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Advanced Age and Post–Acute Care Outcomes After Subarachnoid Hemorrhage

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***Background*—**Older patients with aneurysmal subarachnoid hemorrhage (aSAH) are unique, and determinants of post–acute care outcomes are not well elucidated. The primary objective was to identify hospital characteristics associated with 30-day readmission and mortality rates after hospital discharge among older patients with aSAH.

***Methods and Results*—**This cohort study used Medicare patients ≥65 years discharged from US hospitals from January 1, 2008, to November 30, 2010, after aSAH. Medicare data were linked to American Hospital Association data to describe characteristics of hospitals treating these patients. Using multivariable logistic regression to adjust for patient characteristics, hospital factors associated with (1) hospital readmission and (2) mortality within 30 days after discharge were identified. A total of 5515 patients ≥65 years underwent surgical repair for aSAH in 431 hospitals. Readmission rate was 17%, and 8.5% of patients died within 30 days of discharge. In multivariable analyses, patients treated in hospitals with lower annualized aSAH volumes were more likely to be readmitted 30 days after discharge (lowest versus highest quintile, 1–2 versus 16–30 cases; adjusted odds ratio, 2.10; 95% confidence interval, 1.56–2.84). Patients treated in hospitals with lower annualized aSAH volumes (lowest versus highest quintile: adjusted odds ratio, 1.52; 95% confidence interval, 1.05–2.19) had a greater likelihood of dying 30 days after discharge.

***Conclusions*—**Older patients with aSAH discharged from hospitals treating lower volumes of such cases are at greater risk of readmission and dying within 30 days. These findings may guide clinician referrals, practice guidelines, and regulatory policies influencing which hospitals should care for older patients with aSAH. **(*J Am Heart Assoc*. 2017;6:e006696. DOI: 10.1161/JAHA.117.006696.)**

Key Words: aging • hospital systems • outcome • post-acute care • quality of care • subarachnoid hemorrhage

An estimated 15% to 20% of patients with aneurysmal subarachnoid hemorrhage (aSAH) are >70 years, but they incur relatively high healthcare expenditures.[1,2] Compared with younger populations, older patients also have higher rates of mortality and long-term disability after aSAH.[3,4] Among all patients with aSAH, there is a 27% to 44% rate of early mortality, and survivors are frequently left with significant cognitive and physical disabilities.[5] Thirty-day readmission rates, a key quality measure by Centers for Medicare and Medicaid Services,[6] are an additional potential adverse outcome for older patients after aSAH, because they are both burdensome and delay rehabilitation.

There is only limited understanding of the hospital-level determinants of 30-day readmission and mortality after aSAH among older patients. Prior analyses are limited by focusing on patient-level characteristics[7–9] and in-patient mortality.[10–12] A single-center study found most readmissions after aSAH were related to infections or symptomatic hydrocephalus.[7] A population-based study found no difference in mortality or readmission rates between clipping and endovascular coiling among older patients with aSAH.[13] Prior work demonstrates an association between higher-volume centers and lower in-hospital mortality rates,[10–12] but little is known about the characteristics of hospitals associated with the key post–acute care outcomes of 30-day readmission and postdischarge mortality among those surviving the acute hospitalization period.

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Clinical Perspective

What Is New?

- Older patients with subarachnoid hemorrhage are less common, but at greater risk for poor outcomes.
- After controlling for individual patient characteristics, patients treated in hospitals with low annual volumes of older patients with subarachnoid hemorrhage were associated with greater odds of death and readmission.

What Are the Clinical Implications?

- The volume-outcome relationship extends to the post–acute care period, and the unique needs of older patients with subarachnoid hemorrhage should be matched by referral patterns and regulatory incentives favoring only higher-volume centers.

To fill this knowledge gap, we examined hospital-level characteristics associated with 30-day readmission and mortality among older patients after aSAH. Because a volume-outcome relationship exists for mortality during the index admission,[10,11] we hypothesized that after discharge, hospitals treating fewer patients with aSAH would have higher 30-day readmission and mortality rates.

Methods

This study was approved by the Brown University Institutional Review Board. For this type of study, formal consent is not required.

