HHS Public Access
Author manuscript
Transl Stroke Res. Author manuscript; available in PMC 2024 June 01.

Published in final edited form as:
Transl Stroke Res. 2023 June ; 14(3): 347–356. doi:10.1007/s12975-022-01065-w.

A Nationwide Analysis of Aneurysmal Subarachnoid Hemorrhage Mortality, Complications, and Health Economics in the United States

Lefko T Charalambous, MD, MBA[1,*], **Syed M Adil, MD**[1], **Shashank Rajkumar, MD**[1], **Robert Gramer, MD**[1], **Elayna Kirsch, BS**[1], **Beiyu Liu, PhD**[2], **Ali Zomorodi, MD**[1], **Mark McClellan, MD,PhD**[3], **Shivanand P. Lad, MD, PhD**[1,3,*]

[1]Department of Neurosurgery, Duke University Medical Center, Durham, NC, USA

[2]Department of Biostatistics and Bioinformatics, Duke University Medical Center, Durham, NC, USA

[3]Duke-Robert J. Margolis Center for Health Policy, Duke University, Durham, NC, USA.

Abstract

Background: Aneurysmal subarachnoid hemorrhage (aSAH) is a devastating neurological condition. Endovascular coiling or surgical clipping have equivocal success rates, but relatively little is known regarding the health economics and complications of these procedures at the population level.

Objective: To analyze the complication profiles and healthcare resource utilization (HRCU) associated with treatment of aSAH in the Unites States.

Methods: We performed a retrospective analysis utilizing the IBM MarketScan database between 2008 and 2015. Primary outcomes included economic analysis stratified by post-operative complication; determination of the effect of several factors on total cost by multivariable regression; and analysis of the incidence, timing, and associated HCRU of aSAH-related postoperative complications.

Results: Of the 2,374 patients meeting inclusion criteria for economic analysis, 1783 (75.1%) patients had at least one of the ten complications. The most common complications included hydrocephalus (43.8%), transient cerebral ischemia (including vasospasm) (30.6%), ischemic stroke (29.1%), syndrome of inappropriate antidiuretic hormone (SIADH)/hyposmolarity/ hyponatremia (22.1%), and seizures (14.9%). Patients who experienced complications had higher

[*]Corresponding Authors: Shivanand P. Lad, M.D. PhD, Duke University, Box 3807, Durham, NC 27710, Phone: 919-681-4986, Fax: 919-681-1236, nandan.lad@duke.edu; Lefko Charalambous, MBA, Duke University, Box 3807, Durham, NC 27710, Ltc7@duke.edu.

Funding and/or Conflicts of interests/Competing interests
Disclosures: SPL is a consultant for Abbott, Boston Scientific, Higgs Boson Health, Medtronic, Minnetronix, Nevro, and Presidio Medical. SMA and LTC are consultants for Higgs Boson Health. Research reported in this publication was supported by the National Center for Advancing Translational Sciences of the National Institutes of Health under Award Number UL1TR002553. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. All other authors report no conflicts of interest or funding support. This study was declared exempt from Institutional Review Board approval as it does not report private health information.

Portions of this work have been previously presented as a poster at the AANS annual meeting in San Diego, CA, in April of 2019.

median 90-day total costs [$161,127 (Q1 to Q3, $101,411 to $257,662)] than those who did not [$97,376 (Q1 to Q3, $55,692 to $147,447)]. Length of stay was longest for those with pulmonary embolism and pneumonia (27 days) and shortest for those with SIADH/hyposmolarity/hyponatremia (16 days). Brain compression/herniation had the highest mortality rate (19.5%). In total, 14.6% of all patients experienced a readmission within 30 days.

Conclusions: Patients with aSAH have high postoperative complication rates and costs. Development of novel interventions to reduce complications and improve outcomes is crucial.

Keywords

Aneurysmal Subarachnoid Hemorrhage; Healthcare Economics; Healthcare Resource Utilization; Neurosurgical Complications; Subarachnoid Hemorrhage

INTRODUCTION

Intracranial saccular aneurysms are common lesions, found in 5% of the population in autopsy studies.[1] Further, these aneurysms account for approximately 85% of non-traumatic subarachnoid hemorrhage (SAH),[1, 2] which has approximately a 50% one-month mortality rate and 25% disability rate.[3, 4] Furthermore, affected at a mean age of 55 years, SAH patients lose as many years of productive life as do patients who suffer from ischemic stroke.[5]

Ruptured intracranial aneurysms were historically treated with neurosurgical clipping of the neck of the aneurysm to prevent re-rupture and further aneurysmal SAH (aSAH). However, the introduction of the detachable coil in the 1990s led to the alternative therapeutic choice of endovascular coiling for intracranial aneurysms. To compare these two treatments, the International Subarachnoid Aneurysm Trial (ISAT) randomized patients with recent rupture of intracranial aneurysm to either neurosurgical clipping or endovascular coiling. This study changed the landscape of neurosurgical treatment of this disease, as it showed that patients treated with coiling had better outcomes at one year.[6] Furthermore, many studies have compared various aspects of the two procedures including surgical complications, mortality, retreatment, costs, and neurocognitive outcomes.[1, 3, 5–37]

This study aims to broaden understanding of aSAH treatment and post-operative sequelae in the United States, with a focus on incidence and timing of complications, costs, and healthcare resource utilization. We present a nationwide retrospective analysis using both unadjusted comparisons and adjusted regression models to examine rates of complications, mortality, and healthcare resource utilization (HCRU) associated with aSAH treatment in the United States.

METHODS

Data Acquisition and Patient Population

The IBM MarketScan research database (a national claims-based dataset covering inpatient admissions, outpatient services, and outpatient pharmacy costs)[38] was utilized to identify patients who suffered aSAH and subsequently underwent either surgical clipping or endovascular coiling. All patients were ≥18 years old, treated in the United States between 2008 and 2015, admitted after a diagnosis of aSAH, and had continuous enrollment for at least 12 months before the aSAH diagnosis. Patients were identified by the primary International Classification of Diseases-9 (ICD-9-CM) codes for aSAH and Current Procedural Terminology (CPT) codes for clipping or coiling (Supplementary Tables 1 and 2).

