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ORIGINAL RESEARCH

Association Between Hospital Volumes and Clinical Outcomes for Patients With Nontraumatic Subarachnoid Hemorrhage

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BACKGROUND: Previous studies of patients with nontraumatic subarachnoid hemorrhage (SAH) suggest better outcomes at hospitals with higher case and procedural volumes, but the shape of the volume-outcome curve has not been defined. We sought to establish minimum volume criteria for SAH and aneurysm obliteration procedures that could be used for comprehensive stroke center certification.

METHODS AND RESULTS: Data from 8512 discharges in the National Inpatient Sample (NIS) from 2010 to 2011 were analyzed using logistic regression models to evaluate the association between clinical outcomes (in-hospital mortality and the NIS-SAH Outcome Measure [NIS-SOM]) and measures of hospital annual case volume (nontraumatic SAH discharges, coiling, and clipping procedures). Sensitivity and specificity analyses for the association of desirable outcomes with different volume thresholds were performed. During 8512 SAH hospitalizations, 28.7% of cases underwent clipping and 20.1% underwent coiling with rates of 21.2% for in-hospital mortality and 38.6% for poor outcome on the NIS-SOM. The mean (range) of SAH, coiling, and clipping annual case volumes were 30.9 (1–195), 8.7 (0–94), and 6.1 (0–69), respectively. Logistic regression demonstrated improved outcomes with increasing annual case volumes of SAH discharges and procedures for aneurysm obliteration, with attenuation of the benefit beyond 35 SAH cases/year. Analysis of sensitivity and specificity using different volume thresholds confirmed these results. Analysis of previously proposed volume thresholds, including those utilized as minimum standards for comprehensive stroke center certification, showed that hospitals with more than 35 SAH cases annually had consistently superior outcomes compared with hospitals with fewer cases, although some hospitals below this threshold had similar outcomes. The adjusted odds ratio demonstrating lower risk of poor outcomes with SAH annual case volume ≥35 compared with 20 to 34 was 0.82 for the NIS-SOM (95% CI, 0.71–094; *P*=0.0054) and 0.80 (95% CI, 0.68–0.93; *P*=0.0055) for in-hospital mortality.

CONCLUSIONS: Outcomes for patients with SAH improve with increasing hospital case volumes and procedure volumes, with consistently better outcomes for hospitals with more than 35 SAH cases per year.

Key Words: case volumes ■ cerebral aneurysm ■ clipping ■ coiling ■ comprehensive stroke centers ■ outcomes ■ subarachnoid hemorrhage

Aneurysmal subarachnoid hemorrhage (SAH) occurs in ≈30 000 people per year in the United States and accounts for ≈5% of strokes, but represents 27% of all stroke-related years of life lost before age 65.[1–5] The designation of primary stroke centers along with other efforts has contributed to significant improvements in rates of intravenous thrombolysis and other process metrics and in outcomes after ischemic

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CLINICAL PERSPECTIVE

What Is New?

- Outcomes for patients with subarachnoid hemorrhage improve with increasing case and procedure volumes with consistently better outcomes with more than 35 subarachnoid hemorrhage cases per year though some lower volume centers do have good outcomes.

What Are the Clinical Implications?

- Hospitals that are designated as comprehensive stroke centers should treat at least 35 subarachnoid hemorrhage cases per year.

Nonstandard Abbreviations and Acronyms

ACV	annual case volume
AHA	American Heart Association
CSC	comprehensive stroke center
HCUP	Healthcare Cost and Utilization Project
JC	Joint Commission
NIS	Nationwide Inpatient Sample
NIS-SOM	NIS-SAH Outcome Measure
NIS-SSS	NIS-SAH Severity Score
TAP	Technical Advisory Panel

and hemorrhagic stroke.[6,7] In view of this, it was suggested that a population of complex stroke patients, including those with SAH, may benefit from treatment at institutions that provide an even higher level of care. The Brain Attack Coalition proposed the development of comprehensive stroke centers (CSC) to address the need for optimal care of these patients.[8] Among other requirements, the Brain Attack Coalition recommended that CSCs should treat ≥20 patients with SAH and perform ≥10 craniotomies for aneurysm clipping per year.[8] These volume thresholds were based on expert opinion and on administrative data demonstrating better outcomes in centers treating more aneurysmal patients with SAH, with reported thresholds ranging from 19 to 50 patients with SAH annually.[9–12]

The 2012 American Heart Association (AHA) guidelines for aneurysmal SAH recommended that hospitals discharging fewer than 10 aneurysmal SAH annually should consider transfer of patients to hospitals treating more than 35 cases per year. The AHA and the Joint Commission (JC) subsequently initiated a CSC certification program, utilizing an annual requirement of treating ≥20 aneurysmal patients with SAH and a total of ≥15 endovascular coiling or surgical clipping procedures for aneurysms.[13] These thresholds have been questioned as either arbitrary or too low. We sought to determine if there was a clear inflection point in the volume-outcome relationship in a nationally representative data set to justify setting different minimum annual case volumes (ACV) for CSCs. We analyzed a representative sample of SAH discharges from the Healthcare Cost and Utilization Project (HCUP) Nationwide Inpatient Sample (NIS) database and examined the relationship of outcomes to ACV for SAH and for coiling and clipping procedures.

METHODS

The authors declare that all supporting data are available within the article and its online supplementary file.

Study Population

The NIS is a database of all-payer hospital inpatient stays, including data on patient demographics, diagnoses, procedures, discharge status, and hospital characteristics.[14] The NIS includes over 7 million records annually, representing more than 35 million hospitalizations.[15] The NIS contains only deidentified patient data. This study is a retrospective analysis of deidentified data and was therefore exempt from institutional review board approval (institutional review board exempt status). Starting in 2012, the NIS was redesigned as a sample of discharges rather than a sample of hospitals from which all discharges were retained. Given the relatively low incidence of SAH, we used data from 2010 and 2011 in 20% of all US community-based inpatient healthcare facilities for this analysis.

Patients were included in the analysis if they had a primary *International Classification of Diseases, Ninth Revision* (*ICD-9*) diagnosis code for nontraumatic SAH (430) and were treated at a hospital that performed at least one coiling or clipping procedure during the study period. To remove non-aneurysmal causes of SAH, additional exclusion criteria were added including a secondary diagnosis or procedure code for arteriovenous malformation; secondary diagnosis codes indicating traumatic SAH; elective admission not originating in the emergency department or as a transfer; discharge to home after a length of stay ≤1 day; or transfer to another acute care facility (to avoid crediting a hospital with a case it did not manage). A secondary cohort was defined as patients with SAH undergoing coiling using procedure codes 39.72, 39.75, and 39.76 or clipping using codes 39.51 and 39.52. ACVs were calculated for each hospital for SAH, coiling, clipping, and total coiling+clipping.

Outcomes were (1) in-hospital death and (2) poor outcome assessed by the NIS-SAH Outcome Measure

(NIS-SOM), a standardized measure using variables available in the NIS and validated for use in studies of patients with SAH in the NIS by demonstrating that it correlates well with the modified Rankin score.[16] Poor outcome is defined as any of: in-hospital mortality; discharge to a nursing facility, extended care facility or hospice; placement of a tracheostomy tube; or placement of a gastrostomy tube.

Statistical Analysis

For generating national estimates of numbers of patients and hospitals, NIS sampling weights were used. All other analyses used unweighted sample data.

For summarizing event rates, hospitals were divided into quintiles of ACVs. The association of each ACV with each outcome was assessed using multivariable logistic regression models. In these models, ACVs were considered as continuous variables and were assessed for linearity of their relationship with outcomes using restricted cubic splines[17]; where non-linearity was found, a piecewise linear spline was used to approximate the relationship. Models were adjusted for patient characteristics (age, sex, race, Charlson Comorbidity Index,[18] weekend versus weekday arrival) and hospital characteristics (geographic region, academic status, bed size). Missing rates were low among adjustment variables (<1% for patient characteristics, except race, missing in 15%; <3% among hospital characteristics); missing values for these variables were imputed using multiple imputation. Twenty-five imputation data sets were generated with the fully conditional specification method, which takes into account the joint distribution of all variables. Each complete data set was analyzed using standard statistical analyses, and the results from the 25 complete data sets were averaged to generate the final inferential results; this ensures that the final estimates properly reflect variability and uncertainty due to missing values.[19] Additional analyses included the NIS-SAH Severity Score (NIS-SSS)[16] as a covariate. The NIS-SSS combines variable available in the NIS to generate a measure of SAH severity. The NIS-SSS includes treatment with mechanical ventilation, presence of hydrocephalus, treatment of hydrocephalus, and presence of coma, stupor, cranial nerve palsies, paralysis, paraparesis, and aphasia. The NIS-SSS correlates well with the widely used Hunt-Hess score for grading the severity of SAH clinically. Analyses using the NIS-SSS were considered secondary analyses because the score includes diagnoses that may develop during hospitalization and may therefore reflect not only the initial severity of the SAH but also the subsequent quality of care at the hospital, and may therefore interfere with ascertainment of ACV-risk relationships. Odds ratios were generated from logistic regression models for each 10-case change in ACV. Figures illustrating the relationship of ACVs to outcomes were generated using restricted cubic splines.

To address concerns that specific types of patients or sites with high event risk had a large influence on results, sensitivity analyses were carried out in subgroups of (1) hospitals with SAH ≥20, (2) hospitals with SAH ≥35, and (3) patients who were not transferred from other acute care facilities.

Because several different criteria have been proposed to use as volume standards required for CSCs expected to provide high quality care for cerebrovascular patients including those with aneurysms and other criteria, we compared outcomes at hospitals that met several different ACV standards. Hospitals were grouped according to a set of 6 pre-specified alternative proposed minimum ACV standards that incorporate ACV for SAH discharges and specific procedures. These alternative thresholds reflect proposals considered by the JC Technical Advisory Panel (TAP) including those submitted by various professional societies (David Baker, MD, unpublished data, 2019). These additional groups were compared using the same logistic regression models as above, substituting each new criteria for the ACV measures one at a time.

The utility of different ACV cutoffs for distinguishing better-performing hospitals was assessed by calculating sensitivity and specificity of different ACV cutoffs for SAH and total clipping and total coiling procedures (performed on both ruptured and unruptured aneurysms) for different performance categories, defined by event rates. The Youden Index, defined as sensitivity+specificity–1, was calculated for each set of cutoffs; this index ranges from 0 (a useless test) to 1 (a perfect test) and can be interpreted as the probability of making an informed decision rather than a random guess.[20] Visual examination of scatter plots was also used to explore cutoffs.

Analyses were conducted using SAS version 9.4 or higher (SAS Institute, Cary NC).

RESULTS

NIS Hospital and Patient Characteristics

The NIS data set contained 8,512 patients discharged with nontraumatic SAH in 2010 and 2011 available for review. This random sample of patients represents an estimated 42,390 nontraumatic patients with SAH nationwide during these years. Of the nontraumatic patients with SAH in the NIS, 28.7% underwent clipping and 20.1% underwent coiling. During hospitalization, 21.2% died and 38.6% had a poor outcome as assessed by the NIS-SOM.

Among the hospitals that treated patients with SAH, mean (range) of SAH ACV, coiling ACV, and clipping

ACV were 30.9 (1–195), 8.7 (0–94), and 6.1 (0–69), respectively (Figure 1). (Please see Tables S1 through S4 and Figures S1 through S7 for characteristics of data set at patient and hospital levels).

Table 1 shows rates of outcomes among hospitals grouped into quintiles by SAH ACV, coiling ACV, and clipping ACV. Rates of mortality and poor NIS-SOM outcomes were higher among those in the lowest than those in the highest quintiles for SAH ACV, with 31.5% in-hospital mortality and 49.7% poor outcome rates in the lowest volume group (ACV ≤5) compared to 18.7% and 35.8% in the highest volume group (ACV 49–195), respectively.

In adjusted logistic regression models, both SAH ACV and coiling ACV showed significant nonlinear relationships with both outcomes. Increasing ACVs were associated with decreasing risk of poor outcomes up to a threshold of an ACV in the range of 50 to 70, depending on the ACV and outcome combination, with no further reductions in the risk of poor outcomes for hospitals with the highest ACV (Table 1, Figure 1). Piecewise linear splines were used to generate meaningful odds ratios for the lower part of each ACV range (Table 1), but the underlying relationship shows a more gradual change with no clear inflection point (Figure 1 and Figures S8, S9, S12, S13). Sensitivity analysis that included only hospitals with SAH ACV ≥20 showed a similar risk relationship (Table S19 and Figures S40, S41), confirming that the effect is not dependent on inclusion of hospitals with the lowest SAH ACV although the relationship becomes attenuated for higher volume hospitals, eventually leveling off. Clipping ACV has a linear relationship with mortality, with lower risk for higher volume sites, but not with NIS-SOM poor outcome (Table 1 and Figures S24, S25). Among sites with SAH ACV ≥35, the association of coiling and clipping ACVs with mortality remained significant, as was the relationship of coiling ACV with NIS-SOM poor outcome (Tables S27 through S29 and Figures S57 through S59, S61).

The results were similar when additional analyses were performed that (1) limited the cohort to those undergoing clipping or coiling (Tables S6, S7, and S9 and Figures S10, S11, S14, S15, S18, and S19) and excluded other patients with SAH, (2) when NIS-SSS was added as an adjustment variable (Table S5), and (3) when ACVs for unruptured cerebral aneurysms (UCA) were considered separately (Tables S10, S11, S15, S16 and Figures S20 through S23, S32 through S35).