Population

To capture the broadest representation of hospitals treating older patients with aSAH, Medicare fee-for-service files, capturing all US hospitals treating Medicare patients ≥65 years, were used. Patients were included in the analytical sample if the incident aSAH occurred from January 1, 2008, to November 30, 2010. Patients with aSAH were defined by the presence of the following: (1) *International Classification of Diseases, Ninth Revision* (ICD-9), diagnosis codes for subarachnoid hemorrhage (codes 430, 431, and 432.9) and (2) *ICD* procedure code for aneurysm repair through microsurgical clipping (code 39.51) or endovascular approach (code 39.7x) within the 100% inpatient Standard Analytical File. ICD-9, codes for major operative procedures from hospital claims greatly enhance the sensitivity and specificity of case identification.[14]

Patients diagnosed as having arteriovenous malformation or other cerebrovascular malformation (code 747.81), syphilitic aneurysm (code 094.87), cerebral arteritis (code 437.4), and Moyamoya disease (code 437.5), and those who had undergone treatment of a cerebrovascular malformation either through a surgical approach (code 39.53) or via stereotactic radiosurgery (code 923.x), were excluded. To allow for comparison between aneurysm treatment approaches, patients with both microsurgical clipping (code 39.51) and endovascular coiling (code 39.7x) during the same index hospitalization were excluded (n=113). Only incident aSAH cases were considered in the analysis by including only the first aneurysm clipping or coiling for patients with multiple interventions, and excluding patients with any claims for aneurysmal aSAH 1 year before the cohort inception date. Finally, patients with length of index hospitalization lasting <48 hours were considered as possible early transfers to higher-level care facilities and were, therefore, excluded (n=176).

Patient-Level Characteristics

Patient characteristics believed to be potentially associated with readmission or mortality after aSAH were selected a priori from the available Medicare claims based on the literature[7–9,13] and our clinical experience. Demographic characteristics were derived from Medicare Enrollment files, including age, sex, race, and zip code of primary residence. Age was grouped in ranges of 5 years (65–69, 70–74, 75–79, 80–84, 85–89, and ≥90 years). Race was categorized as white (referent), black, or other. Patient's zip codes, if primary residence, were linked to US Census Data to determine median income.[15,16] The median income for the entire cohort ($50 160) was used to create a dichotomous variable indicating primary residence in a zip code lower than the cohort median. Patients with an acute hospital admission for any cause within 1 year before index aSAH admission were identified using Medicare Part A claims. The source of acute inpatient admission was classified from Part A claims as hospital transfer, emergency department, physician referral, or other. A composite measure of individual patient comorbidity was calculated with the Elixhauser score (range, 0–28; with higher scores indicating a greater comorbidity), which was analyzed as quartiles (1, 2, 3, and ≥4) based on its distribution.[17]

Other patient variables related to their index hospitalization included the following: tracheostomy (codes 31.1, 31.2. 31.21, and 31.29), gastrostomy feeding tube placement (codes 43.1, 43.11, 43.19, 44.32, 44.38, and 44.39), and procedural rates of microsurgical clipping (code 39.51) or endovascular embolization (codes 39.52, 39.72, 39.75, 39.76, and 39.79). Only the index procedure was considered among patients with multiple aneurysms and multiple procedures.

The severity of the aSAH was quantified using the Nationwide Inpatient Sample Subarachnoid Hemorrhage Severity Score (NIS-SSS),[18] a validated ICD-9–based measure ranging from 0 to 15, with higher scores indicating greater severity. The NIS-SSS is highly correlated with the widely known Hunt Hess clinical grading scale.[19] Hunt Hess grades ≥4 are considered "poor grade." A dichotomous variable was created using a cut point of NIS-SSS >7 because of its correlation with a Hunt Hess grade ≥4.[18]

Hospital-Level Characteristics

Hospital facility characteristics were obtained from the American Hospital Association Annual Survey Database for fiscal year 2010.[20] The database contains nationwide information relating to hospital fiscal and corporate structure, certifications, licensure, and staffing levels. All acute-care hospitals caring for patients with aSAH >65 years in the United States were included. Variables were chosen a priori on the basis of publications delineating facility determinants of readmission and mortality in related conditions, as well as expert opinion.[11,13] There was a 100% match rate among patients with aSAH in the analytical sample with the corresponding Medicare facility identification number in the American Hospital Association database (N=431 hospitals).