Demographics and Patient Characteristics

Descriptive patient characteristics were collected for the entire cohort, including age at aSAH diagnosis, sex, insurance status, and Charlson Comorbidity Index (CCI) score. CCI score was calculated using encounter services in the 1-year period before the initial diagnosis date.

Healthcare Resource Utilization

HCRU analysis comprised total length of stay (LOS) for the initial inpatient encounter, service costs, outpatient medications costs, total healthcare costs (inpatient costs + outpatient costs + medication costs), and 30-day readmission status. HCRU data were collected for the 1-year period prior to aSAH diagnosis to acquire a baseline and then through 5 years post-diagnosis. Costs were also tallied in the initial 90-day period immediately after diagnosis to better capture effects in the acute setting. HCRU analysis by specific post-operative complication was also performed, as was multivariable regression to evaluate the effect of several factors on total cost.

All costs were adjusted for inflation based on the US Bureau of Labor Statistics indices to the 2017 USD.[39] In order to assess for the change in HCRU over time, only patients who had continuous enrollment for at least 12 months before and 90 days after the initial diagnosis were included in the analysis. Patients who did not survive more than 90 days after the initial diagnosis and those who did not have prescription information captured by MarketScan were also excluded from cost analysis. Finally, patients with total payments above the 99th percentile were removed as outliers.

Post-Operative Complications

Analysis of the incidence, timing, and associated HCRU of aSAH-related postoperative complications was conducted for hydrocephalus, infection, pulmonary embolism (PE), pneumonia, urinary tract infection (UTI), syndrome of inappropriate antidiuretic hormone secretion (SIADH) / hyposmolarity / hyponatremia, seizures, brainstem compression / herniation, transient cerebral ischemia (including vasospasm).

Discharge Status

Secondary outcomes of interest included discharge status and 30-day readmission rates. For 30-day readmission, patients with continuous enrollment for at least 90 days after admission were included to account for length of the initial hospitalization.

Statistical Analysis

In addition to descriptive univariate statistics, a multivariable longitudinal analysis to determine the effects of various factors on total cost over time was conducted. Due to the skewed distribution of total cost, the model was fit using the generalized estimating equations (GEE) method with log link. The following were included as explanatory variables: surgery type (clipping or coiling), CCI score, insurance type, sex, time period, and the interaction term between surgery type and time period. All statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA).

RESULTS

Cohort Identification

Between 2008 and 2015, a total of 8108 adult patients were diagnosed with aSAH and underwent either clipping or coiling. Of these, 3807 had continuous enrollment for at least 12 months before aSAH diagnosis and were included in the survival and complication analyses, and 2374 patients had ≥ 90 days of continuous enrollment after diagnosis and were thus included in HCRU analysis.

Patient Demographics

Demographic data for the cohort is displayed in Table 1. The collective aSAH cohort had a mean age of 55.2 years and 71.7% were female (n=2,728). Most patients had commercial insurance (73.5%, n=2,800), 27.1% (n=1,032) worked full or part time, and 10.0% (n=381) were on Medicaid. At baseline, mean CCI was 0.7 (standard deviation [SD], 1.3). These demographic patterns were similar in the subset of patients used for HCRU analysis (Supplementary Table 3).

Incidence of Clipping and Coiling

From 2008 to 2015, there was a decrease in incidence of clipping from 31.4% to 23.5% (total n = 974), whereas incidence of coiling grew from 68.6% to 76.5% (total n = 2833).

Overall Healthcare Resource Utilization

Length of Stay and Readmission Rate—For the initial aSAH admission, median LOS was 15 days (Q1 to Q3, 10 to 22 days). In the 90-day period post-aSAH diagnosis, the median LOS was 17 days (Q1 to Q3, 12 to 31 days), with the patients who received clipping spending slightly more time in the hospital than patients who received coiling (19 days vs. 17 days) (Supplementary Table 4). Overall, 458 of 3133 (14.6%) of patients experienced a readmission within 30 days.

Total Cost, Univariable—At baseline, the median annual costs for the patients who went on to experience an aSAH was $2,966 (Q1 to Q3, $751 to $9,557) (Table 2). Cost rapidly escalated upon experiencing the aneurysmal rupture and through the 90-day period immediately following aSAH diagnosis, reaching $142,801 (Q1 to Q3, $85,378 to $233,208). In the next period from 90 days to 1-year post-diagnosis, the cost fell to $12,213 (Q1 to Q3, $4,494 to $29,425). Annual cost stabilized hereafter, such that the cumulative median 5-year total cost for the overall cohort was $199,476. Because of the requirement for continuous enrollment, only a small fraction of patients could be used to calculate total cost in the later years (see evolution of N in Table 2).

Total Cost, Multivariable—Insurance was a significant predictor for total cost (Table 3). The total cost for patients with Medicaid was 61.0% of that for patients with Commercial claims (cost ratio [CR] = 0.61, 95% confidence interval [CI], 0.5 to 0.74], p <0.001). CCI score was also a significant predictor for total cost. With 1-unit increase of CCI, the total cost was 38% higher (CR=1.38, 95% CI, 1.32 to 1.44; p < 0.001).

With other covariates held fixed, the total cost significantly increased within the 90-day period post-aSAH diagnosis compared to the pre-rupture baseline. The average total cost in the 90-day period after diagnosis was 24.88 times higher than that of the baseline level for patients who had clipping (CR=24.88, 95% CI, 20.63 to 30; p < 0.001) and was 16.71 times higher than that of the baseline level for those who had coiling (CR=16.71, 95% CI, 14.44 to 19.35; p < 0.001).

For both groups, in the period from 90 to 365 days post-aSAH diagnosis, the total cost decreased drastically but was still significantly higher than at baseline. For those undergoing clipping, the average total cost in this period was 11.0% of that in the first 90-day period (CR=0.11, 95% CI, 0.09 to 0.13; p < 0.001), but 2.61 times of that in the baseline period (CR=2.61, 95% CI, 2.03 to 3.35; p < 0.001). For those undergoing coiling, the average total cost in this period was 17.0% of that in the first 90-day period (CR=0.17, 95% CI, 0.15 to 0.18; p < 0.001), but 2.82 times of that in the baseline level (CR=2.82, 95% CI, 2.4 to 3.31; p < 0.001).