Alternative Volume Standards

Several organizations and existing certification programs have suggested combinations of minimum volume thresholds different from those used by the JC CSC Program of annual aneurysmal SAH cases (n≥20) and aneurysm procedures (n≥15 coiling or clipping). We compared a new requirement proposed by a TAP advising the JC and 5 alternatives. We evaluated these and focused the analyses to explore the range of 20 to 35 SAH ACV (Table 2), which has more variability in outcomes than is found when SAH ACV is >35.

Hospitals within the NIS that meet the proposed TAP standards had better outcomes and lower in-hospital mortality for patients with SAH than those meeting only the current JC standards (Table 3 and Table S30), but the differences were not significant after adjustment for patient and hospital characteristics.

We considered two alternative sets of criteria that had the same SAH ACV requirement as the one proposed by the TAP but less restrictive procedure requirements (Table 2) and a simplified criterion with the same SAH ACV requirement but no procedure requirement. Reducing or eliminating the procedure requirements added 20 hospitals within the NIS sample; 18 of these met the procedure requirement for Alternative I and 19 of them for Alternative II (Table 2), so these alternatives all turned out to lead to nearly identical sets of facilities. Risk of NIS-SOM poor outcome was actually higher at hospitals meeting the TAP criteria than at those meeting only the alternative standards, but there was no difference for in-hospital mortality. Of note, the effects on NIS-SOM outcomes lose significance or nearly do so (P≥0.05) if the NIS-SSS was also used to adjust risk (Table S30) and may reflect more serious cases being treated at facilities that tend to do more procedures.

Finally, comparison of simplified criteria that compared hospitals with SAH ACV ≥35 to those with SAH ACV between 20 and 34 demonstrated significantly better outcomes and lower in-hospital mortality for the higher volume hospitals (Table 3).

ACV Cutoffs

The sensitivity and specificity was calculated individually for each ACV category (SAH discharges, coiling, and clipping) for its ability to identify hospitals with lower rates of poor outcomes, defined by a range of event rates (Table 4). While minimum ACV cut-offs with high specificity for identifying poorly performing sites exist within the range of values that have been proposed as CSC minimum volume criteria, these cut-offs are associated with low sensitivity for identifying sites with good performance and would exclude many sites with apparently good outcomes but low volumes. The Youden Index, which combines sensitivity and specificity and ranges from 0 (worst) to 1 (best), was no higher than 0.42 for any cutoff for NIS-SOM or 0.35 for mortality.

To investigate whether greater accuracy and sensitivity could be achieved with standards combining

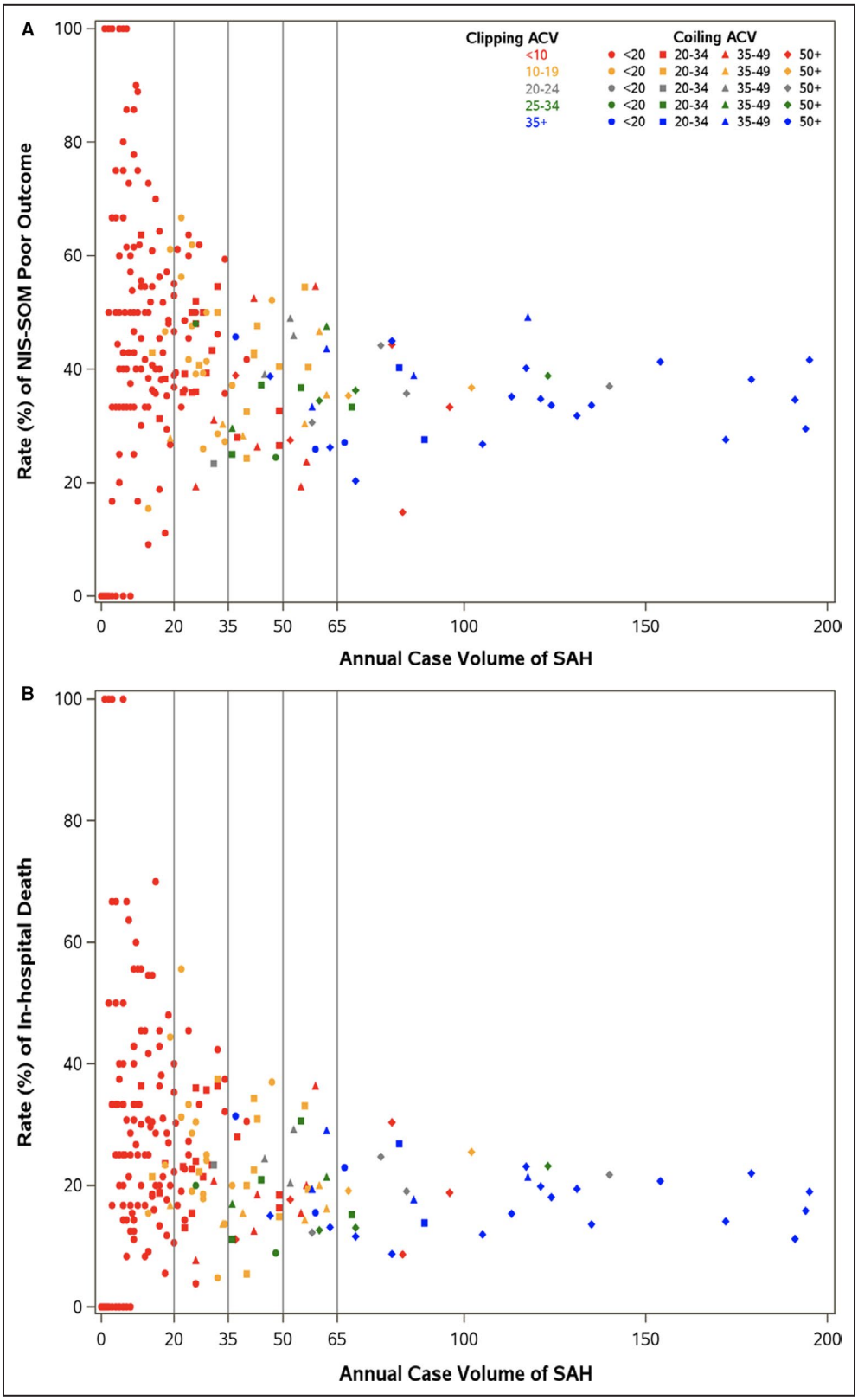

Figure 1. Outcomes and ACV of SAH admissions, ACV for clipping procedures, and ACV for coiling procedures.

A, National Inpatient Sample Subarachnoid Outcome Measure (NIS-SOM) poor outcomes. **B**, In-hospital mortality. A single dot may represent more than 1 hospital with the same ACV and event rate. ACV indicates annual case volume; SAH, subarachnoid hemorrhage.

Table 1. Outcomes of Patients With SAH and ACV for Hospitals by Quintiles of Hospital ACV. NIS-SOM (National Inpatient Sample-SAH Outcome Measure)

	Quintile of Hospital ACV	ACV (Min–Max)	No. of Patients	NIS-SOM Poor Outcome	In-Hospital Death
Outcomes and SAH ACV					
	1	0–5	143	49.7%	31.5%
	2	6–13	527	50.1%	29.6%
	3	13.5–24	995	44.4%	26.8%
	4	25–48	1783	39.0%	22.0%
	5	49–195	5064	35.8%	18.7%
Adjusted OR (95% CI)				0.95 (0.91–0.99)	0.93 (0.90–0.96)
Per 10 case increase up to value shown				*for ACV ≤50*	*for ACV ≤70*
				P=0.007	*P*<0.001
Outcomes and coiling ACV					
	1–2	0–0	970	49.0%	29.4%
	3	0.5–12	914	42.9%	25.8%
	4	13–35	2017	40.5%	23.2%
	5	35.5–188	4611	34.7%	17.8%
Adjusted OR (95% CI)				0.95 (0.93–0.97)	0.92 (0.89–0.94)
Per 10 case increase up to value shown				*for ACV ≤65*	*for ACV ≤65*
				P<0.001	*P*<0.001
Outcomes and clipping ACV					
	1	0–1	668	46.4%	27.4%
	2	1.5–2.5	399	38.8%	22.3%
	3	3–6	1163	41.7%	24.8%
	4	6.5–17	1729	40.7%	24.0%
	5	18–188	4553	35.9%	18.3%
Adjusted OR (95% CI)				1.00 (0.98–1.01)	0.96 (0.95–0.98)
Per 10 case increase				*P*=0.53	*P*<0.001

ACV, annual case volumes; NIS-SOM, National Inpatient Sample-SAH Outcome Measure; and SAH, subarachnoid hemorrhage.

SAH and procedural ACVs, we generated a series of scatterplots (Figures 1 and 2). Hospitals with 20 to 35 SAH cases per year but a total of more than 30 coiling cases and clipping cases performed as well as did those with more than 35 SAH cases per year on either NIS-SOM or in-hospital mortality as outcome measures (Figure 2). There is also a group of hospitals with >20 coiling procedures per year but fewer than 35 SAH per year that have results equivalent to hospitals with more than 35 SAH per year (Figure 1). The results of hospitals with >10 clipping and >20 coiling procedures are at most marginally better than those <10 clipping and >20 coiling procedures when the NIS-SOM is used as the outcome measure (Figure 1A). Very few hospitals in the 20 to 34 SAH ACV range had more than 20 clippings per year, but these did have outcomes similar to hospitals with more than 35 SAH (Figure 1). Hospitals in this SAH volume range with fewer than 20 clippings per year had widely scattered distribution of outcomes (Figure 1). A criterion of a combined coiling and clipping volume >15 per year also identifies hospitals with relatively good outcomes even when the SAH ACV is below 35, but a criterion of a combined volume >30 appears to do so more reliably (Figure 2). Finally, Figures 1 and 2 suggest that the effects of volume on outcome are attenuated at ACV for SAH at the high end of the ACV range for hospitals in our sample.

Finally, we looked at the effects of the rates of transferring patients out to another acute care facility prior to coiling or clipping. Higher volume hospitals tended to have lower transfer rates, but transfer rates did not influence outcomes when hospitals with similar ACV were compared (Figure 3).

DISCUSSION

The aim of our investigations is to provide insights into relationships between hospital ACV and outcomes to

Table 2. Number of Sites and Association With Outcomes Based on Alternative Proposed Thresholds for CSC Certification

	NIS Sites, N=261	National Estimates, N=1274	% NIS-SOM Poor Outcome	% In-Hospital Mortality
Current JC CSC standard (but not TAP) 20–34 SAH ACV ≥15 coiling or clipping ACV Not (≥10 clipping and ≥20 coiling)	29	142	43.8	24.5
TAP recommendations ≥35 SAH AC ≥10 clipping ACV ≥20 coiling ACV	53	258	36.7	18.6
Alternative I ≥35 SAH ACV ≥15 coiling or clipping per year Not (≥10 clipping and ≥20 coiling)	19	93	32.1	20.4
Alternative II ≥35 SAH ACV ≥30 coiling or clipping Not (≥10 clipping and ≥20 coiling)	18	88	31.9	20.5
SAH ACV 20–34	49	240	43.1	24.6
SAH ACV ≥35	73	356	35.9	19.0
SAH ACV ≥35 but not TAP	20	98	32.4	20.8

ACV indicates annual case volume; CSC, comprehensive stroke center; JC, Joint Commission; NIS, National Inpatient Sample; NIS-SOM, NIS-SAH Outcome Measure; SAH, subarachnoid hemorrhage; and TAP, Technical Advisory Panel.

provide an evidence-based framework for CSC designation to improve the care for patients with SAH. While our findings replicate the relationship between better outcomes and higher hospital SAH patient volume and higher procedure volume observed in prior studies, the current work has important practical implications.

Table 3. Statistical Comparison of Outcomes for All Patients With SAH at Sites Meeting Different CSC Certification Criteria Adjusted for Patient and Hospital Characteristics

	NIS-SOM Poor Outcome	In-Hospital Death
TAP vs current standard (but not TAP)	0.86 (0.71–1.05)	0.83 (0.67–1.04)
	0.13	0.11
TAP vs alternative I (but not TAP)	1.35 (1.15–1.59)	0.97 (0.81–1.16)
	0.001	0.75
TAP vs alternative II (but not TAP)	1.37 (1.17–1.61)	0.97 (0.81–1.17)
	0.001	0.78
TAP vs SAH ACV ≥35 (but not TAP)	1.35 (1.15–1.58)	0.97 (0.81–1.16)
	0.001	0.71
SAH ACV ≥35 vs SAH ACV 20–34	0.82 (0.71–0.94)	0.80 (0.68–0.93)
	0.017	0.006

For each outcome, odds ratio with 95% CI and *P* value are shown. ACV indicates annual case volume; CSC, comprehensive stroke center; NIS-SOM, National Inpatient Sample-Subarachnoid Outcome Measure; SAH, subarachnoid hemorrhage; and TAP, Joint Commission Technical Advisory Panel.