Hospital characteristics examined were as follows: ownership (categorized as nonprofit private, government, nonprofit church, or for profit), medical school affiliation, annualized aSAH patient volume (the total number of patients with aSAH cared for during the study period/3) divided into quintiles (1–2, 3–5, 6–8, 9–15, and 16–30 patients), licensed bed capacity grouped into quintiles (214–429, 430–600, 601–730, 731–960, and 961–2482), number of intensive care unit beds grouped by quintiles (8–21, 22–32, 33–48, 49–70, and 71–196 beds), level 1 trauma center designation, inpatient hospice availability, and presence of a palliative care consultation service.

Outcome Measures

The proportion of patients with aSAH experiencing the following 2 outcomes within 30 days of discharge from the index hospitalization were determined: (1) hospital readmission and (2) mortality. Dates of death and readmissions were determined from the Medicare denominator and Part A files, respectively. Patients who died within 30 days after discharge and before a readmission event (n=409) were excluded from analyses examining readmission as an outcome. Readmission events were counted whether they occurred at the same or different hospital as the index aSAH admission.

Statistical Analysis

Analyses to identify factors associated with each of the 2 aforementioned outcomes were conducted separately and at the patient level for each outcome. Candidate independent variables associated with these outcomes included patient and index hospital characteristics. As detailed above, patient variables included age group, sex, race, income, hospitalization in the preceding year, admission source, Elixhauser score, tracheostomy, gastrostomy, open clipping or endovascular coiling, and NIS-SSS grade. Hospital variables included ownership, medical school affiliation, annualized hospital aSAH volume, licensed bed capacity, intensive care unit bed capacity, level 1 trauma designation, availability of inpatient hospice, and no palliative care program.

Bivariate analyses using logistic regression measured the association of individual independent variables with whether patients experienced each of the outcomes. Independent variables associated with the outcomes at $P<0.10$ in these unadjusted analyses were included in multivariable logistic regression models. The generalized estimating equation adjusted for the clustering of individual patients within hospitals.[21] Odds ratios with 95% confidence intervals were generated from these analyses. All analyses were performed using the Stata software package.

Results

Patient and Hospital Characteristics

We identified 5515 patients >65 years with aSAH who underwent endovascular coiling or open surgical clipping. The cohort's median age was 72 years (21% were >80 years), 25% were men, and 81% were white (Table 1). Most patients had a prolonged initial hospital length of stay (median, 17 days; interquartile range, 11–24 days). Only 11.7% of patients had an NIS-SSS ≥7. Hydrocephalus was treated by extraventricular drainage among 37% of patients, and ventriculoperitoneal shunt was required among 17% of patients. Most patients (68%) underwent endovascular coiling for aneurysm repair.

A total of 431 hospitals treated the cohort, of which 56% were nonprofit, 92% were affiliated with a medical school, and 87% had accredited residency programs (87%); there was a median of 700 (interquartile range, 519–926) licensed beds. The hospital median case volume for aSAH patients ≥65 years was 7 (interquartile range, 5–11).

Thirty-Day Readmission

A total of 409 patients with aSAH died within 30 days of discharge and before a readmission and, thus, were excluded from the analyses examining factors associated with readmission. Among the remaining 5106 patients, 893 (17%) had 30-day acute hospital readmissions. In bivariate analyses, the following patient characteristics were associated with a greater likelihood of 30-day readmission at $P<0.10$: male

Table 1. Patient and Hospital Characteristics and Their Unadjusted Associations With 30-Day Readmission After aSAH (N=5106 Patients)