Complications

30-day inpatient complication and procedure rates are summarized in Table 4. The most common complications after treatment of aSAH included hydrocephalus (43.8%), transient cerebral ischemia (including vasospasm, 30.6%), ischemic stroke (29.1%), syndrome of inappropriate antidiuretic hormone secretion (SIADH)/hyposmolarity/hyponatremia (22.1%), and seizures (14.9%).

Time to inpatient complications post-aSAH diagnosis for patients who experienced complications is summarized in Figure 1. The median time to develop hydrocephalus, SIADH/hyposmolarity/hyponatremia, brain compression/herniation, seizures, and ischemic stroke was within two days of diagnosis of aSAH. However, the times to develop pneumonia (11 days), UTI (9 days), and infection (10 days) were longer.

The longest total median LOS by complication type were for PE (27 days; Q1 to Q3, 19 to 37) and pneumonia (27 days; Q1 to Q3, 18 to 32), whereas the shortest was for SIADH/hyposmolarity/hyponatremia at 16 days (Q1 to Q3, 13 to 22) (Supplementary Table 5).

Overall, 1783 (75.1%) patients had at least one of the ten complications. The median 90-day total cost for patients with complications was notably higher at $161,127 (Q1 to Q3, $101,411 to $257,662) versus $97,376 (Q1 to Q3, $55,692 to $147,447) for those without complications. PE was associated with the highest median 90-day total cost at $249,889 (Q1 to Q3, $170,769 to $388,944), whereas SIADH/hyposmolarity/hyponatremia was associated with the lowest cost at $151,522 (Q1 to Q3, $98,675 to $234,633) (Table 4).

Discharge Status of the aSAH Admission

Of the overall aSAH cohort, 50.5% (n=1,924) were discharged home, 1.1% (n=42) went to hospice; and 8.7% (n=332) died (Supplementary Table 6). Patients who developed pneumonia tended to be discharged home less often (18.9%) in favor of being sent to a transitional care facility (SNF 10.8%, rehab 27.0%, long/short-term hospital 27.0%) and patients who developed SIADH/hyposmolarity/hyponatremia were discharged home most often (53.0%). Brain compression/herniation was the deadliest complication (19.5%) (Supplementary Table 7).

DISCUSSION

As healthcare spending eclipses double-digit percentages of the US GDP, it is imperative to have comprehensive and current clinical and financial data summarizing healthcare resource utilization. In our analysis, the 90-day immediate postoperative period, costs associated with clipping were greater than for coiling ($151,321 vs. $139,833). However, the cumulative median costs for coiling negated the earlier cost-savings and eclipsed the costs for patients who received clipping by the 4th year post-diagnosis (coiling: $191,188 vs. clipping: $172,437). This is the largest study of its kind to conduct a rigorous, large-scale, retrospective analysis of the economic impact attributable to the treatment of aneurysmal subarachnoid hemorrhage. While the differences in cost between the two treatment modalities vary temporally, this study summarizes key costs, stratifies by important comorbidities, and identifies key cost drivers to highlight the high cost burden of aSAH.

Although previous analyses of the economic costs associated with aSAH and clipping vs. coiling were performed outside of the US,[3, 8, 25, 37] important trends were identified that did hold true in our analysis. Similar to our study, most studies highlight the importance of temporal changes in cost. Halkes et al. found that coiling was ultimately more expensive after 18 months postoperatively, a similar result and time trend as our study.[3] Wolstenholme and colleagues noted that costs for coiling over the course of the first year postoperatively were substantially increased due to subsequent procedures, angiograms, complications, and adverse events.[37] In the US, Hoh and colleagues also found that clipping was associated with a longer LOS and greater immediate hospital charges, which our results support.[23] Additionally, we noted that regardless of treatment modality, higher comorbidity burden was associated with significantly higher cost, while Medicaid insurance status was associated with significantly lower costs. This conclusion is reasonable, as high comorbidity burden is one of the most important predictors of patient outcomes.[40] Patients with worse outcomes will need more medical attention and use more healthcare resources. Finally, we found that PE had the highest associated median 90-day total cost ($249,889). Given that PE was associated with the longest LOS of any complication, this is an important consideration for future value-based payment models. Recognizing that the fixed cost associated with overnight stays in hospitals is among the most expensive portions of hospital billing, [42] identifying the most common postoperative complications and their associated economic burden is important for future economic modeling. An important point was made by Engele et al. as they systematically reviewed previous studies on this topic. They emphasized that a definitive claim could not be made on the true economic value of the procedure, partly because of ambiguity in the definition of "cost" across studies. [43] Accordingly, our study was conducted using the most recent claims data from the largest healthcare economics database available. From a policy perspective, claims data is ultimately the chief cost to the healthcare system and should be a closer representation of the economic burden of treatment than previous studies. Ultimately, this data can be crucial when developing fair value-based care reimbursement bundles. Without reliable records of cost drivers and summative costs for care delivery, providers are at the whim of insurers or other governmental agencies to determine reimbursement models. Transparency surrounding these costs, as recorded by our data and the work of others, enables physician stakeholders to participate in data-driven advocacy when changes to reimbursement models are proposed.

Overall, the trends in complication incidence were similar across treatment paradigms, with hydrocephalus being the overall most common complication, followed by transient cerebral ischemia (including vasospasm), ischemic stroke, salt-imbalance, seizures, shunting, brain compression/herniation, UTI, angioplasty, PE, pneumonia, and infection. These complications have been associated with aSAH previously, though reported rates of the specific complications vary substantially across studies and are limited by sample size. [44, 45, 46]] We therefore provide one of the largest-scale quantifications of incidences of these complications in the setting of aSAH.[47, 48] Providers should anticipate these complications in patients treated for aSAH and consider them highly, especially if patients become symptomatic. Additionally, identifying patients at increased risk for these complications can be important for hospitals from a healthcare utilization perspective and for payors when stratifying risks and costs for patients.