Previous data used by the Brain Attack Coalition to define CSC requirements showed a 17% decrease in mortality and a 20% decrease in adverse outcome at hospitals treating ≥21 SAH/year versus hospitals treating <21.[9] Another study found that 30-day mortality rates were significantly higher in hospitals with fewer than 10 SAH/year compared to those with more than 35.[10] Cowan et al found better outcomes in hospitals with more than about 30 SAH/year compared to those with fewer than 30.[21]

Since the original Brain Attack Coalition proposal for CSC designation,[8] a number of studies have evaluated the SAH volume-outcome relationship further.[16,22–29] These studies have shown that centers that meet current CSC volume requirements have better outcomes for surgical clipping than centers that have lower volumes for patients with SAH and for those with unruptured aneurysms.[28,29] This relationship is not dichotomous, and the benefit of increasing volume may extend well beyond the threshold of 20 SAH cases and a total of 15 clipping and coiling cases. Studies have found a 21% decrease in the odds of in-hospital mortality between high volume (12.9–94.5 SAH/year) and low volume (4–6.6 SAH/year) centers[26] and demonstrated

Table 4. Sensitivity, Specificity, and YI of ACV as Predictors of Outcome of SAH, as Measured by the NIS-SOM and by In-Hospital Mortality

Outcome Measure	NIS-SOM									In-Hospital Mortality								
% With Poor Outcome	<45%			<50%			<55%			<20%			<25%			<30%		
	Sens	Spec	YI	Sens	Spec	YI	Sens	Spec	YI	Sens	Spec	YI	Sens	Spec	YI	Sens	Spec	YI
SAH ACV cutoff																		
≥20	56.3	66.4	0.23	58.0	75.9	0.34	55.1	83.9	0.39	52.8	57.4	0.10	58.4	68.8	0.27	55.2	70.1	0.25
≥35	40.4	89.1	0.29	39.7	95.4	0.35	35.6	100	0.36	39.6	80.0	0.20	39.6	87.5	0.27	36.8	89.7	0.26
≥50	27.8	92.7	0.21	27.6	97.7	0.25	24.4	100	0.24	28.3	87.1	0.15	28.2	92.9	0.21	26.4	95.4	0.22
≥65	19.2	98.2	0.17	17.8	100	0.18	15.1	100	0.15	18.9	92.9	0.12	18.8	97.3	0.16	17.2	98.9	0.16
Coiling ACV cutoff																		
≥20	47.7	83.6	0.31	46.6	89.7	0.36	43.4	98.2	0.42	44.3	72.3	0.17	49.7	85.7	0.35	45.4	87.4	0.33
≥35	29.8	92.7	0.23	29.3	97.7	0.27	25.9	100	0.26	33.0	88.4	0.21	32.2	95.5	0.28	29.3	97.7	0.27
≥50	19.9	99.1	0.19	17.8	100	0.18	15.1	100	0.15	21.7	94.8	0.17	19.5	98.2	0.18	17.2	98.9	0.16
Clipping ACV cutoff																		
≥10	41.1	82.7	0.24	42.0	90.8	0.33	37.6	92.9	0.30	38.7	74.2	0.13	42.3	83.9	0.26	39.7	86.2	0.26
≥20	25.2	93.6	0.19	25.9	100	0.26	22.0	100	0.22	24.5	87.7	0.12	26.8	95.5	0.22	24.7	97.7	0.22
≥25	21.2	95.5	0.17	21.3	100	0.21	18.0	100	0.18	22.6	91.6	0.14	22.1	96.4	0.19	20.1	97.7	0.18
≥35	15.2	97.3	0.13	14.9	100	0.15	12.7	100	0.13	17.0	94.8	0.12	15.4	97.3	0.13	14.4	98.9	0.13

Sensitivity (or true positive rate) is the percent of sites with good outcomes in the group with ACV above the cutoff value in the first column. Specificity (or true negative rate) is the percent of sites with poor outcomes in the group with ACV below the cutoff value in the first column. The YI, calculated as *Sensitivity+Specificity–1*, ranges from 0 (a useless test) to 1 (a perfect test). It gives equal weight to sensitivity and specificity, and can be interpreted as the probability of making an informed decision rather than a random guess. ACV indicates annual case volume; NIS-SOM, National Inpatient Sample-SAH Outcome Measure; SAH, subarachnoid hemorrhage; Sens, sensitivity; Spec, specificity; and YI, Youden Index.

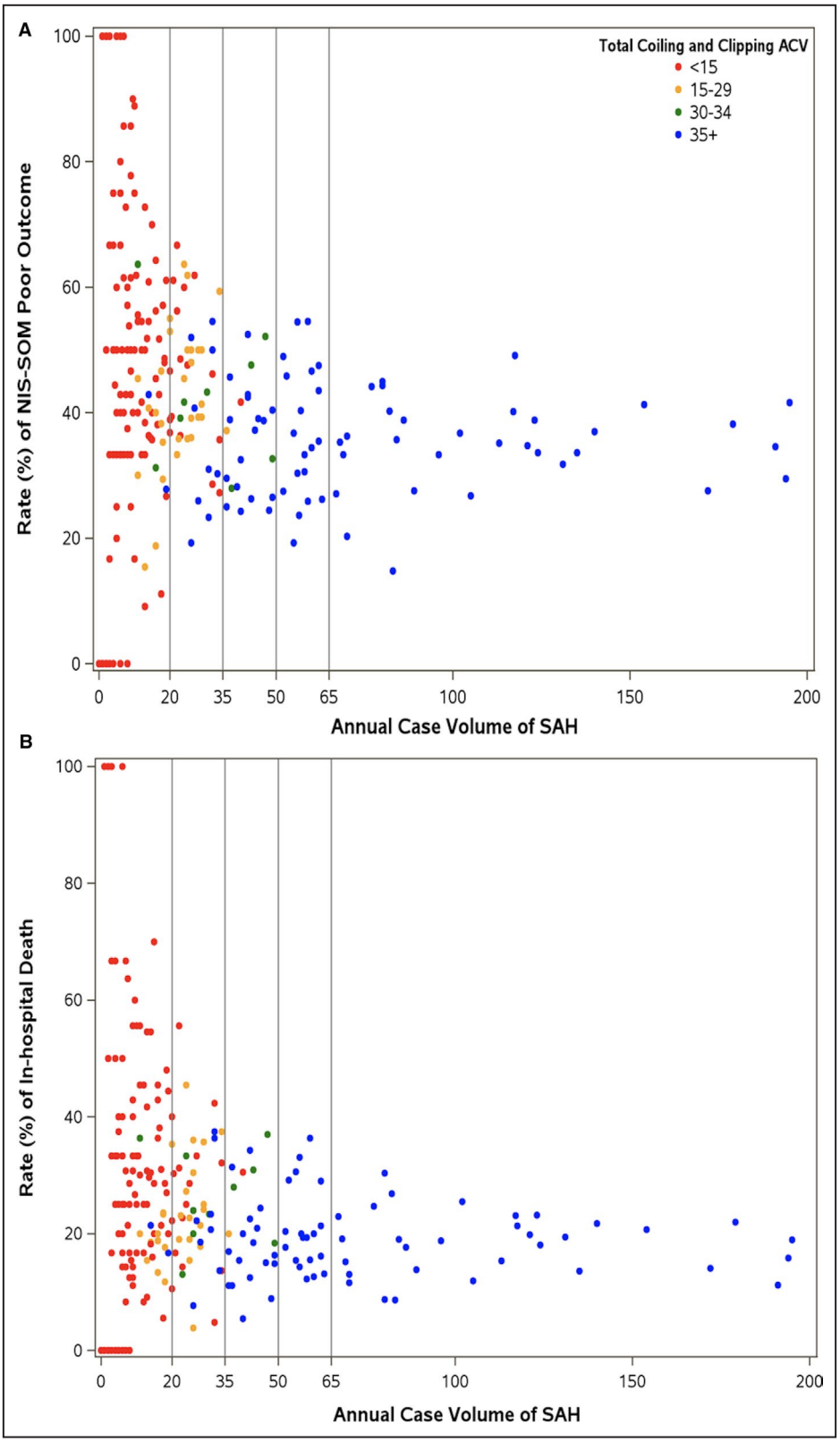

Figure 2. Outcomes and ACV of SAH admissions and total ACV for coiling and clipping procedures combined.
A, National Inpatient Sample Subarachnoid Outcome Measure (NIS-SOM) poor outcomes. **B**, In-hospital mortality. A single dot may represent more than 1 hospital with the same ACV and event rate. ACV indicates annual case volume; and SAH, subarachnoid hemorrhage.

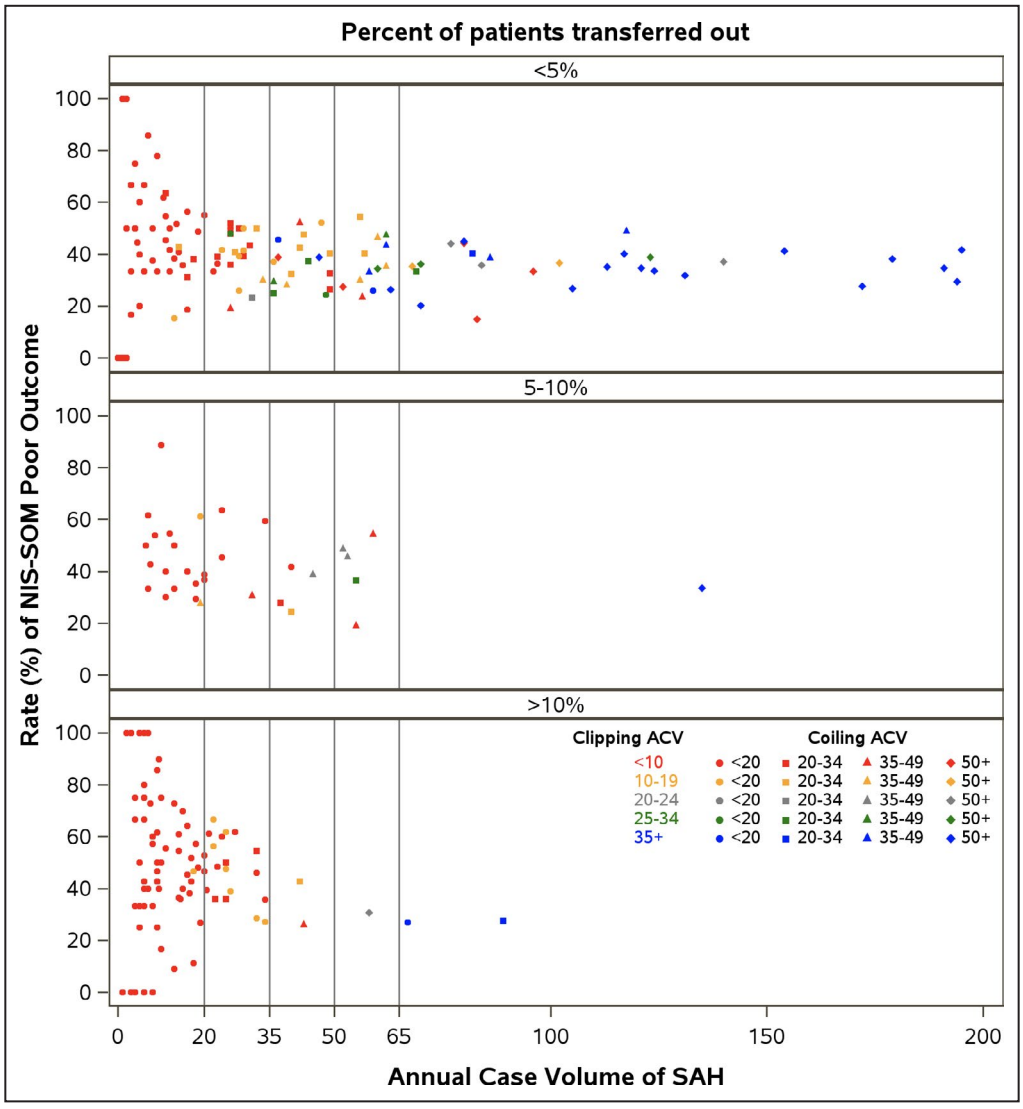

Figure 3. NIS-SOM poor outcomes, ACV for SAH, ACV for clipping procedures, and ACV for coiling procedures for hospitals with different rates of transferring patients with SAH to another acute hospital.

ACV indicates annual case volume; NIS-SOM, National Inpatient Sample Subarachnoid Outcome Measure; and SAH, subarachnoid hemorrhage.

a strong relationship between SAH volume and outcome with mortality increasing from 18.7% at hospitals treating 100 SAH/year to 28.4% at hospitals treating 20 SAH/year.[27] We confirmed and extended these results by demonstrating significant correlations between ACV of SAH and of coiling and clipping procedures with outcomes for patients with SAH treated at hospitals with a wide range of case volumes. Investigation of different volume cut-offs demonstrates that outcomes are better when more stringent cut-offs are used although some low volume centers that would be excluded by this approach appear to have outcomes equivalent to higher volume centers. Our results suggest that hospitals treating more than 35 patients with SAH per year have consistently better outcomes than those treating fewer cases, and that there is a very wide variation in outcomes in hospitals treating fewer than 20 patients per year. Many of these low volume sites have unacceptably high rates of poor outcomes. In the intermediate range of 20 to 35 ACV, features such as larger procedural volumes (more than 20 coiling procedures or more than 20 clipping procedures) appear consistently to identify hospitals with outcomes comparable to the higher volume centers. For hospitals with more than 35 SAH per year, adding procedural volume requirements actually identified hospitals with worse outcomes, but this effect was not significant after correction for hemorrhage severity and may reflect more serious cases being treated at facilities that tend to do more procedures.