Characteristics	No. (%) of Patients With Characteristic	No. (%) Readmitted		OR (95% CI)
		Characteristic Present	Characteristic Absent	
Patient-level characteristics				
Age, y				
65–69	1740 (34)	315 (18)	583 (17)	1.00
70–74	1374 (27)	254 (18)	644 (17)	1.08 (0.90–1.25)
75–79	968 (19)	163 (17)	735 (18)	0.96 (0.78–1.19)
80–84	633 (12)	112 (18)	786 (18)	1.02 (0.81–1.30)
85–89	326 (6)	54 (17)	844 (18)	0.95 (0.69–1.30)
≥90	65 (1)	‖	‖	0.65 (0.29–1.45)
Male sex	1272 (25)	254 (20)	639 (17)	1.25 (1.06–1.47)*
Race				
White	4097 (80)	693 (17)	200 (20)	1.00
Black	537 (11)	119 (22)	774 (17)	0.98 (0.76–1.27)
Other	472 (9)	81 (17)	812 (18)	1.37 (1.00–1.88)*
Lower than median annual income†	2505 (49)	431 (17)	462 (18)	0.96 (0.60–0.83)
Hospitalized 1 y before aSAH‡	1448 (28)	257 (18)	636 (17)	1.03 (0.87–1.20)
Admission source				
Hospital transfer	1920 (38)	345 (18)	573 (18)	0.96 (0.89–1.06)
Emergency department	1811 (35)	325 (18)	593 (18)	0.98 (0.92–1.04)
Physician referral	1120 (22)	179 (16)	638 (16)	1.02 (0.98–1.09)
Other	255 (5)	43 (17)	776 (16)	0.82 (0.64–1.28
Elixhauser score				
1	1836 (36)	269 (15)	624 (19)	1.00
2	1595 (31)	266 (17)	627 (18)	1.17 (0.97–1.40)
3	1029 (20)	171 (17)	722 (18)	1.16 (0.94–1.43)
≥4	646 (13)	187 (29)	706 (16)	2.37 (1.92–2.94)
Open clipping	1609 (32)	282 (18)	611 (17)	1.00 (0.86–1.17)
Endovascular coiling	3497 (68)	446 (13)	447 (27)	0.65 (0.56–0.75)*
Tracheostomy	768 (15)	177 (23)	716 (17)	1.51 (1.25–1.82)*
Gastrostomy	609 (12)	143 (23)	750 (17)	1.53 (1.25–1.88)*
Poor grade (NIS-SSS ≥7)§	2027 (40)	302 (15)	591 (19)	0.74 (0.63–0.86)*
Hospital-level characteristics				
Ownership				
Nonprofit church	603 (12)	86 (14)	780 (17)	1.00
Nonprofit private	3198 (63)	572 (18)	294 (16)	1.30 (1.02–1.67)*
Government	974 (19)	156 (16)	710 (17)	1.15 (0.86–1.53)
For profit	295 (6)	52 (18)	814 (17)	1.29 (0.88–1.87)
Medical school affiliation	4440 (87)	737 (17)	156 (23)	1.29 (1.06–1.58)*

Continued

Table 1. Continued

Characteristics	No. (%) of Patients With Characteristic	No. (%) Readmitted		OR (95% CI)
		Characteristic Present	Characteristic Absent	
Annualized hospital aSAH volume				
1–2	1007 (20)	246 (24)	647 (16)	2.08 (1.64–2.63)*
3–5	1026 (20)	164 (16)	729 (18)	1.22 (0.95–1.57)*
6–8	1057 (21)	178 (17)	715 (18)	1.30 (1.02–1.66)*
9–15	1066 (21)	177 (17)	716 (18)	1.28 (0.99–1.63)
16–30	950 (19)	128 (13)	765 (18)	1.00
Licensed beds				
214–429	973 (19)	194 (20)	633 (16)	1.31 (1.03–1.65)*
430–600	960 (19)	157 (16)	673 (17)	1.02 (0.80–1.31)
601–730	970 (19)	169 (17)	661 (17)	1.11 (0.87–1.41)
731–960	993 (19)	156 (16)	674 (17)	0.98 (0.78–1.25)
961–2482	962 (19)	154 (16)	676 (15)	1.00
Intensive care beds				
8–21	1016 (20)	184 (18)	647 (17)	1.00
22–32	939 (18)	164 (17)	667 (17)	0.97 (0.78–1.22)
33–48	1030 (20)	160 (16)	671 (17)	0.86 (0.68–1.07)
49–70	994 (19)	188 (19)	643 (17)	1.05 (0.85–1.31)
71–196	887 (17)	135 (15)	696 (17)	0.81 (0.64–1.03)
Level I trauma center	3881 (76)	648 (17)	245 (20)	0.87 (0.72–1.05)
Inpatient hospice available	1702 (33)	275 (16)	618 (18)	0.90 (0.77–1.06)
No palliative care program	593 (12)	124 (21)	769 (17)	1.29 (1.04–1.59)*

Column 2, "No. (%) of Patients With Characteristic," represents the number of subjects with the row characteristic, which was used for each bivariate comparison. Columns 3 and 4 are side-by-side proportions of patients with the outcome event who had the row characteristic and the proportion of patients without the row characteristic who had the outcome event, respectively. aSAH indicates aneurysmal subarachnoid hemorrhage; CI, confidence interval; NIS-SSS, Nationwide Inpatient Sample Subarachnoid Hemorrhage Severity Score; and OR, odds ratio.