In a sub-analysis stratifying LOS by complication, PE and pneumonia were associated with the longest LOS, whereas SIADH/hyposmoloarity/hyponatremia patients had the shortest LOS. Further, while most patients were discharged home overall, patients who develop pneumonia were most often discharged to a transitional care facility and patients with SIADH/hyposmolarity/hyponatremia were most frequently discharged home. This result highlights the importance of identifying patients at high risk of pneumonia or PE after clipping/coiling and implementing strategies to reduce the rate of these complications. Notably, while these complications are associated with the largest increase in length of stay, it is important to recognize that they are partially preventable complications, thus presenting an important cost containment opportunity. A study utilizing basic preventative strategies (e.g. nursing education, inceptive spirometer use, automized pneumonia prevention order set, etc.) in reducing the rates of postoperative pneumonia found a 43.6% decrease in the incidence of this complication, associated with estimated cost savings of about $280 million. [49] This stresses the importance of basic pulmonary hygiene. Together, our results highlight the value of preventing medical complications in mitigating increased resource utilization and morbidity.

Limitations

We recognize several limitations inherent to our study. We relied on diagnosis and procedure codes for data collection, which are subject to errors based on inaccurate coding. Flaws inherent to databases tracking intracranial aneurysms have been addressed previously.[50] We were limited in using data beyond 2015 due to the change from ICD-9 to ICD-10 coding, with our aim of high-fidelity analysis based on consistent coding. Additionally, our dataset only included data up to 2015, limiting the potential for including more recent costs. Rates of complications and outcomes were assessed at 30 days, 90 days, and one year following the initial procedure, and differences in these trends may become apparent at longer follow-up intervals. Further, in this retrospective nonrandomized review, patient selection based on severity of illness may have affected both the treatment choice and the postoperative outcome; the databases used do not contain information specific to the severity of aSAH, the location of the lesion, or the WFNS grade, and therefore we were unable to stratify patients in either treatment group based on illness severity. However, our patient cohort of over 3000 patients has substantial power, and this work delineates trends in complex outcomes and enables insight into how the financial and clinical results might be combined into a more nuanced value-based care approach to healthcare costs.

CONCLUSION

Using a large national database, we rigorously quantified HCRU for the various treatments of aSAH. Patients with aSAH have high postoperative complication rates and costs. There are cost differences by treatment modality which vary over time, and postoperative sequelae from aSAH remain a significant burden in terms of length of stay, cost, and healthcare utilization. More work is needed to develop novel interventions that can reduce complications and improve outcomes. Until then, expert opinion will be important in guiding therapeutic choice for patients with this morbid and expensive disease.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Data Availability Statement

The datasets generated during and/or analysed during the current study are not publicly available due to the sensitive nature of the data. Specifically, this was queried from the IBM MarketScan database which is privately held and requires a paid subscription to access. Additionally, the queried data is exported and analyzed in an encrypted virtual workstation held at the institution performing the research. The data and analysis can be made available from the corresponding author on reasonable request.

REFERENCES

[1]. International Study of Unruptured Intracranial Aneurysms I. Unruptured intracranial aneurysms--risk of rupture and risks of surgical intervention. N Engl J Med. 1998;339:1725–33. [PubMed: 9867550]

[2]. Kassell NF, Torner JC, Jane JA, Haley EC Jr., Adams HP. The International Cooperative Study on the Timing of Aneurysm Surgery. Part 2: Surgical results. J Neurosurg. 1990;73:37–47. [PubMed: 2191091]

[3]. Halkes PH, Wermer MJ, Rinkel GJ, Buskens E. Direct costs of surgical clipping and endovascular coiling of unruptured intracranial aneurysms. Cerebrovasc Dis. 2006;22:40–5. [PubMed: 16567936]

[4]. Hop JW, Rinkel GJ, Algra A, van Gijn J. Case-fatality rates and functional outcome after subarachnoid hemorrhage: a systematic review. Stroke. 1997;28:660–4. [PubMed: 9056628]

[5]. van der Schaaf I, Algra A, Wermer M, Molyneux A, Clarke M, van Gijn J, et al. Endovascular coiling versus neurosurgical clipping for patients with aneurysmal subarachnoid haemorrhage. Cochrane Database Syst Rev. 2005:CD003085. [PubMed: 16235314]

[6]. Molyneux A, Kerr R, International Subarachnoid Aneurysm Trial Collaborative G, Stratton I, Sandercock P, Clarke M, et al. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomized trial. J Stroke Cerebrovasc Dis. 2002;11:304–14. [PubMed: 17903891]

[7]. Ahn JY, Han IB, Yoon PH, Kim SH, Kim NK, Kim S, et al. Clipping vs coiling of posterior communicating artery aneurysms with third nerve palsy. Neurology. 2006;66:121–3. [PubMed: 16401861]

[8]. Bairstow P, Dodgson A, Linto J, Khangure M. Comparison of cost and outcome of endovascular and neurosurgical procedures in the treatment of ruptured intracranial aneurysms. Australas Radiol. 2002;46:249–51. [PubMed: 12196230]

[9]. Barker FG 2nd, Amin-Hanjani S, Butler WE, Hoh BL, Rabinov JD, Pryor JC, et al. Age-dependent differences in short-term outcome after surgical or endovascular treatment of unruptured intracranial aneurysms in the United States, 1996–2000. Neurosurgery. 2004;54:18–28; discussion –30. [PubMed: 14683537]

[10]. Bellebaum C, Schafers L, Schoch B, Wanke I, Stolke D, Forsting M, et al. Clipping versus coiling: neuropsychological follow up after aneurysmal subarachnoid haemorrhage (SAH). J Clin Exp Neuropsychol. 2004;26:1081–92. [PubMed: 15590461]

[11]. Brilstra EH, Rinkel GJ, van der Graaf Y, Sluzewski M, Groen RJ, Lo RT, et al. Quality of life after treatment of unruptured intracranial aneurysms by neurosurgical clipping or by embolisation with coils. A prospective, observational study. Cerebrovasc Dis. 2004;17:44–52. [PubMed: 14530637]

[12]. Campi A, Ramzi N, Molyneux AJ, Summers PE, Kerr RS, Sneade M, et al. Retreatment of ruptured cerebral aneurysms in patients randomized by coiling or clipping in the International Subarachnoid Aneurysm Trial (ISAT). Stroke. 2007;38:1538–44. [PubMed: 17395870]