Introducing volume thresholds for certification does pose a risk of creating perverse incentives, whereby hospitals may wish to keep patients who might benefit from transfer. In developing standards for CSCs, it may be desirable to allow hospitals that do not have an SAH ACV of 35 to be CSCs if they have an adequate number of coiling and/or clipping cases or meet outcome standards similar to those achieved by higher volume centers. Some of these low volume hospitals may have proceduralists and neuro-intensivists they share with larger volume centers in view of the similar outcomes reported at low and high volume hospitals affiliated with the same medical school.[12]

Another option for CSC standards would be to require hospitals to achieve a certain percentage of good outcomes as measured by the NIS-SOM or by in-hospital mortality regardless of annual case volumes. Using outcomes directly to set standards avoids the problem of excluding hospitals that have low volumes but good outcomes, but opens the process to concerns about proper risk adjustment, or improving outcomes by transferring out patients expected to do poorly to other acute centers or to nursing or hospice facilities to lower in-hospital mortality. These issues could be dealt with by including patients transferred out in the statistics of the transferring hospital (in addition to including them in the statistics of receiving acute care hospitals). There is much debate about the proper methods for risk adjustment, and the use of the NIS-SSS as a risk adjustment variable has not been validated. It may be challenging to identify and administer the most optimal thresholds for defining certification, and often criteria default to volumes as they are easily measured, have high rates of inter-rater reliability and are difficult to manipulate. It will be important to ensure that low volume hospitals in regions of the country with no alternative access have a method for recognition as an appropriate site for care if they have consistently good outcomes and meet all of the other requirements.

Limitations

Our study has several important limitations. The data are drawn from the NIS which is an administrative data set, and therefore the data available are inherently limited. There are no data assessing initial clinical severity directly, which likely contributes strongly to outcomes. In secondary analyses, we did attempt to correct for severity using the NIS-SSS which does correlate with the Hunt-Hess measure of clinical severity but incorporates variables related to subsequent treatment so it may itself be influenced by the quality of treatment. In any case, controlling for the NIS-SSS did not change the results of the primary models that we investigated although it did reduce the significance of related to some of the alternative volume standards that have been proposed.

The sampling methods in the NIS may also have impacted the findings. Another limitation is that we did not have data available about the volumes of individual surgeons, which is another factor that likely influences outcomes. In particular, one explanation for the finding of some low volume centers with good outcomes may be that they have a single proceduralist who does most or all of the procedures and therefore has a relatively high volume of procedures compared to other hospitals that may have more proceduralists who each do fewer cases. In addition, the diagnostic categories in the NIS did not distinguish between aneurysmal and nonaneurysmal SAH, which are clinically distinct with the former having a worse prognosis and the latter not needing coiling or clipping procedures. In addition, clipping and coiling rates were relatively lower than might be expected at 28.7% and 20.1%, respectively; this likely reflects inclusion in the population we identified of patients who had unrecognized trauma, sinus thrombosis, amyloid-related hemorrhages, and other nonaneurysmal causes of hemorrhage. In this regard, secondary analyses limited to patients who underwent coiling or clipping did not change the main results significantly. Lastly, while the relationship between volume and outcome in our study extends beyond 35 SAH cases per year, it is attenuated at higher volume levels. There are hospitals in other countries where aneurysm care is more centralized with higher case volumes; our results cannot address the association of outcomes with very high ACV since few US centers had more than 100 SAH cases/year and none had more than 200. In this regard, McNeill et al found a 24% decrease in mortality for patients with SAH with every 100 additional cases per year in a survey of British centers treating between 50 and 367 SAH per year.[24] This is an important point to consider in deciding about how centralized the care of aneurysmal patients with SAH should be. As noted above, our sample included few sites with more than 100 patients, so we cannot make definite conclusions about how outcomes may change at very high volumes, though the effects of increased volume that we observed appear to become weaker at the higher end of the volumes that were present in our sample.

In summary, our data suggest that increasing the minimum ACV for SAH to 35 is warranted as a requirement for CSC to maximize the percentage of CSCs likely to have low rates of poor outcomes. It is unclear the extent to which individual versus combined measures of procedural volume add discriminating information to distinguish high performing centers, but all CSCs should be able to safely and effectively perform surgical clipping when necessary despite the growing trend toward endovascular coiling as the preferred method for treatment.

ARTICLE INFORMATION

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Dr Leifer has served on the AHA Hospital Accreditation Science Committee (HASC) and is on the New York State Department of Health Stroke Physician Advisory Panel. Dr Fonarow receives research funding from the Patient Centered Outcome Research Institute, serves on the AHA HASC, and is employed by the University of California Regents which have a patent on endovascular devices. Drs Baker and Williams are employed by the JC, Mr Schoeberl by the AHA and Dr Suter formerly by the AHA. Dr Schwamm serves as chair of the AHA HASC and Quality Oversight Committees and as a member of the JC Technical Advisory Panel for CSCs. The remaining authors have no disclosures to report.

Supplementary Material

Tables S1–S30
Figures S1–S68

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SUPPLEMENTAL MATERIAL

Table S1. Description of patients in subarachnoid (SAH) analysis population.
Continuous variables are shown as mean (SD) and categorical variables as percent (n). (National Inpatient Sample (NIS)).

	All SAH admissions in NIS	Nationwide estimate*
N	8,512	42,390
Demographics		
Age	57.1 (16.1)	57.1 (35.8)
Female	62.4% (5,299)	62.4% (26,411)
Race		
White	61.4% (4,470)	61.3% (22,272)
Black	16.4% (1,193)	16.4% (5,953)
Hispanic	12.4% (903)	12.5% (4,556)
Asian or Pacific Islander	4.3% (316)	4.4% (1,598)
Native American	0.6% (46)	0.7% (246)
Other	4.8% (351)	4.8% (1,730)
Median household income for patient ZIP code, quartile**		
1st (<$40K)	29.3% (2,427)	29.3% (12,080)
2nd ($40-49K)	25.5% (2,115)	25.5% (10,531)
3rd ($50-65K)	24.4% (2,019)	24.4% (10,051)
4th (>$65K)	20.8% (1,725)	20.8% (8,592)
Admission		
Admission source		
ER	20.6% (1,740)	21.0% (8,839)
Another hospital	42.8% (3,615)	43.0% (18,106)
Another facility including long term care	4.3% (365)	4.4% (1,837)
Routine/other†	32.3% (2,730)	31.6% (13,301)
Elective admission†	3.7% (318)	3.7% (1,575)
Admission on weekend	28.1% (2,394)	28.1% (11,905)
Comorbidities‡		
Charlson Comorbidity Index	1.8 (1.3)	1.8 (2.8)
Alcohol abuse	5.8% (496)	5.8% (2,472)
Congestive heart failure	5.9% (499)	5.8% (2,472)
Chronic pulmonary disease	12.2% (1,039)	12.2% (5,151)
Coagulopathy	5.7% (487)	5.7% (2,433)
Deficiency anemias	16.3% (1,387)	16.3% (6,908)
Depression	7.6% (648)	7.5% (3,182)
Diabetes, uncomplicated	13.5% (1,152)	13.5% (5,725)
Diabetes, with chronic complications	1.6% (138)	1.6% (691)
Drug abuse	4.6% (392)	4.6% (1,956)
Hypertension	65.1% (5,539)	65.0% (27,548)
Liver disease	1.5% (124)	1.4% (611)
Other neurological disorders	5.7% (482)	5.7% (2,409)
Obesity	6.9% (590)	6.9% (2,926)

	All SAH admissions in NIS	Nationwide estimate*
N	8,512	42,390
Peripheral vascular disorders	6.1% (521)	6.1% (2,588)
Renal failure	5.3% (453)	5.3% (2,244)
Valvular disease	3.2% (276)	3.2% (1,374)
Hospital stay		
Treatment		
Coiling	28.7% (2,439)	28.8% (12,229)
Clipping	20.1% (1,711)	20.1% (8,502)
Coiling or clipping	47.6% (4,049)	47.7% (20,232)
Length of stay (days)	13.1 (13.0)	13.2 (29.1)
Disposition		
Routine (home/self-care or court/law enforcement)	40.4% (3,440)	40.5% (17,175)
Transfer to other facility (not acute care)		
In-patient rehab	14.7% (1,247)	14.7% (6,209)
SNF, ICF, LTCH, or hospice	12.8% (1,091)	12.8% (5,422)
Unspecified other facility	3.6% (307)	3.7% (1,550)
Home health care	6.8% (575)	6.8% (2,862)
Left against medical advice	0.4% (36)	0.4% (176)
Died in hospital	21.2% (1,808)	21.1% (8,956)
NIS-SSS	6.5 (11.9)	6.6 (26.8)
NIS-SOM	38.6% (3,286)	38.5% (16,313)

*Nationwide estimates are derived by applying NIS-supplied weights to data from discharges in NIS. Thus, these are the estimates among all hospital discharges in the AHA universe, i.e., among all discharges from U.S. community, non-rehabilitation hospitals. Since approximately 20% of hospitals are sampled, each discharge in the NIS represents about 5 discharges in the universe.

**Endpoints for income quartiles are approximate, as they were slightly different for the two years.

†Patients are not considered to have SAH if Admission type = elective and Admission source is not the ER or transfer from another health care institution. Therefore the analysis cohort still contains reported routine admissions if admission type=non-elective, and reported elective admissions if admission source is the ER or transfer.

‡AHRQ comorbidity measures.

Missing data

Variables in the table above are missing at the following rates in the SAH sample:

Variable	Missing rate	Notes
Race	14.5% (1233)	Some states do not supply this information to the NIS.

Income quartile	2.7% (226)
Admission source	0.7% (62)
Sex	0.2% (15)
Elective admission	0.1% (8)
Age	0.1% (5)

No other variables have missing values.

Table S2. Description of patients in SAH analysis population, by quintile of hospital ACV of total coiling and clipping.

Footnotes from Table 1 apply.

	SAH patients of hospital group 1	SAH patients of hospital group 2	SAH patients of hospital group 3	SAH patients of hospital group 4	SAH patients of hospital group 5
Coiling or clipping ACV at hospitals in group	0.5 to 1.5	2 to 4.5	5 to 18.5	19 to 50	51 to 376
Number of hospitals in group	52	44	60	51	54
Number of discharges in NIS	315	393	1,007	1,723	5,074
Number of discharges represented in nationwide estimate	1506	1905	4997	8664	25,317
Demographics					
Age	62.5 (19.4)	61.9 (17.2)	59.4 (16.4)	57.2 (16.0)	55.9 (15.5)
Female	55.6% (175)	60.2% (236)	62.8% (629)	61.7% (1,059)	63.1% (3,200)
Race					
White	62.2% (161)	57.5% (200)	61.6% (555)	61.7% (973)	61.6% (2,581)
Black	12.0% (31)	14.9% (52)	15.5% (140)	16.3% (257)	17.0% (713)
Hispanic	18.9% (49)	15.2% (53)	13.4% (121)	12.4% (196)	11.5% (484)
Asian or Pacific Islander	3.5% (9)	6.0% (21)	5.7% (51)	4.8% (76)	3.8% (159)
Native American	0	2.9% (10)	0.3% (3)	0.7% (11)	0.5% (22)
Other	3.5% (9)	3.4% (12)	3.4% (31)	4.1% (65)	5.6% (234)
Median household income for patient ZIP code, quartile					
1st (<$40K)	22.2% (68)	30.5% (117)	26.9% (266)	30.7% (511)	29.7% (1,465)
2nd ($40-49K)	27.8% (85)	27.4% (105)	23.7% (235)	25.5% (425)	25.6% (1,265)
3rd ($50-65K)	26.8% (82)	23.5% (90)	25.6% (253)	25.5% (425)	23.7% (1,169)
4th (>$65K)	23.2% (71)	18.5% (71)	23.8% (236)	18.4% (306)	21.1% (1,041)
Admission					
Admission source					
ER	28.0% (88)	39.2% (153)	30.2% (300)	29.4% (505)	13.8% (694)
Another hospital	15.0% (47)	10.5% (41)	21.9% (218)	28.3% (486)	56.1% (2,823)
Another facility including long term care	4.8% (15)	6.2% (24)	5.1% (51)	2.6% (45)	4.6% (230)
Routine/other	52.2% (164)	44.1% (172)	42.8% (425)	39.7% (683)	25.6% (1,286)

	SAH patients of hospital group 1	SAH patients of hospital group 2	SAH patients of hospital group 3	SAH patients of hospital group 4	SAH patients of hospital group 5
Elective admission	3.5% (11)	1.8% (7)	5.4% (54)	5.2% (90)	3.1% (156)
Admission on weekend	28.6% (90)	25.7% (101)	25.8% (260)	28.8% (497)	28.5% (1,446)
Comorbidities					
Charlson Comorbidity Index	2.1 (1.6)	1.9 (1.3)	1.8 (1.3)	1.7 (1.2)	1.8 (1.3)
Alcohol abuse	6.0% (19)	5.9% (23)	5.9% (59)	6.4% (111)	5.6% (284)
Congestive heart failure	7.3% (23)	7.4% (29)	5.3% (53)	6.0% (103)	5.7% (291)
Chronic pulmonary disease	13.0% (41)	15.8% (62)	12.6% (127)	9.6% (165)	12.7% (644)
Coagulopathy	6.3% (20)	5.6% (22)	6.5% (65)	5.7% (98)	5.6% (282)
Deficiency anemias	14.0% (44)	14.2% (56)	14.9% (150)	16.9% (292)	16.7% (845)
Depression	8.3% (26)	7.4% (29)	7.9% (80)	7.6% (131)	7.5% (382)
Diabetes, uncomplicated	14.3% (45)	16.5% (65)	15.1% (152)	13.9% (239)	12.8% (651)
Diabetes, with chronic complications	1.9% (6)	2.3% (9)	1.6% (16)	1.2% (21)	1.7% (86)
Drug abuse	1.3% (4)	3.8% (15)	4.5% (45)	4.0% (69)	5.1% (259)
Hypertension	62.9% (198)	71.2% (280)	68.6% (691)	63.5% (1,094)	64.6% (3,276)
Liver disease	2.5% (8)	1.0% (4)	1.9% (19)	1.2% (21)	1.4% (72)
Other neurological disorders	1.3% (4)	4.6% (18)	3.8% (38)	5.5% (95)	6.4% (327)
Obesity	8.6% (27)	6.6% (26)	7.4% (75)	6.7% (115)	6.8% (347)
Peripheral vascular disorders	5.1% (16)	4.6% (18)	7.1% (71)	4.5% (77)	6.7% (339)
Renal failure	10.5% (33)	8.1% (32)	6.0% (60)	4.8% (83)	4.8% (245)
Valvular disease	2.2% (7)	3.8% (15)	3.8% (38)	3.4% (58)	3.1% (158)
Hospital stay					
Treatment					
Coiling	0.6% (2)	3.1% (12)	12.9% (130)	33.1% (570)	34.0% (1,725)
Clipping	9.5% (30)	17.6% (69)	20.8% (209)	15.7% (271)	22.3% (1,132)
Coiling or clipping	10.2% (32)	20.6% (81)	33.2% (334)	47.5% (819)	54.8% (2,783)
Length of stay (days)	7.1 (7.1)	9.0 (10.8)	10.9 (12.3)	13.4 (15.6)	14.2 (12.4)
Disposition					
Routine (home/self-care or court/law enforcement)	32.7% (103)	27.2% (107)	36.7% (370)	38.1% (656)	43.4% (2,204)
Transfer to other facility (not acute care)					