*Indicates variable with $P<0.10$, and thus included in multivariable models. Income calculated from US zip code of primary residence from US Census data for 2008. Median income for the entire study cohort was $50 160.

†All-cause hospitalizations, with prior aSAH-associated hospitalizations excluded.

‡Elixhauser score was analyzed as a continuous variable. The score ranges from 0 to 28, where higher scores indicate greater comorbidity.

§The NIS-SSS measures SAH severity, with a range of 0 to 15, where higher scores indicate greater severity. The variable was analyzed as a dichotomous variable with a cut point of 7.

‖Output suppressed per Medicare reporting rules to protect patient identity.

sex, race classified as other (versus white), higher Elixhauser score (greater comorbidity), tracheostomy, and gastrostomy. Patients with worse SAH severity (NIS-SSS ≥7) and those undergoing endovascular coiling were less likely to be readmitted. Hospital characteristics associated with higher likelihood of a patient being readmitted with 30 days in the unadjusted analyses included the following: affiliation with a medical school, nonprofit private ownership, lower aSAH case volume, fewer licensed beds, and lack of a palliative care program.

In the multivariable model, patient factors that remained independently associated with 30-day readmission included the following: male sex, higher Elixhauser score, endovascular coiling, tracheostomy, gastrostomy, and NIS-SSS ≥7. After adjusting for these patient characteristics, hospital-level factors significantly associated with 30-day readmission were ownership and annualized hospital aSAH volume (Table 2). Relative to hospitals owned by church-affiliated nonprofit entities, patients in private nonprofit organizations had greater odds of readmission (adjusted odds ratio, 1.54; 95% confidence interval, 1.16–2.05). Patients treated in hospitals with the lowest quintile (versus highest quintile) aSAH case volume were more likely to be readmitted within 30 days (adjusted odds ratio, 2.10; 95% confidence interval, 1.56–2.84).

Thirty-Day Mortality

Among 5515 patients with aSAH, 470 (8.5%) died within 30 days of discharge from the index hospitalization. Bivariate analyses identified the following patient characteristics

Table 2. Multivariable Analysis of Patient and Hospital Characteristics Associated With Readmission 30 Days After aSAH (N=5106 Patients)

Characteristics	Adjusted OR (95% CI)
Patient-level characteristics	
Male sex	1.26 (1.07–1.49)
Elixhauser score*	
1	1.00
2	1.15 (0.95–1.40)
3	1.14 (0.92–1.42)
≥4	2.26 (1.80–2.83)
Endovascular coiling	0.76 (0.65–0.88)
Tracheostomy	1.80 (1.45–2.25)
Gastrostomy	1.37 (1.10–1.72)
Poor clinical grade (NIS-SSS >7)[†]	0.69 (0.59–0.81)
Hospital-level characteristics	
Hospital ownership	
Nonprofit church	1.00
Nonprofit	1.54 (1.16–2.04)
Government	1.37 (0.98–1.92)
For profit	1.20 (0.79–1.82)
Annualized hospital aSAH case volume	
1–2	2.10 (1.56–2.84)
3–5	1.19 (0.87–1.64)
6–8	1.25 (0.91–1.72)
9–15	1.23 (0.89–1.71)
16–30	1.00

Analyses conducted at the patient level and adjusted for clustering at the hospital level using generalized estimating equations. Model C-statistic was 0.68. aSAH indicates aneurysmal subarachnoid hemorrhage; CI, confidence interval; NIS-SSS, Nationwide Inpatient Sample Subarachnoid Hemorrhage Severity Score; and OR, odds ratio.
*Elixhauser score was analyzed as a continuous variable. The score ranges from 0 to 28, with higher scores indicate greater comorbidity.
[†]The NIS-SSS measures SAH severity, with a range of 0 to 15, where higher scores indicate greater severity. The variable was analyzed as a dichotomous variable with a cut point of 7.

associated with a greater likelihood of 30-day mortality at $P<0.10$: older age, male sex, nonwhite race, hospitalization during the year before aSAH admission, tracheostomy, gastrostomy, and NIS-SSS ≥7 (Table 3). Endovascular coiling was associated with a lower likelihood of dying with 30 days. Hospital characteristics associated with higher likelihood of 30-day mortality in unadjusted analyses included medical school affiliation, lower aSAH case volume, fewer number of beds, and no palliative care program.