[13]. Chan A, Ho S, Poon WS. Neuropsychological sequelae of patients treated with microsurgical clipping or endovascular embolization for anterior communicating artery aneurysm. Eur Neurol. 2002;47:37–44. [PubMed: 11803191]

[14]. Chen PR, Amin-Hanjani S, Albuquerque FC, McDougall C, Zabramski JM, Spetzler RF. Outcome of oculomotor nerve palsy from posterior communicating artery aneurysms: comparison of clipping and coiling. Neurosurgery. 2006;58:1040–6; discussion –6. [PubMed: 16723882]

[15]. Cowan JA Jr., Ziewacz J, Dimick JB, Upchurch GR Jr., Thompson BG. Use of endovascular coil embolization and surgical clip occlusion for cerebral artery aneurysms. J Neurosurg. 2007;107:530–5. [PubMed: 17886551]

[16]. de Oliveira JG, Beck J, Setzer M, Gerlach R, Vatter H, Seifert V, et al. Risk of shunt-dependent hydrocephalus after occlusion of ruptured intracranial aneurysms by surgical clipping or endovascular coiling: a single-institution series and meta-analysis. Neurosurgery. 2007;61:924–33; discussion 33–4. [PubMed: 18091269]

[17]. Fontanella M, Perozzo P, Ursone R, Garbossa D, Bergui M. Neuropsychological assessment after microsurgical clipping or endovascular treatment for anterior communicating artery aneurysm. Acta Neurochir (Wien). 2003;145:867–72; discussion 72. [PubMed: 14577008]

[18]. Frazer D, Ahuja A, Watkins L, Cipolotti L. Coiling versus clipping for the treatment of aneurysmal subarachnoid hemorrhage: a longitudinal investigation into cognitive outcome. Neurosurgery. 2007;60:434–41; discussion 41–2. [PubMed: 17327787]

[19]. Gonda DD, Khalessi AA, McCutcheon BA, Marcus LP, Noorbakhsh A, Chen CC, et al. Long-term follow-up of unruptured intracranial aneurysms repaired in California. J Neurosurg. 2014;120:1349–57. [PubMed: 24724850]

[20]. Groden C, Regelsberger J, Neumaier-Probst E, Grzyska U, Herrmann HD, Zeumer H. Operative or endovascular treatment of ruptured intracranial vertebral artery aneurysms? Neuroradiology. 2000;42:685–91. [PubMed: 11071445]

[21]. Helland CA, Krakenes J, Moen G, Wester K. A population-based study of neurosurgical and endovascular treatment of ruptured, intracranial aneurysms in a small neurosurgical unit. Neurosurgery. 2006;59:1168–75; discussion 75–6. [PubMed: 17277679]

[22]. Hoh BL, Chi YY, Dermott MA, Lipori PJ, Lewis SB. The effect of coiling versus clipping of ruptured and unruptured cerebral aneurysms on length of stay, hospital cost, hospital reimbursement, and surgeon reimbursement at the university of Florida. Neurosurgery. 2009;64:614–9; discussion 9–21. [PubMed: 19197221]

[23]. 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. [PubMed: 20044522]

[24]. Investigators C Rates of delayed rebleeding from intracranial aneurysms are low after surgical and endovascular treatment. Stroke. 2006;37:1437–42. [PubMed: 16627789]

[25]. Javadpour M, Jain H, Wallace MC, Willinsky RA, ter Brugge KG, Tymianski M. Analysis of cost related to clinical and angiographic outcomes of aneurysm patients enrolled in the international subarachnoid aneurysm trial in a North American setting. Neurosurgery. 2005;56:886–94; discussion –94. [PubMed: 15854235]

[26]. Koivisto T, Vanninen R, Hurskainen H, Saari T, Hernesniemi J, Vapalahti M. Outcomes of early endovascular versus surgical treatment of ruptured cerebral aneurysms. A prospective randomized study. Stroke. 2000;31:2369–77. [PubMed: 11022066]

[27]. Lad SP, Babu R, Rhee MS, Franklin RL, Ugiliweneza B, Hodes J, et al. Long-term economic impact of coiling vs clipping for unruptured intracranial aneurysms. Neurosurgery. 2013;72:1000–11; discussion 11–3. [PubMed: 23612602]

[28]. Lusseveld E, Brilstra EH, Nijssen PC, van Rooij WJ, Sluzewski M, Tulleken CA, et al. Endovascular coiling versus neurosurgical clipping in patients with a ruptured basilar tip aneurysm. J Neurol Neurosurg Psychiatry. 2002;73:591–3. [PubMed: 12397159]

[29]. Maud A, Lakshminarayan K, Suri MF, Vazquez G, Lanzino G, Qureshi AI. Cost-effectiveness analysis of endovascular versus neurosurgical treatment for ruptured intracranial aneurysms in the United States. J Neurosurg. 2009;110:880–6. [PubMed: 19199452]

[30]. Molyneux AJ, Birks J, Clarke A, Sneade M, Kerr RS. The durability of endovascular coiling versus neurosurgical clipping of ruptured cerebral aneurysms: 18 year follow-up of the UK cohort of the International Subarachnoid Aneurysm Trial (ISAT). Lancet. 2015;385:691–7. [PubMed: 25465111]

[31]. Molyneux AJ, Kerr RS, Yu LM, Clarke M, Sneade M, Yarnold JA, et al. International subarachnoid aneurysm trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. Lancet. 2005;366:809–17. [PubMed: 16139655]

[32]. Nagashima H, Kobayashi S, Tanaka Y, Hongo K. Endovascular therapy versus surgical clipping for basilar artery bifurcation aneurysm: retrospective analysis of 117 cases. J Clin Neurosci. 2004;11:475–9. [PubMed: 15177386]

[33]. Qureshi AI, Janardhan V, Hanel RA, Lanzino G. Comparison of endovascular and surgical treatments for intracranial aneurysms: an evidence-based review. Lancet Neurol. 2007;6:816–25. [PubMed: 17706565]

[34]. Taha MM, Nakahara I, Higashi T, Iwamuro Y, Iwaasa M, Watanabe Y, et al. Endovascular embolization vs surgical clipping in treatment of cerebral aneurysms: morbidity and mortality with short-term outcome. Surg Neurol. 2006;66:277–84; discussion 84. [PubMed: 16935636]