	SAH patients of hospital group 1	SAH patients of hospital group 2	SAH patients of hospital group 3	SAH patients of hospital group 4	SAH patients of hospital group 5
In-patient rehab	7.8% (117)	9.2% (174)	11.1% (552)	15.6% (1,349)	15.9% (4,017)
SNF, ICF, LTCH, or hospice	14.7% (221)	16.4% (311)	14.9% (742)	11.8% (1,019)	12.4% (3,129)
Unspecified other facility	6.6% (99)	6.1% (115)	6.2% (309)	4.1% (355)	2.7% (672)
Home health care	7.0% (22)	6.6% (26)	5.2% (52)	6.2% (106)	7.3% (369)
Left against medical advice	0	0.5% (2)	0.7% (7)	0.6% (10)	0.3% (17)
Died in hospital	31.1% (98)	34.1% (134)	25.4% (256)	23.4% (404)	18.1% (916)
NIS-SSS	5.9 (11.3)	7.2 (11.9)	6.8 (12.4)	6.4 (11.2)	6.5 (12.1)
NIS-SOM	50.2% (158)	53.4% (210)	44.2% (445)	40.0% (690)	35.1% (1,783)

Table S3. Hospital characteristics and annual case volumes, among hospitals that performed at least one coiling or clipping. For hospital characteristics, mean (SD) or percent (n) are shown. For annual case volumes, statistics include mean (SD), {minimum, maximum}, and median [25th, 75th percentiles].

	All hospitals in NIS	National estimate*
N	261	1274
Hospital Characteristics		
Geographic region		
Northeast	11.1% (29)	11.0% (140)
Midwest	23.8% (62)	23.7% (302)
South	42.1% (110)	42.4% (540)
West	23.0% (60)	22.9% (292)
Bed size**		
Small	7.5% (19)	7.4% (92)
Medium	22.0% (56)	22.1% (274)
Large	70.5% (179)	70.5% (874)
Ownership of hospital		
Government, nonfederal	12.6% (32)	12.6% (156)
Private, non-profit	74.4% (189)	74.4% (923)
Private, investor-owned	13.0% (33)	13.0% (161)
Rural (vs. urban) location	3.1% (8)	3.2% (39)
Teaching hospital	64.2% (163)	64.1% (794)
Total annual discharges, mean (SD)	24,172 (14,219)	24,167 (31,333)
Incidence of diagnoses and procedures		
At least one SAH case	98.9% (258)	98.9% (1259)
At least one UCA case	99.2% (259)	99.2% (1264)
At least one SAH or UCA case	100% (261)	100% (1274)
At least one coiling procedure (SAH/UCA)	60.5% (158)	60.5% (771)
At least one clipping procedure (SAH/UCA)	90.4% (236)	90.4% (1152)
At least one coiling or clipping procedure (SAH/UCA)	100% (261)	100% (1274)
Annual case volumes, mean (SD) {min,max}, median [Q1, Q3]		

	All hospitals in NIS	National estimate*
N	261	1274
Diagnoses		
SAH or UCA	76.5 (90.9) {2, 590}	76.3 (200.4) {2, 590}
	44 [20, 97]	44 [20, 97]
SAH	30.9 (36.8) {0, 195}	30.8 (81.1) {0, 195}
	18 [7, 40]	18 [7, 40]
UCA	45.6 (58.0) {0, 399}	45.5 (127.9) {0, 399}
	26 [11, 54]	26 [11, 54]
Procedures		
Total coiling or clipping		
with SAH or UCA diagnosis	34.8 (55.5) {1, 376}	34.7 (122.6) {1, 376}
	11 [2, 43]	11 [2, 43]
with SAH diagnosis	14.8 (22.6) {0, 130}	14.8 (49.9) {0, 130}
	5 [1, 20]	5 [1, 20]
with UCA diagnosis	20.0 (34.9) {0, 261}	19.9 (77.1) {0, 261}
	5 [1, 24]	5 [1, 24]
Coiling		
with SAH or UCA diagnosis	21.4 (35.3) {0, 188}	21.4 (78.0) {0, 188}
	4 [0, 29]	4 [0, 29]
with SAH diagnosis	8.7 (14.7) {0, 94}	8.7 (32.4) {0, 94}
	2 [0, 12]	2 [0, 12]
with UCA diagnosis	12.7 (22.3) {0, 133}	12.7 (49.1) {0, 133}
	2 [0, 17]	2 [0, 17]
Clipping		
with SAH or UCA diagnosis	13.4 (25.4) {0, 188}	13.4 (56.0) {0, 188}
	4 [1, 12]	4 [1, 12]
with SAH diagnosis	6.1 (11.0) {0, 69}	6.1 (24.2) {0, 69}
	2 [1, 6]	2 [1, 6]
with UCA diagnosis	7.3 (15.8) {0, 128}	7.3 (34.8) {0, 128}
	2 [0, 6]	2 [0, 6]

[*]Nationwide estimates are derived by applying NIS-supplied weights to data from all hospitals in NIS. Thus, these are the estimates among all hospitals in the AHA universe, i.e., among all U.S. community, non-rehabilitation hospitals. Since approximately 20% of hospitals are sampled, each hospital in the NIS represents about 5 hospitals in the universe.

[**]The definition of small, medium, and large hospital varies with geographic region, rural vs. urban location, and teaching status. For example, for a rural non-teaching hospital in the Western region, Small = 1-24 beds, Medium = 25-44 beds, and Large = 45+; while for an urban teaching hospital in the Southern region, Small = 1-249 beds, Medium = 250-449 beds, and Large = 450+. The actual number of beds is not available.

Missing data

Variables in the table above are missing at the following rates among all hospitals used in this analysis:

Variable	Missing rate
Bed size	2.7% (7)
Ownership	2.7% (7)
Rural vs. urban	2.7% (7)
Teaching status	2.7% (7)

No other variables have missing values.

Table S4. Hospital characteristics and annual case volumes, by quintiles of hospital ACV of total coiling and clipping.
Footnotes from Table III apply.

	Hospital group 1	Hospital group 2	Hospital group 3	Hospital group 4	Hospital group 5
Coiling or clipping ACV at hospitals in group	0.5 to 1.5	2 to 4.5	5 to 18.5	19 to 50	51 to 376
Number of hospitals in NIS	52	44	60	51	54
Number of hospitals represented in nationwide estimate	255	214	293	250	262
Hospital Characteristics					
Geographic region					
Northeast	7.7% (4)	11.4% (5)	5.0% (3)	9.8% (5)	22.2% (12)
Midwest	17.3% (9)	20.5% (9)	33.3% (20)	29.4% (15)	16.7% (9)
South	53.8% (28)	45.5% (20)	36.7% (22)	37.3% (19)	38.9% (21)
West	21.2% (11)	22.7% (10)	25.0% (15)	23.5% (12)	22.2% (12)
Bed size					
Small	19.2% (10)	4.7% (2)	6.9% (4)	2.1% (1)	3.8% (2)
Medium	21.2% (11)	30.2% (13)	29.3% (17)	18.8% (9)	11.3% (6)
Large	59.6% (31)	65.1% (28)	63.8% (37)	79.2% (38)	84.9% (45)
Ownership of hospital					
Government, nonfederal	11.5% (6)	7.0% (3)	10.3% (6)	12.5% (6)	20.8% (11)
Private, non-profit	65.4% (34)	76.7% (33)	74.1% (43)	81.3% (39)	75.5% (40)
Private, investor-owned	23.1% (12)	16.3% (7)	15.5% (9)	6.3% (3)	3.8% (2)
Rural (vs. urban) location	7.7% (4)	2.3% (1)	1.7% (1)	2.1% (1)	1.9% (1)
Teaching hospital	40.4% (21)	37.2% (16)	69.0% (40)	72.9% (35)	96.2% (51)
Total annual discharges, mean (SD)	16,958 (9,248)	17,512 (9,472)	20,811 (7,430)	25,884 (8,672)	38,661 (19,673)
Incidence of diagnoses and procedures					
At least one SAH case	94.2% (49)	100% (44)	100% (60)	100% (51)	100% (54)
At least one UCA case	100% (52)	95.5% (42)	100% (60)	100% (51)	100% (54)
At least one SAH or UCA case	100% (52)	100% (44)	100% (60)	100% (51)	100% (54)
At least one coiling procedure (SAH/UCA)	15.4% (8)	25.0% (11)	58.3% (35)	98.0% (50)	100% (54)
At least one clipping procedure (SAH/UCA)	86.5% (45)	86.4% (38)	90.0% (54)	92.2% (47)	96.3% (52)
At least one coiling or clipping procedure (SAH/UCA)	100% (52)	100% (44)	100% (60)	100% (51)	100% (54)

Annual case volumes, mean (SD), median [Q1, Q3]

	Hospital group 1	Hospital group 2	Hospital group 3	Hospital group 4	Hospital group 5
Coiling or clipping ACV at hospitals in group	0.5 to 1.5	2 to 4.5	5 to 18.5	19 to 50	51 to 376
Number of hospitals in NIS	52	44	60	51	54
Diagnoses					
SAH or UCA	16.7 (13.0)	21.6 (11.5)	40.9 (16.2)	78.0 (21.9)	216.8 (109.5)
	12 [8, 25]	19 [14, 26]	38 [31, 52]	76 [59, 98]	178 [135, 279]
SAH	5.7 (5.2)	9.5 (6.3)	17.0 (7.7)	32.0 (13.5)	86.9 (43.7)
	4 [2, 7]	8 [5, 12]	16 [12, 21]	29 [25, 42]	70 [56, 117]
UCA	11.0 (10.6)	12.1 (8.4)	23.9 (12.7)	45.9 (18.4)	129.8 (77.3)
	7 [4, 15]	11 [6, 17]	22 [14, 32]	42 [33, 56]	111 [75, 160]
Procedures					
Total coiling or clipping					
with SAH or UCA diagnosis	1.0 (0.2)	2.9 (0.9)	10.7 (4.7)	34.6 (9.1)	120.3 (70.4)
	1 [1, 1]	3 [2, 4]	11 [6, 15]	33 [28, 42]	95 [60, 162]
with SAH diagnosis	0.5 (0.5)	1.8 (1.1)	5.4 (3.1)	15.3 (7.0)	49.2 (28.4)
	1 [0, 1]	2 [1, 3]	5 [3, 7]	15 [10, 20]	39 [29, 68]
with UCA diagnosis	0.5 (0.5)	1.1 (1.1)	5.3 (3.3)	19.3 (7.7)	71.2 (48.2)
	0 [0, 1]	1 [0, 2]	5 [3, 6]	19 [13, 25]	59 [33, 87]
Coiling					
with SAH or UCA diagnosis	0.1 (0.3)	0.6 (1.1)	4.7 (5.2)	23.8 (9.4)	75.0 (44.1)
	0 [0, 0]	0 [0, 1]	4 [0, 9]	25 [18, 30]	64 [42, 97]
with SAH diagnosis	0.0 (0.1)	0.3 (0.6)	2.2 (2.7)	10.1 (5.5)	29.9 (19.4)
	0 [0, 0]	0 [0, 0]	1 [0, 4]	10 [6, 13]	24 [15, 41]
with UCA diagnosis	0.1 (0.3)	0.3 (0.8)	2.6 (3.2)	13.7 (7.7)	45.2 (29.8)
	0 [0, 0]	0 [0, 0]	1 [0, 4]	13 [8, 20]	33 [23, 58]
Clipping					
with SAH or UCA diagnosis	0.8 (0.4)	2.3 (1.3)	5.9 (4.2)	10.8 (9.1)	45.3 (41.3)
	1 [1, 1]	2 [2, 3]	6 [3, 8]	9 [5, 15]	29 [18, 67]
with SAH diagnosis	0.5 (0.5)	1.5 (1.2)	3.2 (2.9)	5.3 (5.2)	19.3 (18.0)
	0 [0, 1]	1 [0, 2]	3 [1, 5]	4 [2, 7]	12 [7, 29]
with UCA diagnosis	0.4 (0.5)	0.9 (1.0)	2.7 (2.5)	5.5 (5.4)	26.0 (26.9)
	0 [0, 1]	1 [0, 1]	2 [1, 4]	4 [2, 7]	18 [8, 33]

Table S5. Adjusted outcomes with NIH-SSS added to models for primary cohort.