In the multivariable model, patient factors that remained independently associated with 30-day postdischarge mortality included older age, male sex, nonwhite race, tracheostomy, endovascular coiling, and NIS-SSS ≥7 (Table 4). After adjusting for these patient characteristics, the only hospital-level factor that remained significantly associated with greater odds of 30-day postdischarge mortality was annualized hospital aSAH volume (Table 4); patients receiving care in low-volume aSAH hospitals were significantly more likely to die (lowest versus highest quintile: adjusted odds ratio, 1.52; 95% confidence interval, 1.05–2.19).

Discussion

This nationwide analysis of Medicare fee-for-service beneficiaries >65 years revealed that hospitals treating low volumes of patients with aSAH placed them at higher risk of 30-day readmission and mortality after discharge. Measurement of outcomes at different time points across the continuum of care is fundamental to understanding quality. This report fills a gap in previous studies focusing on inpatient outcomes, with the finding that that hospital volume may also be a modifiable determinant of outcomes extending to the post–acute care setting.

Once a patient with aSAH is discharged from the hospital, there is a notable 8.5% rate of mortality within 30 days. This novel finding highlights the disproportionate burden of negative outcomes among a growing population of older patients with aSAH.[3–5] In comparison to previous reports of younger aSAH populations,[7,8] this study found a higher (17%) rate of 30-day readmission among older patients with aSAH, which is identical to the only comparable nationwide analysis to date.[13] In contrast, our study showed aneurysm ablation via endovascular coiling to be associated with lower rates of readmission and death. The finding may be explained by differing analytical approaches and larger cohort size in our study. Older patients with aSAH are increasingly being treated with endovascular embolization.[22] Our findings add evidence to support the practice of endovascular techniques among older patients often with multiple comorbidities.

This study corroborates earlier work revealing a volume-outcome relationship for in-patient mortality during the initial hospitalization in patients with aSAH, and extends that observation to early postdischarge mortality and readmission rates.[11,23–25] Current aSAH guidelines cite this earlier work to advocate for transfer of patients with aSAH to higher-volume centers.[10–12] With this in mind, our findings are particularly relevant given the following trends during the past 20 years: (1) the aging of the aSAH population with identification of frailty as a geriatric syndrome requiring specialized care, (2) proliferation of endovascular aneurysm treatment, and (3) the advent of comprehensive stroke centers and neurointensive care units.[12,13] Hospitals in the second volume quintile (3–5 cases/year) did not statistically differ from those in successively higher-volume quintiles. The finding may be the

Table 3. Patient and Hospital Characteristics and Their Unadjusted Associations With Mortality Within 30 Days of Discharge for aSAH (N=5515 Patients)