[35]. Thomas AJ, Ogilvy CS. ISAT: equipoise in treatment of ruptured cerebral aneurysms? Lancet. 2015;385:666–8. [PubMed: 25465112]

[36]. Vanninen R, Koivisto T, Saari T, Hernesniemi J, Vapalahti M. Ruptured intracranial aneurysms: acute endovascular treatment with electrolytically detachable coils--a prospective randomized study. Radiology. 1999;211:325–36. [PubMed: 10228510]

[37]. Wolstenholme J, Rivero-Arias O, Gray A, Molyneux AJ, Kerr RS, Yarnold JA, et al. Treatment pathways, resource use, and costs of endovascular coiling versus surgical clipping after aSAH. Stroke. 2008;39:111–9. [PubMed: 18048858]

[38]. L H. The Truven Health MarketScan Databases for life sciences researchers: White Paper. 2017.

[40]. Valderas JM, Starfield B, Sibbald B, Salisbury C, Roland M. Defining comorbidity: implications for understanding health and health services. Ann Fam Med. 2009;7:357–63. [PubMed: 19597174]

[41]. Foundation KF. Medicaid-to-Medicare Fee Index. KFF State Health Facts. 2016.

[42]. Roberts RR, Frutos PW, Ciavarella GG, Gussow LM, Mensah EK, Kampe LM, et al. Distribution of variable vs fixed costs of hospital care. JAMA. 1999;281:644–9. [PubMed: 10029127]

[43]. Engele T, Brettschneider C, Emami P, Konig HH. Cost Comparison of Surgical Clipping and Endovascular Coiling of Unruptured Intracranial Aneurysms: A Systematic Review. World Neurosurg. 2019;125:461–8. [PubMed: 30743038]

[44]. Chen S, Luo J, Reis C, Manaenko A, Zhang J. Hydrocephalus after Subarachnoid Hemorrhage: Pathophysiology, Diagnosis, and Treatment. Biomed Res Int. 2017;2017:8584753. [PubMed: 28373987]

[45]. Lu J, Ji N, Yang Z, Zhao X. Prognosis and treatment of acute hydrocephalus following aneurysmal subarachnoid haemorrhage. J Clin Neurosci. 2012;19:669–72. [PubMed: 22361252]

[46]. Nassar HGE, Ghali AA, Bahnasy WS, Elawady MM. Vasospasm following aneurysmal subarachnoid hemorrhage: prediction, detection, and intervention. Egypt J Neurol Psychiatr Neurosurg. 2019;55:3. [PubMed: 30686913]

[47]. Solenski NJ, Haley EC Jr., Kassell NF, Kongable G, Germanson T, Truskowski L, et al. Medical complications of aneurysmal subarachnoid hemorrhage: a report of the multicenter, cooperative aneurysm study. Participants of the Multicenter Cooperative Aneurysm Study. Crit Care Med. 1995;23:1007–17. [PubMed: 7774210]

[48]. Rose MJ. Aneurysmal subarachnoid hemorrhage: an update on the medical complications and treatments strategies seen in these patients. Curr Opin Anaesthesiol. 2011;24:500–7. [PubMed: 21869679]

[49]. Wartenberg KE, Mayer SA. Medical complications after subarachnoid hemorrhage: new strategies for prevention and management. Current opinion in critical care. 2006;12:78–84. [PubMed: 16543780]

[50]. Woodworth GF, Baird CJ, Garces-Ambrossi G, Tonascia J, Tamargo RJ. Inaccuracy of the administrative database: comparative analysis of two databases for the diagnosis and treatment of intracranial aneurysms. Neurosurgery. 2009;65:251–6; discussion 6–7. [PubMed: 19625902]