			NIS-SOM Poor Outcome	In-hospital death
Model results	Hospital ACV for SAH	OR (95% CI)	0.94 (0.90, 0.99)	0.91 (0.88, 0.94)
			for each 10 case increase up to 50	for each 10 case increase up to 70
		P	0.016	<0.001
	Hospital ACV for clipping	OR (95% CI)	0.93 (0.91, 0.96)	0.89 (0.87, 0.92)
			for each 10 case increase up to 65	for each 10 case increase up to 65
		P	<0.001	<0.001
	Hospital ACV for coiling	OR (95% CI)	0.85 (0.79, 0.91)	0.78 (0.72, 0.84)
			for each 10 case increase up to 25	for each 10 case increase up to 25
		P	<0.001	<0.001

Table S6. Outcomes by SAH ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 5	34	58.8% (20)	32.4% (11)
	2	6 - 13	137	38.7% (53)	17.5% (24)
	3	13.5 - 24	308	34.4% (106)	15.3% (47)
	4	25 - 48	859	33.5% (288)	12.1% (104)
	5	49 - 195	2,711	31.9% (866)	11.1% (301)
Model results	Unadjusted	OR (95% CI)		0.92 (0.88, 0.97)	0.92 (0.88, 0.96)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		0.0032	<0.001
	Adjusted	OR (95% CI)		0.93 (0.87, 1.00)	0.93 (0.87, 0.99)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		0.041	0.015
	Adjusted + NIS-SSS	OR (95% CI)		0.99 (0.92, 1.07)	0.96 (0.90, 1.02)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		0.85	0.18

Table S7. Outcomes by coiling ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile*	ACV (min-max)	N		
	1	0 - 0	224	43.8% (98)	19.6% (44)
	2	0.5 - 12	297	29.6% (88)	12.1% (36)
	3	13 - 35	997	35.1% (350)	13.8% (138)
	4	35.5 - 188	2,531	31.5% (797)	10.6% (269)
Model results	Unadjusted	OR (95% CI)		0.96 (0.93, 0.99) for each 10 case increase up to 65	0.92 (0.88, 0.96) for each 10 case increase up to 65
		P		0.0084	<0.001
	Adjusted	OR (95% CI)		0.95 (0.91, 0.98) for each 10 case increase up to 65	0.92 (0.87, 0.96) for each 10 case increase up to 65
		P		0.0049	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.96 (0.92, 1.00) for each 10 case increase up to 65	0.93 (0.88, 0.98) for each 10 case increase up to 65
		P		0.064	0.0062

*The first two quintiles of the distribution are both 0-0. To avoid arbitrarily placing sites with the same ACV into different groups, these quintiles are combined. Thus only 4 “quintiles” are shown, and the first “quintile” represents 40% of sites.

Table S8. Outcomes by SAH coiling ACV — Primary analysis cohort (all SAH admissions).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile*	ACV (min-max)	N		
	1	0 - 0	1,086	48.7% (529)	29.3% (318)
	2	0.5 - 5	715	42.0% (300)	24.3% (174)
	3	5.5 - 14	2,109	40.4% (851)	22.4% (472)
	4	15 - 94	4,602	34.9% (1606)	18.3% (844)
Model results	Unadjusted	OR (95% CI)		0.82 (0.79, 0.86)	0.79 (0.75, 0.83)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		0.89 (0.84, 0.94)	0.83 (0.78, 0.88)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		<0.001	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.85 (0.79, 0.91)	0.78 (0.72, 0.84)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		<0.001	<0.001

*The first two quintiles of the distribution are both 0-0. To avoid arbitrarily placing sites with the same ACV into different groups, these quintiles are combined. Thus only 4 “quintiles” are shown, and the first “quintile” represents 40% of sites.

Table S9. Outcomes by SAH coiling ACV — <u>Secondary</u> analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile*	ACV (min-max)	N		
	1	0 - 0	245	42.9% (105)	19.2% (47)
	2	0.5 - 5	248	31.9% (79)	14.1% (35)
	3	5.5 - 14	1,012	35.0% (354)	12.4% (125)
	4	15 - 94	2,544	31.3% (795)	11.0% (280)
Model results	Unadjusted	OR (95% CI)		0.90 (0.83, 0.97)	0.82 (0.73, 0.91)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.005	<0.001
	Adjusted	OR (95% CI)		0.85 (0.78, 0.94)	0.81 (0.71, 0.93)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.0013	0.0021
	Adjusted + NIS-SSS	OR (95% CI)		0.89 (0.80, 1.00)	0.85 (0.74, 0.98)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.043	0.023

*The first two quintiles of the distribution are both 0-0. To avoid arbitrarily placing sites with the same ACV into different groups, these quintiles are combined. Thus only 4 “quintiles” are shown, and the first “quintile” represents 40% of sites.

Table S10. Outcomes by UCA coiling ACV — Primary analysis cohort (all SAH admissions).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile*	ACV (min-max)	N		
	1	0 - 0	1,046	48.9% (512)	29.4% (308)
	2	1 - 6	797	44.3% (353)	25.8% (206)
	3	7 - 20	2,046	38.1% (780)	22.7% (464)
	4	21 - 133	4,623	35.5% (1641)	18.0% (830)
Model results	Unadjusted	OR (95% CI)		0.87 (0.84, 0.90)	0.83 (0.80, 0.86)
				for each 10 case increase up to 35	for each 10 case increase up to 35
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		0.92 (0.88, 0.96)	0.86 (0.83, 0.90)
				for each 10 case increase up to 35	for each 10 case increase up to 35
		P		<0.001	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.89 (0.85, 0.94)	0.82 (0.78, 0.87)
				for each 10 case increase up to 35	for each 10 case increase up to 35
		P		<0.001	<0.001

*The first two quintiles of the distribution are both 0-0. To avoid arbitrarily placing sites with the same ACV into different groups, these quintiles are combined. Thus only 4 “quintiles” are shown, and the first “quintile” represents 40% of sites.

Table S11. Outcomes by UCA coiling ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile*	ACV (min-max)	N		
	1	0 - 0	243	44.4% (108)	21.0% (51)
	2	1 - 6	264	30.7% (81)	10.6% (28)
	3	7 - 20	988	31.6% (312)	13.3% (131)
	4	21 - 133	2,554	32.6% (832)	10.8% (277)
Model results	Unadjusted	OR (95% CI)		0.94 (0.90, 1.00) for each 10 case increase up to 35	0.86 (0.80, 0.93) for each 10 case increase up to 35
		P		0.032	<0.001
	Adjusted	OR (95% CI)		0.94 (0.88, 1.00) for each 10 case increase up to 35	0.88 (0.80, 0.96) for each 10 case increase up to 35
		P		0.063	0.0046
	Adjusted + NIS-SSS	OR (95% CI)		0.96 (0.89, 1.04) for each 10 case increase up to 35	0.89 (0.81, 0.98) for each 10 case increase up to 35
		P		0.31	0.018

*The first two quintiles of the distribution are both 0-0. To avoid arbitrarily placing sites with the same ACV into different groups, these quintiles are combined. Thus only 4 “quintiles” are shown, and the first “quintile” represents 40% of sites.

Table S12. Outcomes by clipping ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 1	202	37.6% (76)	14.9% (30)
	2	1.5 - 2.5	108	28.7% (31)	13.9% (15)
	3	3 - 6	471	33.1% (156)	14.4% (68)
	4	6.5 - 17	768	33.3% (256)	12.9% (99)
	5	18 - 188	2,500	32.6% (814)	11.0% (275)
Model results	Unadjusted	OR (95% CI)		0.99 (0.98, 1.01) for each 10 case increase	0.95 (0.93, 0.98) for each 10 case increase
		P		0.26	<0.001
	Adjusted	OR (95% CI)		1.00 (0.98, 1.02) for each 10 case increase	0.96 (0.93, 0.98) for each 10 case increase
		P		0.86	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		1.02 (1.00, 1.04) for each 10 case increase	0.96 (0.94, 0.99) for each 10 case increase
		P		0.12	0.0059

Table S13. Outcomes by SAH clipping ACV — Primary analysis cohort (all SAH admissions).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 0	498	45.2% (225)	25.5% (127)
	2	0.5 - 1	714	40.6% (290)	24.5% (175)
	3	1.5 - 3	1,081	43.3% (468)	26.6% (288)
	4	3.5 - 7	1,834	38.4% (705)	21.0% (386)
	5	8 - 69	4,385	36.4% (1598)	19.0% (832)
Model results	Unadjusted	OR (95% CI)		0.95 (0.93, 0.98) for each 10 case increase	0.91 (0.89, 0.94) for each 10 case increase
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		1.01 (0.98, 1.03) for each 10 case increase	0.94 (0.91, 0.97) for each 10 case increase
		P		0.69	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		1.02 (0.98, 1.05) for each 10 case increase	0.92 (0.89, 0.96) for each 10 case increase
		P		0.32	<0.001

Table S14. Outcomes by SAH Clipping ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 0	166	32.5% (54)	11.4% (19)
	2	0.5 - 1	209	32.1% (67)	13.4% (28)
	3	1.5 - 3	405	35.3% (143)	16.5% (67)
	4	3.5 - 7	875	33.5% (293)	12.0% (105)
	5	8 - 69	2,394	32.4% (776)	11.2% (268)
Model results	Unadjusted	OR (95% CI)		0.98 (0.95, 1.01) for each 10 case increase	0.91 (0.86, 0.95) for each 10 case increase
		P		0.19	<0.001
	Adjusted	OR (95% CI)		1.01 (0.97, 1.05) for each 10 case increase	0.92 (0.87, 0.98) for each 10 case increase
		P		0.66	0.0064
	Adjusted + NIS-SSS	OR (95% CI)		1.05 (1.00, 1.10) for each 10 case increase	0.94 (0.88, 1.00) for each 10 case increase
		P		0.035	0.044

Table S15. Outcomes by UCA clipping ACV — <u>Primary</u> analysis cohort (all SAH admissions).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 0	911	44.6% (406)	24.6% (224)
	2	0.5 - 1	649	39.8% (258)	27.3% (177)
	3	2 - 3	778	44.3% (345)	26.0% (202)
	4	3.5 - 8	1,624	40.1% (652)	22.7% (369)
	5	9 - 128	4,550	35.7% (1625)	18.4% (836)
Model results	Unadjusted	OR (95% CI)		0.96 (0.94, 0.98) for each 10 case increase	0.92 (0.90, 0.94) for each 10 case increase
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		0.99 (0.97, 1.01) for each 10 case increase	0.94 (0.91, 0.96) for each 10 case increase
		P		0.20	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.99 (0.97, 1.02) for each 10 case increase	0.92 (0.90, 0.95) for each 10 case increase
		P		0.48	<0.001

Table S16. Outcomes by UCA Clipping ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 0	320	36.6% (117)	14.1% (45)
	2	0.5 - 1	240	30.8% (74)	16.7% (40)
	3	2 - 3	282	38.3% (108)	16.0% (45)
	4	3.5 - 8	712	32.3% (230)	11.5% (82)
	5	9 - 128	2,495	32.2% (804)	11.0% (275)
Model results	Unadjusted	OR (95% CI)		0.99 (0.97, 1.01) for each 10 case increase	0.93 (0.90, 0.97) for each 10 case increase
		P		0.36	<0.001
	Adjusted	OR (95% CI)		1.00 (0.97, 1.03) for each 10 case increase	0.93 (0.89, 0.97) for each 10 case increase
		P		0.98	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		1.02 (0.99, 1.05) for each 10 case increase	0.94 (0.90, 0.98) for each 10 case increase
		P		0.30	0.0028

Table S17. Outcomes by SAH ACV — Primary analysis cohort (all SAH admissions), excluding patients who transfer in from another acute care facility. There are 4897 patients in this subgroup (of 8512 in the full cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 5	125	49.6% (62)	30.4% (38)
	2	6 - 13	444	50.5% (224)	29.5% (131)
	3	14 - 24	794	45.0% (357)	28.1% (223)
	4	25 - 48	1,196	40.1% (479)	23.6% (282)
	5	49 - 195	2,338	37.0% (864)	20.6% (481)
Model results	Unadjusted	OR (95% CI)		0.97 (0.95, 0.98) for each 10 case increase	0.96 (0.95, 0.98) for each 10 case increase
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		0.98 (0.97, 1.00) for each 10 case increase	0.97 (0.96, 0.99) for each 10 case increase
		P		0.032	0.0047
	Adjusted + NIS-SSS	OR (95% CI)		0.98 (0.96, 1.00) for each 10 case increase	0.97 (0.95, 0.99) for each 10 case increase
		P		0.050	0.0017

Notes

- In this subset, unlike in the full analysis cohort, SAH ACV has a straight-line relationship with each outcome. There is no apparent change in the risk relationship (such as leveling off) at any point.