Characteristics	No. (%) of Patients With Characteristic	No. (%) Who Died		OR (95% CI)
		With Characteristic	Without Characteristic	
Patient-level characteristics				
Age, y				
65–69	1825 (33)	108 (6)	359 (10)	1.00
70–74	1446 (26)	86 (6)	381 (9)	1.00 (0.75–1.34)
75–79	1064 (19)	105 (10)	362 (8)	1.74 (1.32–2.30)*
80–84	719 (13)	93 (13)	374 (8)	2.36 (1.76–3.16)*
85–89	379 (7)	59 (16)	408 (8)	2.93 (2.09–4.11)*
≥90	73 (1)	16 (22)	467 (9)	4.46 (2.48–8.03)*
Male sex	1398 (25)	144 (10)	326 (8)	1.34 (1.09–1.64)*
Race				
White	4449 (81)	396 (9)	74 (7)	1.00
Black	575 (10)	53 (9)	417 (8)	2.19 (1.40–3.42)*
Other	491 (9)	21 (4)	449 (9)	2.27 (1.35–3.82)*
Lower than the median annual income[†]	2711 (49)	242 (9)	228 (8)	1.11 (0.92–1.34)
Hospitalized 1 y before aSAH[‡]	1587 (29)	161 (10)	309 (8)	1.32 (1.08–1.62)*
Admission source				
Hospital transfer	2090 (38)	167 (9)	308 (9)	0.98 (0.75–1.21)
Emergency department	1940 (35)	175 (9)	322 (9)	0.97 (0.77–1.23)
Physician referral	1129 (20)	102 (9)	321 (9)	0.98 (0.72–1.32)
Other	356 (7)	28 (8)	464 (9)	0.76 (0.62–1.79)
Elixhauser score				
1	1998 (36)	177 (9)	293 (8)	1.00
2	1721 (31)	149 (9)	321 (8)	0.98 (0.78–1.23)
3	1108 (20)	86 (8)	384 (9)	0.87 (0.66–1.13)
>4	688 (12)	58 (8)	412 (9)	0.95 (0.69–1.29)
Open clipping	1743 (32)	154 (9)	316 (8)	1.05 (0.87–1.30)
Endovascular coiling	3772 (68)	236 (6)	234 (13)	0.70 (0.58–0.85)*
Tracheostomy	857 (16)	105 (12)	365 (8)	1.64 (1.30–2.07)*
Gastrostomy	663 (12)	70 (11)	400 (8)	1.31 (1.00–1.72)*
Poor grade (NIS-SSS >7)	2255 (41)	251 (11)	219 (7)	1.73 (1.44–2.10)*
Hospital-level characteristics				
Ownership				
Nonprofit	3446 (62)	281 (8)	182 (9)	1.00
Government	1048 (19)	89 (8)	374 (8)	1.05 (0.81–1.34)
Nonprofit church	659 (12)	61 (9)	402 (8)	1.15 (0.86–1.56)
For profit	320 (6)	32 (10)	431 (8)	1.25 (0.85–1.84)
Medical school affiliation	4777 (87)	386 (8)	84 (11)	1.42 (1.09–1.83)*

Continued

Table 3. Continued

Characteristics	No. (%) of Patients With Characteristic	No. (%) Who Died		OR (95% CI)
		With Characteristic	Without Characteristic	
Annualized hospital aSAH volume				
1–2	1123 (20)	138 (12)	332 (8)	1.81 (1.34–2.44)*
3–5	1100 (20)	83 (8)	387 (9)	1.05 (0.76–1.46)
6–8	1128 (20)	84 (7)	386 (9)	1.04 (0.75–1.44)
9–15	1148 (21)	92 (8)	378 (9)	1.13 (0.82–1.55)
16–30	1016 (18)	73 (7)	397 (9)	1.00
Licensed beds				
214–429	1056 (19)	99 (9)	340 (8)	1.38 (1.00–1.89)*
430–600	1043 (19)	101 (10)	338 (8)	1.42 (1.04–2.00)*
601–730	1048 (19)	89 (8)	350 (8)	1.23 (0.89–1.71)
731–960	1063 (19)	78 (7)	361 (9)	1.05 (0.76–1.47)
961–2482	1030 (19)	72 (7)	367 (9)	1.00
Intensive care beds				
8–21	1104 (20)	106 (10)	336 (8)	1.00
22–32	1026 (19)	103 (10)	339 (8)	1.05 (0.79–1.40)
33–48	1109 (20)	88 (9)	351 (8)	0.81 (0.60–1.09)
49–70	1058 (19)	74 (7)	368 (9)	0.71 (0.52–0.97)
71–196	954 (17)	71 (7)	371 (9)	0.76 (0.55–1.04)
Level I trauma center	4189 (76)	352 (8)	118 (9)	0.99 (0.78–1.26)
Inpatient hospice available	1834 (33)	151 (34)	319 (9)	0.96 (0.78–1.18)
No palliative care program	652 (12)	79 (12)	391 (8)	1.57 (1.22–2.04)*

Column 2, "No. (%) of Patients With Characteristic," represents the number of subjects with the row characteristic, which was used for each bivariate comparison. Columns 3 and 4 are side-by-side proportions of patients with the outcome event who had the row characteristic and the proportion of patients without the row characteristic who had the outcome event, respectively. aSAH indicates aneurysmal subarachnoid hemorrhage; CI, confidence interval; NIS-SSS, Nationwide Inpatient Sample Subarachnoid Hemorrhage Severity Score; and OR, odds ratio.
*Indicates variable with $P<0.10$, and thus included in multivariable models.
†Income calculated from US zip code of primary residence from US Census data for 2008.
‡All-cause hospitalizations, with prior aSAH-associated hospitalizations excluded.