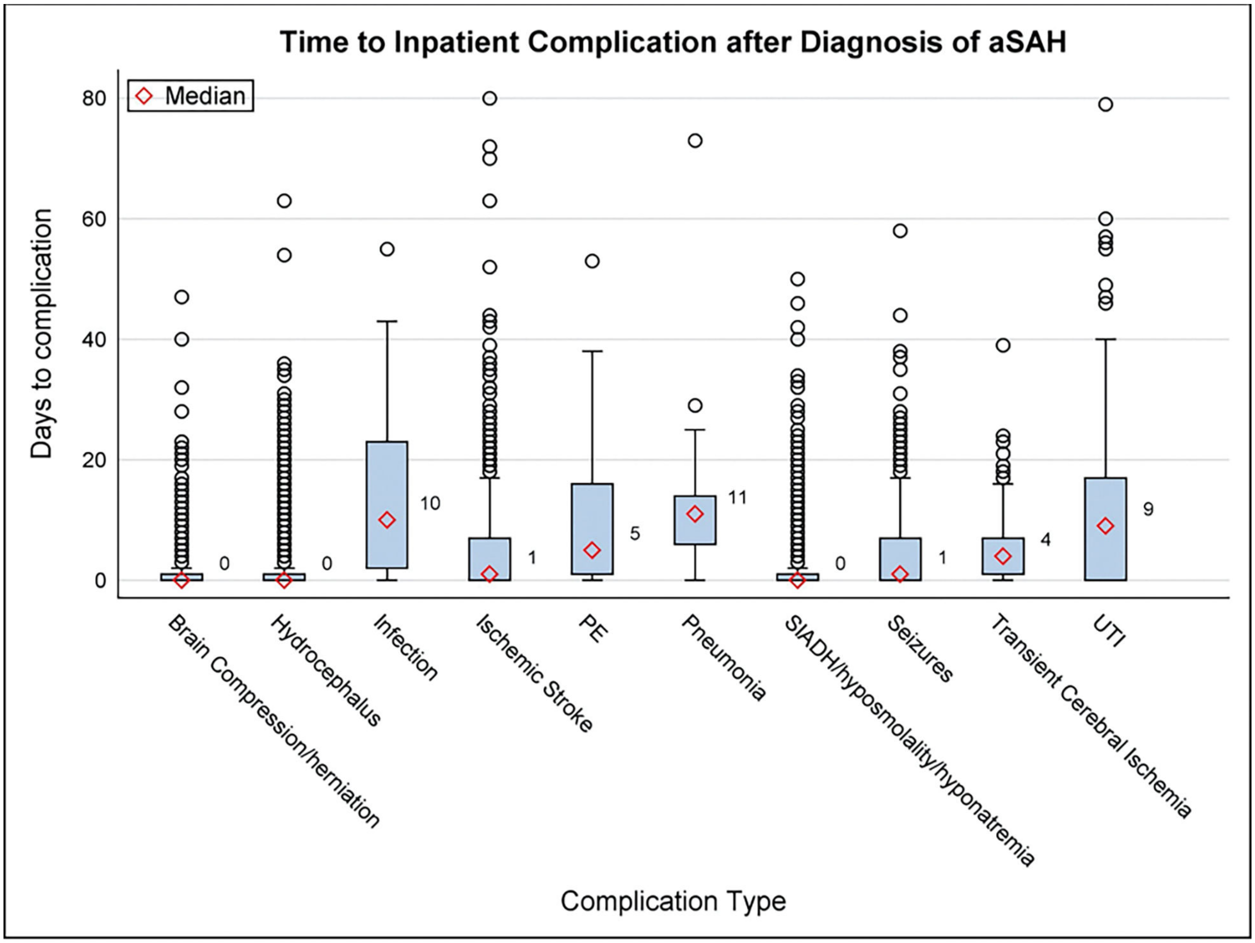

Figure 1:

Time to inpatient complications/procedures. Red diamond and the number on its right represent the median time from diagnosis to complication

Table 1.

Baseline overall cohort demographics.

	Clipping (N=974)	Coiling (N=2833)	Total (N=3807)
Age at SAH diagnosis			
Mean (SD)	53.6 (11.5)	55.7 (12.6)	55.2 (12.4)
Gender			
Male	275 (28.2%)	804 (28.4%)	1079 (28.3%)
Female	699 (71.8%)	2029 (71.6%)	2728 (71.7%)
Insurance			
Commercial Claims	750 (77.0%)	2050 (72.4%)	2800 (73.5%)
Medicaid	93 (9.5%)	288 (10.2%)	381 (10.0%)
Medicare	131 (13.4%)	495 (17.5%)	626 (16.4%)
Region			
Northeast Region	178 (18.3%)	483 (17.0%)	661 (17.4%)
North Central Region	197 (20.2%)	677 (23.9%)	874 (23.0%)
South Region	345 (35.4%)	987 (34.8%)	1332 (35.0%)
West Region	139 (14.3%)	351 (12.4%)	490 (12.9%)
Unknown Region	115 (11.8%)	335 (11.9%)	450 (11.8%)
Employment Status			
Full Time/ Part Time	268 (27.5%)	764 (27.0%)	1032 (27.1%)
Retiree	142 (14.6%)	523 (18.5%)	665 (17.5%)
Medicaid	93 (9.5%)	288 (10.2%)	381 (10.0%)
Other	471 (48.3%)	1258 (44.4%)	1729 (45.4%)
Charlson Comorbidity Score			
Mean (SD)	0.7 (1.2)	0.7 (1.3)	0.7 (1.3)
Charlson Comorbidity Score			
0	614 (63.0%)	1774 (62.6%)	2388 (62.7%)
1	198 (20.3%)	541 (19.1%)	739 (19.4%)
2	88 (9.0%)	291 (10.3%)	379 (10.0%)
3+	74 (7.6%)	227 (8.0%)	301 (7.9%)

Table 2.

Total cost over time, broken down into hospital service cost (HSC) and medication cost.

	Clipping	Coiling	Total
One-Year Period Prior to Diagnosis (baseline)			
N	593	1781	2374
Median total cost (Q1, Q3)	2728.1 (680.7 to 9039.3)	3082.5 (771.2, 9644.7)	2965.5 (751.2, 9556.6)
Median HSC (Q1, Q3)	1641.3 (381.6, 6156.0)	1875.1 (429.7, 6956.3)	1810.0 (420.3, 6743.7)
Median medication cost (Q1, Q3)	276.3 (6.5, 1605.8)	375.7 (23.4, 1848.0)	358.3 (17.6, 1791.7)
90-day Period Post-Diagnosis			
N	593	1781	2374
Median total cost (Q1, Q3)	151321.0 (94323.5, 243117.2)	139833.7 (83309.3, 230732.1)	142801.1 (85378.2, 233207.5)
Median HSC (Q1, Q3)	151321.0 (94270.0, 242930.3)	139267.6 (82536.4, 228960.2)	142024.0 (84787.5, 232493.5)
Median medication cost (Q1, Q3)	191.7 (20.6, 739.6)	327.3 (46.5, 891.5)	285.1 (35.3, 874.7)
90-day to One-Year Period Post-Diagnosis			
N	378	1159	1537
Median total cost (Q1, Q3)	6575.3 (1804.8, 21197.0)	13980.7 (5742.4, 33503.9)	12213.4 (4494.4, 29425.1)
Median HSC (Q1, Q3)	5184.6 (1243.4, 18444.1)	12301.4 (4479.0, 30954.9)	10677.1 (3258.0, 26916.6)
Median medication cost (Q1, Q3)	611.7 (61.2, 1802.6)	752.5 (171.7, 2015.4)	718.6 (136.0, 1955.4)
1-year median cumulative cost (Q1, Q3)	159677.1 (103306.2, 253814.2)	154967.7 (94003.7, 250136.5)	156261.7 (96892.2, 250136.5)
2nd One-Year Period Post-Diagnosis			
N	231	702	933
Median total cost (Q1, Q3)	5053.5 (1982.2, 16588.9)	8581.3 (2979.2, 20492.1)	7693.4 (2670.0, 19531.3)
Median HSC (Q1, Q3)	3448.5 (1113.5, 13593.0)	6360.1 (2186.3, 17305.7)	5606.5 (1803.0, 16259.2)
Median medication cost (Q1, Q3)	800.0 (128.8, 2597.7)	834.1 (177.9, 2705.3)	827.8 (162.0, 2699.2)
2-year median cumulative cost (Q1, Q3)	171543.1 (114752.3, 268633.1)	164251.7 (105338.5, 256904.7)	167687.5 (109431.5, 260433.4)
3rd One-Year Period Post-Diagnosis			
N	159	504	663
Median total cost (Q1, Q3)	3645.9 (1537.0, 13425.3)	5348.1 (2100.2, 13599.0)	4893.2 (2003.4, 13550.0)
Median HSC (Q1, Q3)	2589.7 (894.3, 8163.0)	3518.0 (1351.7, 10692.5)	3185.7 (1116.7, 10211.7)
Median medication cost (Q1, Q3)	770.9 (193.2, 2928.5)	716.0 (147.9, 2202.2)	717.3 (156.4, 2237.9)
3-year median cumulative cost (Q1, Q3)	178659.9 (129990.3, 272850.3)	172713.8 (115123.1, 264598.5)	176574.6 (116323, 266314.7)
4th One-Year Period Post-Diagnosis			
N	105	289	394
Median total cost (Q1, Q3)	4034.3 (1441.1, 11859.8)	5007.9 (1904.4, 15487.3)	4616.5 (1652.5, 13795.7)
Median HSC (Q1, Q3)	1876.1 (731.4, 6483.0)	3249.3 (996.8, 9950.8)	3123.5 (865.1, 8769.2)
Median medication cost (Q1, Q3)	806.7 (108.8, 2752.2)	873.5 (138.0, 2378.7)	866.9 (124.5, 2416.9)