Table S18. Outcomes by SAH ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping), excluding patients who transfer in from another acute care facility. There are 2031 patients in this subgroup (of 4049 in the secondary cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	0 - 5	28	60.7% (17)	32.1% (9)
	2	6 - 13	114	41.2% (47)	19.3% (22)
	3	14 - 24	236	33.1% (78)	16.1% (38)
	4	25 - 48	538	32.9% (177)	13.0% (70)
	5	49 - 195	1,115	33.3% (371)	13.5% (150)
Model results	Unadjusted	OR (95% CI)		0.98 (0.96, 1.00) for each 10 case increase	0.97 (0.95, 1.00) for each 10 case increase
		P		0.12	0.068
	Adjusted	OR (95% CI)		0.99 (0.97, 1.02) for each 10 case increase	0.99 (0.96, 1.03) for each 10 case increase
		P		0.66	0.70
	Adjusted + NIS-SSS	OR (95% CI)		1.01 (0.98, 1.04) for each 10 case increase	1.00 (0.97, 1.04) for each 10 case increase
		P		0.55	0.95

Note:
In this subset, unlike in the full (secondary) analysis cohort, SAH ACV has a straight line relationship with each outcome. There is no apparent leveling off of risk at any point. Event rates do appear higher in the first quintile, but there are too few patients in this group to influence model fit. It is possible that a non-linear relationship would be significant with more patients in the lower quintiles.

Table S19. Outcomes by SAH ACV — Primary analysis cohort (all SAH admissions), among hospitals with SAH ACV ≥ 20. There are 7249 patients in this subgroup (of 8512 in the full cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	20 - 25	505	46.5% (235)	25.7% (130)
	2	26 - 34	784	40.9% (321)	23.9% (187)
	3	36 - 52	1,141	36.1% (412)	19.9% (227)
	4	53 - 77	1,525	36.1% (551)	20.1% (307)
	5	80 - 195	3,294	35.7% (1177)	18.2% (598)
Model results	Unadjusted	OR (95% CI)		0.88 (0.84, 0.93)	0.92 (0.89, 0.95)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		<0.001	<0.001
	Adjusted	OR (95% CI)		0.93 (0.87, 0.99)	0.94 (0.90, 0.98)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		0.017	0.0024
	Adjusted + NIS-SSS	OR (95% CI)		0.94 (0.87, 1.01)	0.93 (0.89, 0.98)
				for each 10 case increase up to 50	for each 10 case increase up to 70
		P		0.12	0.0035

Table S20. Outcomes by SAH ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping), among hospitals with SAH ACV ≥ 20. There are 3705 patients in this subgroup (of 4049 in the secondary cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	20 - 25	185	38.4% (71)	15.7% (29)
	2	26 - 34	346	36.4% (126)	13.6% (47)
	3	36 - 52	566	29.7% (168)	10.4% (59)
	4	53 - 77	773	31.8% (246)	12.7% (98)
	5	80 - 195	1,835	32.3% (593)	10.6% (195)
Model results	Unadjusted	OR (95% CI)		0.92 (0.85, 1.00) for each 10 case increase up to 50	0.94 (0.88, 1.00) for each 10 case increase up to 70
		P		0.060	0.035
	Adjusted	OR (95% CI)		0.93 (0.84, 1.03) for each 10 case increase up to 50	0.96 (0.89, 1.04) for each 10 case increase up to 70
		P		0.15	0.34
	Adjusted + NIS-SSS	OR (95% CI)		1.00 (0.89, 1.12) for each 10 case increase up to 50	1.00 (0.92, 1.08) for each 10 case increase up to 70
		P		0.99	0.92

Table S21. Outcomes by SAH ACV — Primary analysis cohort (all SAH admissions), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer from another acute care facility. There are 3837 patients in this subgroup (of 8512 in the full cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	20 - 25	389	47.0% (183)	27.5% (107)
	2	26 - 34	537	43.4% (233)	26.3% (141)
	3	36 - 52	700	36.7% (257)	21.6% (151)
	4	53 - 77	1,018	37.6% (383)	21.5% (219)
	5	80 - 195	1,193	36.1% (431)	19.7% (235)
Model results	Unadjusted	OR (95% CI)		0.98 (0.96, 0.99) for each 10 case increase	0.97 (0.95, 0.99) for each 10 case increase
		P		0.0019	<0.001
	Adjusted	OR (95% CI)		0.99 (0.97, 1.00) for each 10 case increase	0.98 (0.96, 1.00) for each 10 case increase
		P		0.10	0.041
	Adjusted + NIS-SSS	OR (95% CI)		0.99 (0.97, 1.01) for each 10 case increase	0.98 (0.95, 1.00) for each 10 case increase
		P		0.26	0.049

Table S22. Outcomes by SAH ACV — Secondary analysis cohort (SAH admissions who underwent coiling or clipping), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer in. There are 1749 patients in this subgroup (of 4049 in the secondary cohort).

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital ACV	Quintile	ACV (min-max)	N		
	1	20 - 25	136	38.2% (52)	17.6% (24)
	2	26 - 34	218	37.2% (81)	14.2% (31)
	3	36 - 52	332	28.0% (93)	11.1% (37)
	4	53 - 77	492	33.9% (167)	14.6% (72)
	5	80 - 195	571	33.3% (190)	13.0% (74)
Model results	Unadjusted	OR (95% CI)		0.99 (0.97, 1.01) for each 10 case increase	0.98 (0.95, 1.02) for each 10 case increase
		P		0.39	0.33
	Adjusted	OR (95% CI)		1.00 (0.98, 1.03) for each 10 case increase	1.01 (0.97, 1.05) for each 10 case increase
		P		0.90	0.64
	Adjusted + NIS-SSS	OR (95% CI)		1.02 (0.98, 1.05) for each 10 case increase	1.02 (0.98, 1.06) for each 10 case increase
		P		0.33	0.43

Table S23. Outcomes by Coiling ACV, for SAH pts who undergo coiling.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital Coiling ACV	Quintile	ACV (min-max)	N (pts)		
	1	0.5 - 9	80	35.0% (28)	17.5% (14)
	2	10 - 20	176	27.8% (49)	9.7% (17)
	3	21 - 32	402	30.8% (124)	14.4% (58)
	4	33 - 62	504	34.5% (174)	14.5% (73)
	5	63 - 188	1,277	32.8% (419)	11.0% (140)
Model results	Unadjusted	OR (95% CI)		1.02 (0.97, 1.06) for each 10 case increase up to 65	0.94 (0.89, 1.00) for each 10 case increase up to 65
		P		0.45	0.060
	Adjusted	OR (95% CI)		1.02 (0.96, 1.08) for each 10 case increase up to 65	0.94 (0.87, 1.01) for each 10 case increase up to 65
		P		0.61	0.090
	Adjusted + NIS-SSS	OR (95% CI)		1.03 (0.96, 1.10) for each 10 case increase up to 65	0.93 (0.86, 1.01) for each 10 case increase up to 65
		P		0.41	0.087

Table S24. Outcomes by SAH Coiling ACV, for SAH pts who undergo coiling.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital SAH Coiling ACV	Quintile	ACV (min-max)	N (pts)		
	1	0.5 - 3.5	52	36.5% (19)	15.4% (8)
	2	4 - 7	191	31.4% (60)	13.1% (25)
	3	8 - 13	361	36.0% (130)	15.5% (56)
	4	14 - 23	508	31.7% (161)	12.6% (64)
	5	24 - 94	1,327	32.0% (424)	11.2% (149)
Model results	Unadjusted	OR (95% CI)		0.97 (0.86, 1.09)	0.84 (0.71, 0.99)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.63	0.041
	Adjusted	OR (95% CI)		0.98 (0.83, 1.14)	0.85 (0.68, 1.04)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.76	0.12
	Adjusted + NIS-SSS	OR (95% CI)		1.04 (0.87, 1.24)	0.86 (0.69, 1.08)
				for each 10 case increase up to 25	for each 10 case increase up to 25
		P		0.70	0.19

Table S25. Outcomes by Clipping ACV, for SAH pts who undergo clipping.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital Clipping ACV	Quintile	ACV (min-max)	N (pts)		
	1	0.5 - 2	63	50.8% (32)	27.0% (17)
	2	2.5 - 4.5	81	42.0% (34)	19.8% (16)
	3	5 - 9	164	39.0% (64)	18.3% (30)
	4	9.5 - 22	314	37.6% (118)	10.8% (34)
	5	23 - 188	1,089	30.7% (334)	9.5% (103)
Model results	Unadjusted	OR (95% CI)		0.97 (0.95, 0.99) for each 10 case increase	0.94 (0.90, 0.97) for each 10 case increase
		P		0.0011	<0.001
	Adjusted	OR (95% CI)		0.97 (0.94, 0.99) for each 10 case increase	0.94 (0.91, 0.98) for each 10 case increase
		P		0.0084	0.0023
	Adjusted + NIS-SSS	OR (95% CI)		0.99 (0.96, 1.02) for each 10 case increase	0.96 (0.93, 1.00) for each 10 case increase
		P		0.51	0.067

Table S26. Outcomes by SAH Clipping ACV, for SAH pts who undergo clipping.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital SAH Clipping ACV	Quintile	ACV (min-max)	N (pts)		
	1	0.5 - 1	55	52.7% (29)	30.9% (17)
	2	1.5 - 2.5	75	54.7% (41)	24.0% (18)
	3	3 - 4.5	159	35.8% (57)	18.2% (29)
	4	5 - 9	308	33.4% (103)	10.1% (31)
	5	10 - 69	1,114	31.6% (352)	9.4% (105)
Model results	Unadjusted	OR (95% CI)		0.93 (0.89, 0.97)	0.86 (0.80, 0.93)
				for each 10 case increase	for each 10 case increase
		P		0.0017	<0.001
	Adjusted	OR (95% CI)		0.93 (0.87, 0.98)	0.88 (0.80, 0.96)
				for each 10 case increase	for each 10 case increase
		P		0.011	0.0028
	Adjusted + NIS-SSS	OR (95% CI)		1.01 (0.94, 1.08)	0.94 (0.86, 1.03)
				for each 10 case increase	for each 10 case increase
		P		0.79	0.18

Table S27. Outcomes by Clipping ACV, at sites with SAH ACV ≥ 35.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital Clipping ACV	Quintile	ACV (min-max)	N (pts)		
	1	0 - 9.5	840	31.8% (267)	20.4% (171)
	2	10 - 18	776	40.7% (316)	22.2% (172)
	3	19 - 30	1,087	37.4% (406)	20.2% (220)
	4	31 - 66	1,160	34.7% (402)	18.5% (215)
	5	67 - 188	2,097	35.7% (749)	16.9% (354)
Model results	Unadjusted	OR (95% CI)		0.99 (0.98, 1.01) for each 10 case increase	0.97 (0.96, 0.98) for each 10 case increase
		P		0.32	<0.001
	Adjusted	OR (95% CI)		1.00 (0.99, 1.01) for each 10 case increase	0.97 (0.96, 0.99) for each 10 case increase
		P		0.81	0.0010
	Adjusted + NIS-SSS	OR (95% CI)		1.01 (0.99, 1.02) for each 10 case increase	0.97 (0.95, 0.98) for each 10 case increase
		P		0.41	<0.001

Table S28. Outcomes by Coiling ACV, at sites with SAH ACV ≥ 35.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital Coiling ACV	Quintile	ACV (min-max)	N (pts)		
	1	4 - 25	678	38.3% (260)	23.9% (162)
	2	27 - 38	954	39.5% (377)	20.8% (198)
	3	39 - 53	1,001	36.7% (367)	21.2% (212)
	4	62 - 95	1,484	32.4% (481)	16.0% (238)
	5	97 - 188	1,843	35.5% (655)	17.5% (322)
Model results	Unadjusted	OR (95% CI)		0.96 (0.93, 0.99)	0.92 (0.89, 0.95)
				for each 10 case increase up to 65	for each 10 case increase up to 65
		P		0.0048	<0.001
	Adjusted	OR (95% CI)		0.94 (0.91, 0.98)	0.92 (0.88, 0.97)
				for each 10 case increase up to 65	for each 10 case increase up to 65
		P		0.0020	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.90 (0.86, 0.94)	0.89 (0.84, 0.94)
				for each 10 case increase up to 65	for each 10 case increase up to 65
		P		<0.001	<0.001

Table S29. Outcomes by Total Coiling + Clipping ACV, at sites with SAH ACV ≥ 35.

				NIS-SOM Poor Outcome	In-hospital death
Event rates by quintile of hospital Coiling + Clipping ACV	Quintile	ACV (min-max)	N (pts)		
	1	11 - 44	694	40.5% (281)	24.5% (170)
	2	45 - 56	784	32.9% (258)	18.8% (147)
	3	57 - 88	947	36.0% (341)	20.9% (198)
	4	93 - 161	1,533	38.1% (584)	18.5% (284)
	5	162 - 376	2,002	33.8% (676)	16.6% (333)
Model results	Unadjusted	OR (95% CI)		0.99 (0.98, 1.00) for each 20 case increase	0.96 (0.95, 0.98) for each 20 case increase
		P		0.092	<0.001
	Adjusted	OR (95% CI)		0.99 (0.98, 1.01) for each 20 case increase	0.97 (0.95, 0.98) for each 20 case increase
		P		0.35	<0.001
	Adjusted + NIS-SSS	OR (95% CI)		0.99 (0.97, 1.01) for each 20 case increase	0.95 (0.93, 0.97) for each 20 case increase
		P		0.18	<0.001

Table S30. Outcomes for all SAH patients at sites meeting different criteria using unadjusted model, model adjusted for patient and hospital risk factors, and model also adjusted for severity using the NIS-SSS. Odds ratio with 95% CI and P-value are shown.