result of our annualized rate calculation during the 3-year study period, and 1 to 2 annual cases may not be the exact volume threshold unless volumes are calculated as a similar 3-year average. Separately, aSAH care requires unique expertise, and there is evidence for less overall variation in quality between hospitals performing more highly specialized procedures.[26] Individual surgeon and hospital volume-outcome relationships have led to greater regionalization among higher-volume centers for other surgical conditions.[26–29] This study suggests that hospital certification and referral policies for aSAH need to be further honed, and older patients with aSAH may require specific consideration.

In contrast to our findings of higher rates of readmission and mortality among low-volume centers, high-volume teaching hospitals are more likely to incur Centers for Medicare and Medicaid Services reimbursement penalties for readmissions.[30] Efforts to reliably identify patients with neurologic injuries at risk for readmission have proved challenging.[31] Targeted multidisciplinary team-based interventions to reduce preventable readmissions have proved beneficial for other conditions.[32] Potentially important determinants for preventing readmission found in larger, high-volume hospitals include dedicated neurointensive care units, neuroscience-specialized nursing care, social work, case management, and rehabilitation services that may be important determinants of readmission for aSAH.[12]

The following limitations to our study should also be considered. First, there is the potential for unmeasured confounding, particularly by underestimating comorbidity of patients admitted to high-volume hospitals. However, that possibility would act to strengthen the association reported herein.[33] Second, although we excluded patients with aSAH

Table 4. Multivariable Analysis of Patient and Hospital Characteristics Associated With Mortality Within 30 Days of Discharge After aSAH (N=5515)

Characteristics	Adjusted OR (95% CI)
Patient-level characteristics	
Age, y	
65–69	1.00
70–74	1.12 (0.80–1.57)
75–79	1.96 (1.41–2.72)
80–84	2.90 (2.06–4.08)
85–89	3.63 (2.42–5.44)
>90	6.63 (3.54–12.4)
Male sex	1.49 (1.17–1.90)
Race	
White	1.00
Black	2.65 (1.42–4.91)
Other	2.71 (1.35–5.45)
Endovascular coiling	0.69 (0.55–0.87)
Tracheostomy	1.55 (1.26–1.91)
Poor clinical grade (NIS-SSS >7)*	1.69 (1.35–2.13)
Hospital-level characteristics	
Annualized hospital aSAH case volume	
1–2	1.52 (1.05–2.19)
3–5	0.88 (0.59–1.31)
6–8	1.08 (0.73–1.58)
9–15	1.30 (0.90–1.91)
16–30	1.00

Analyses conducted at the patient level and adjusted for clustering at the hospital level using generalized estimating equations. Model C-statistic was 0.81. aSAH indicates aneurysmal subarachnoid hemorrhage; CI, confidence interval; NIS-SSS, Nationwide Inpatient Sample Subarachnoid Hemorrhage Severity Score; and OR, odds ratio.
*The NIS-SSS measures SAH severity, with a range of 0 to 15, where higher scores indicate greater severity. The variable was analyzed as a dichotomous variable with a cut point of 7.

with an index hospitalization of <48 hours, transfers to another hospital beyond 48 hours may have been misclassified as a readmission. However, given that the cohort's median length of stay was 17 days (interquartile range, 11–24 days), this scenario is likely to be a rare event. Third, regional factors (eg, quality of post–acute care) that influence 30-day readmission and mortality rates were not considered in these analyses. Finally, our findings may not be generalizable to patients with aSAH <65 years.

Conclusions

Treating the system as a means to improve the care of patients is a topic of ongoing debate in the United States.[34] This study extends inpatient volume-outcome relationships in aSAH to outcomes measured in the post–acute care setting, where hospitals treating low volumes of older patients with aSAH have higher rates of readmission and postdischarge mortality at 30 days. Hospitals with higher volumes of older patients with aSAH may have the resources and expertise necessary to prevent poor outcomes after hospital discharge. These findings should inform state-level referral policies and Centers for Medicare and Medicaid Services standards required for the care of older patients with aSAH.

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Disclosures

None.

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