	Clipping	Coiling	Total
4-year median cumulative cost (Q1, Q3)	172437.6 (117922.6, 247200.4)	191189 (119492.7, 285308)	186341.9 (119385.2, 277216.8)
5th One-Year Period Post-Diagnosis			
N	61	164	225
Median total cost (Q1, Q3)	3936.5 (1075.6, 12229.0)	5603.8 (2333.0, 15194.6)	4944.0 (1964.4, 14555.6)
Median HSC (Q1, Q3)	1913.4 (541.0, 7905.3)	3177.6 (1077.3, 10981.8)	2783.5 (974.6, 10188.9)
Median medication cost (Q1, Q3)	643.8 (121.2, 2966.9)	1063.0 (229.9, 2604.1)	1011.7 (204.9, 2681.7)
5-year median cumulative cost (Q1, Q3)	174523.9 (112105.1, 270228.8)	214253.3 (131184.4, 312529.9)	199476 (127377.8, 295075.3)

Table 3.

Multivariable regression for total/annual cost.

Covariate	Level	Cost Ratio (95% CI)	(95% Confidence Interval)	P-value
Baseline Gender of Patient	Male	1.11	(0.97, 1.27)	0.118
	Female	Reference		
Baseline Index Charlson comorbidity score		1.38	(1.32, 1.44)	<0.001
Baseline Insurance Type	Medicaid	0.61	(0.5, 0.74)	<0.001
	Medicare	0.88	(0.73, 1.07)	0.199
	Commercial Claims	Reference		
Clipping	1–90 Days	24.88	(20.63, 30)	<0.001
	Baseline	Reference		
Coiling:	1–90 Days	16.71	(14.44, 19.35)	<0.001
	Baseline	Reference		
Clipping:	90–365 Days	0.11	(0.09, 0.13)	<0.001
	1–90 Days	Reference		
Coiling:	90–365 Days	0.17	(0.15, 0.18)	<0.001
	1–90 Days	Reference		
Clipping:	90–365 Days	2.61	(2.03, 3.35)	<0.001
	Baseline	Reference		
Coiling:	90–365 Days	2.82	(2.4, 3.31)	<0.001
	Baseline	Reference		
Baseline: Coiling vs. Clipping	Coiling	1.38	(1.11, 1.72)	0.003
	Clipping	Reference		
1–90 Days: Coiling vs. Clipping	Coiling	0.93	(0.87, 1)	0.043
	Clipping	Reference		
90–365 Days: Coiling vs. Clipping	Coiling	1.49	(1.21, 1.85)	<0.001
	Clipping	Reference		
1–2 years: Coiling vs. Clipping	Coiling	1.24	(0.95, 1.6)	0.111
	Clipping	Reference		
2–3 years: Coiling vs. Clipping	Coiling	1	(0.65, 1.54)	0.999
	Clipping	Reference		
3–4 years: Coiling vs. Clipping	Coiling	1.15	(0.65, 2.02)	0.632
	Clipping	Reference		
4–5 years: Coiling vs. Clipping	Coiling	1.04	(0.64, 1.7)	0.87
	Clipping	Reference		

*Number of Observations Used in the Regression: 8500

Table 4.

Incidence rates of inpatient complications during initial aSAH admission.

	Clipping (N=974)	Coiling (N=2833)	Total (N=3807)	90-day Total Cost N	90-day Total Cost Median 90-day cost (Q1, Q3)
Hydrocephalus	382 (39.2%)	1285 (45.4%)	1667 (43.8%)	997	188193.5 (113877.8, 287353.8)
Transient Cerebral Ischemia	343 (35.2%)	821 (29.0%)	1164 (30.6%)	716	193084.4 (115602.3, 298897.2)
Ischemic Stroke	312 (32.0%)	794 (28.0%)	1106 (29.1%)	636	192128.0 (114412.5, 307596.2)
SIADH/hyposmolarity/hyponatremia	202 (20.7%)	641 (22.6%)	843 (22.1%)	531	151521.6 (98675.2, 234633.1)
Seizures	146 (15.0%)	421 (14.9%)	567 (14.9%)	330	209325.2 (112189.5, 333090.0)
Brain compression/herniation	78 (8.0%)	204 (7.2%)	282 (7.4%)	148	203330.5 (123963.0, 333803.6)
UTI	68 (7.0%)	208 (7.3%)	276 (7.2%)	191	193281.3 (104430.2, 306649.8)
PE	26 (2.7%)	45 (1.6%)	71 (1.9%)	46	249889.1 (170769.2, 388943.5)
Infection *	16 (1.6%)	26 (0.9%)	42 (1.1%)	23	216012.5 (125499.5, 306010.2)
Pneumonia	9 (0.9%)	28 (1.0%)	37 (1.0%)	22	223736.7 (142710.7, 388498.2)

* Infection other than UTI