1371	695	41.42	676	41.91	0.803
Hyponatremia	591	285	16.98	306	18.97	0.150
Seizures	64	31	1.85	33	2.05	0.775
Pulmonary embolus	84	45	2.68	39	2.42	0.712
DVT	83	47	2.80	36	2.23	0.352

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SD: standard deviation; F: female; M: male; TIA: transient ischemic attack; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; CHF: congestive heart failure; DVT: deep vein thrombosis

Income quartiles were created with equal number of patients per quartile

Table 3

Inflation adjusted cost data

Total				Model cohort				Validation cohort			
Unruptured aneurysms											
Mean	95% CI	Median	IQR	Mean	95% C.I.	Median	IQR	Mean	95% C.I.	Median	IQR
32,872	32,068–33,677	24,398	17,079–38,249	33,498	32,332–34,665	24,596	17,180–38,693	32,209	31,106–33,312	24,100	17,005–37,771
Ruptured aneurysms											
93,180	90,701–95,660	73,694	46,270–115,128	92,572	89,111–96,033	72,685	45,010–116,046	93,813	90,255–97,371	74,577	47,951–114,320

95% CI: 95% confidence intervals; IQR: interquartile range

All cost values are inflation adjusted and have been converted to 2010 price values based on the consumer index

Table 4

Percent change in hospitalization cost after clipping of ruptured and unruptured cerebral aneurysms for the variables included in the final predictive models

Ruptured aneurysms		Unruptured aneurysms	
Variable	% Change in cost	Variable	% Change in cost
Length of stay [*]	0.55	Length of stay [*]	0.42
Number of procedures [*]	0.27	Number of procedures [*]	0.25
Number of diagnoses [*]	0.06	Number of diagnoses [*]	0.07
Midwest Region ¹	-5.35	Midwest Region ¹	-6.85
South Region ¹	-24.27	South Region ¹	-26.43
West region ¹	22.88	West region ¹	20.56
Large Bedsize ²	6.40	Large Bedsize ²	6.50
Urban Nonteaching hospital ³	-10.15	Urban Nonteaching hospital ³	17.82
Self-Pay ⁴	-9.24	Urban Teaching hospital ³	20.08
Postoperative complications	5.23	Self-Pay ⁴	-8.97
Seizures	19.24	African American ⁵	5.76
Hyperlipidemia	-6.01	History of ischemic stroke	16.07
3 rd income quartile ⁶	4.81	Tobacco exposure	-7.87
4 th income quartile ⁶	10.52	4 th income quartile ⁶	8.65

* = Numbers represent percent change in cost for 1% change in the exposure variable (length of stay, number of procedures, number of diagnoses)

¹ in comparison to Northeast;

² in comparison to small bedsize;

³ in comparison to rural hospital;

⁴ in comparison to Medicare;

⁵ in comparison to Caucasian;

⁶ in comparison to the 1st (lowest) income quartile