		NIS-SOM Poor Outcome	In-hospital death
TAP vs. Current standard but not TAP	Unadjusted	0.74 (0.64, 0.87) P<0.001	0.71 (0.59, 0.84) P<0.001
	Adjusted	0.86 (0.71, 1.05) P=0.13	0.83 (0.67, 1.04) P=0.11
	Adjusted +NIS-SSS	0.83 (0.65, 1.06) P=0.13	0.77 (0.60, 1.00) P=0.046
TAP vs. Alternative I but not TAP	Unadjusted	1.23 (1.06, 1.41) P=0.0047	0.89 (0.75, 1.05) P=0.16
	Adjusted	1.35 (1.15, 1.59) P<0.001	0.97 (0.81, 1.16) P=0.75
	Adjusted +NIS-SSS	1.19 (0.98, 1.45) P=0.076	0.76 (0.61, 0.93) P=0.0087
TAP vs. Alternative II but not TAP	Unadjusted	1.23 (1.07, 1.42) P=0.0039	0.89 (0.75, 1.05) P=0.16
	Adjusted	1.37 (1.17, 1.61) P<0.001	0.97 (0.81, 1.17) P=0.78
	Adjusted +NIS-SSS	1.22 (1.00, 1.48) P=0.050	0.76 (0.62, 0.94) P=0.012
TAP vs. SAH ACV ≥ 35 but not TAP	Unadjusted	1.21 (1.05, 1.39) P=0.0076	0.87 (0.74, 1.02) P=0.094
	Adjusted	1.35 (1.15, 1.58) P<0.001	0.97 (0.81, 1.16) P=0.71
	Adjusted +NIS-SSS	1.19 (0.98, 1.44) P=0.084	0.75 (0.61, 0.92) P=0.0062
SAH ACV ≥ 35 vs. SAH ACV 20-34	Unadjusted	0.74 (0.65, 0.83) P<0.001	0.72 (0.62, 0.83) P<0.001
	Adjusted	0.82 (0.71, 0.94) P=0.0054	0.80 (0.68, 0.93) P=0.0055
	Adjusted +NIS-SSS	0.81 (0.68, 0.96) P=0.017	0.76 (0.63, 0.92) P=0.0040

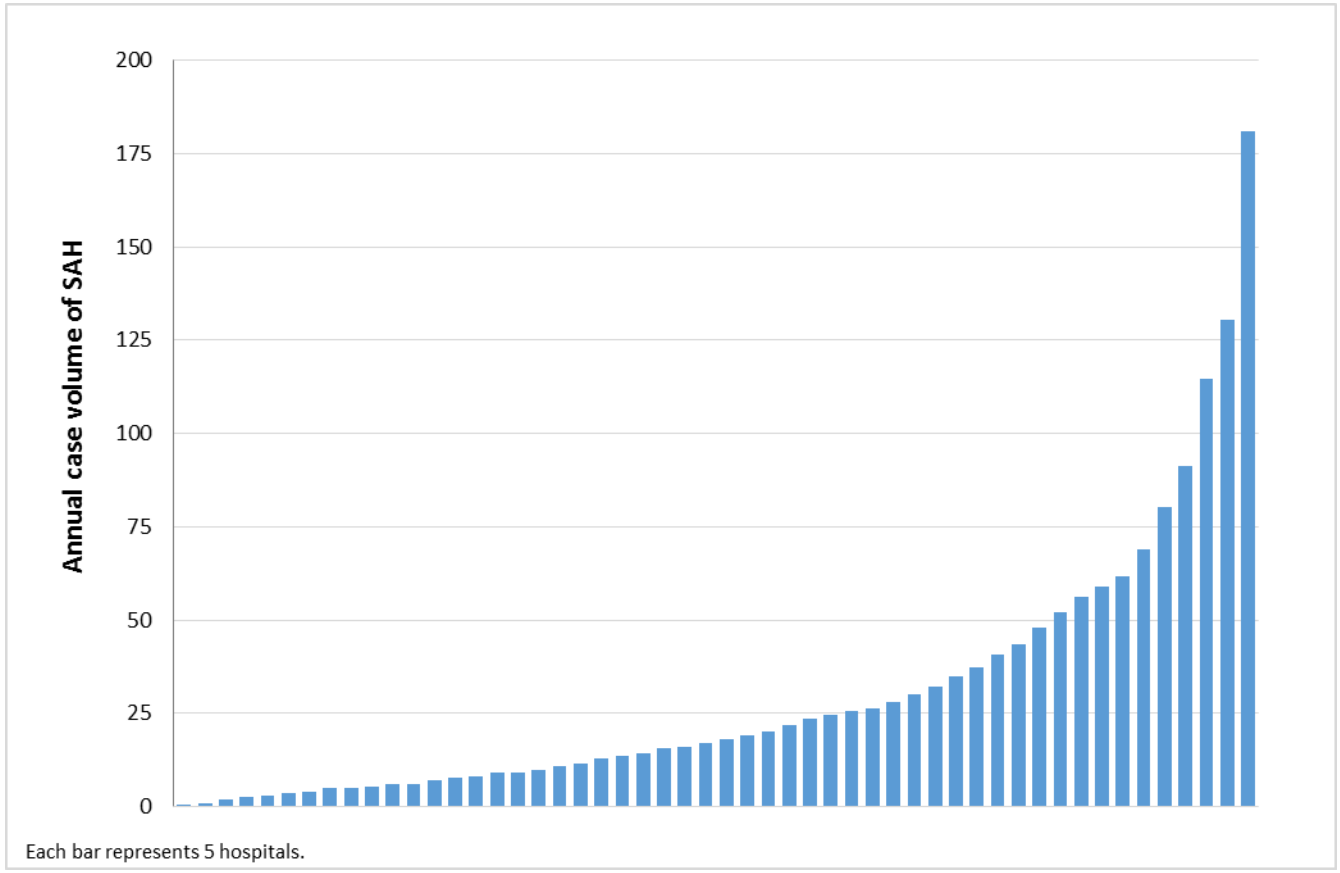


Figure S1. Distribution of annual case volume of SAH, among hospitals that performed at least one coiling or clipping for SAH or UCA. 3 hospitals had no SAH cases during the study period.

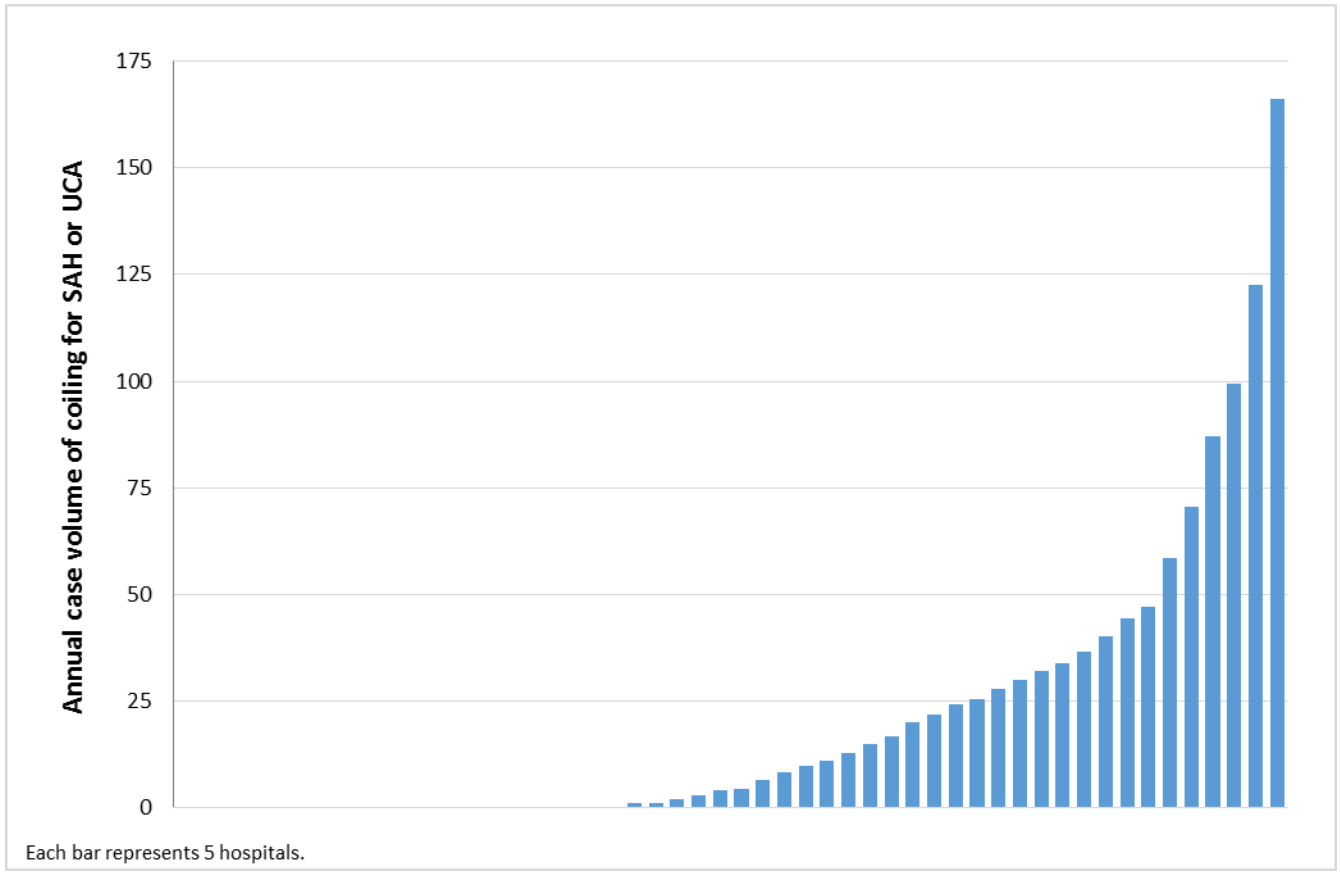


Figure S2. Distribution of annual case volume of coiling for SAH or UCA, among hospitals that performed at least one coiling or clipping for SAH or UCA. 103 hospitals (39%) did not perform coiling during the study period.

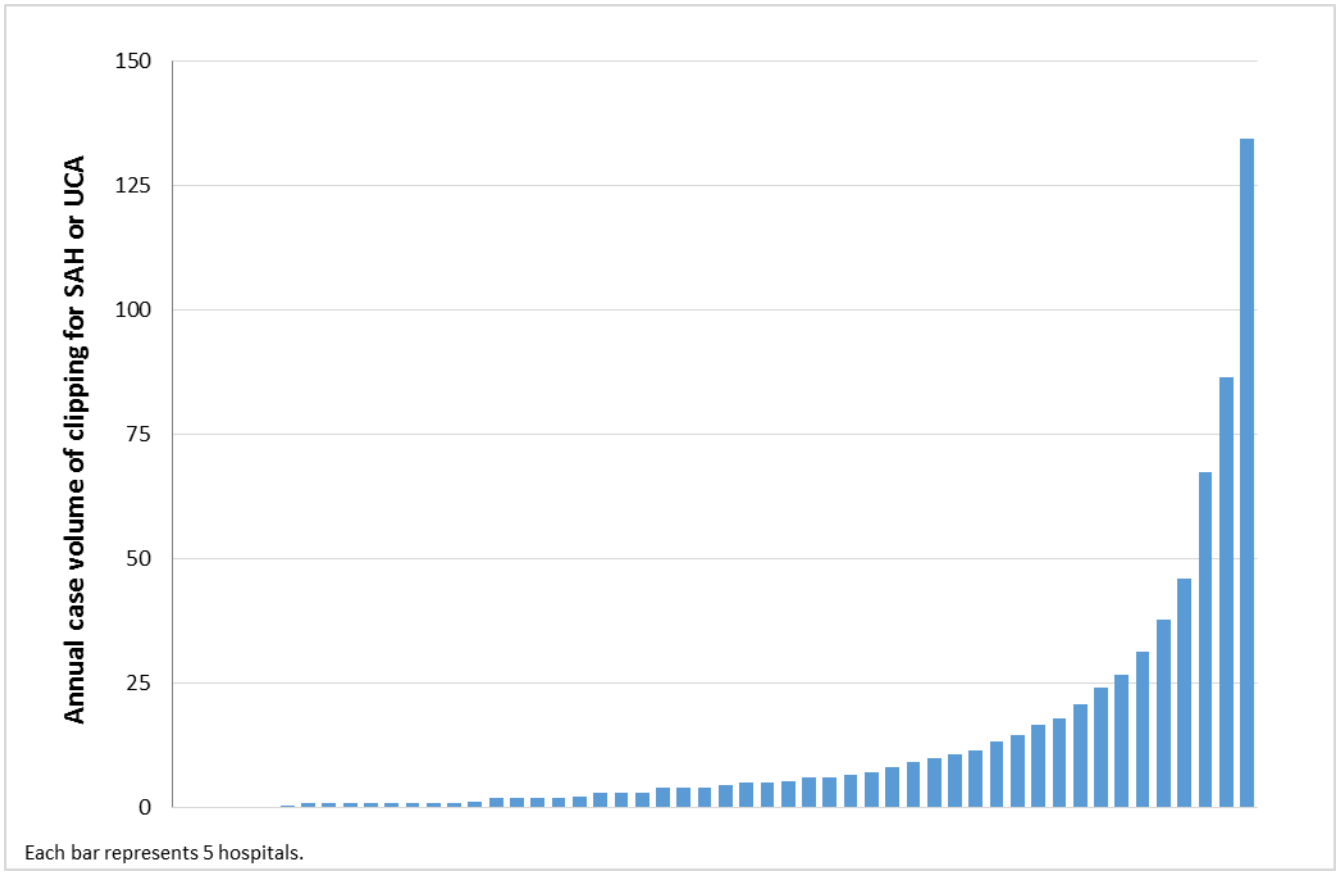


Figure S3. Distribution of annual case volume of clipping for SAH or UCA, among hospitals that performed at least one coiling or clipping for SAH or UCA. 25 hospitals (10%) did not perform clipping during the study period.

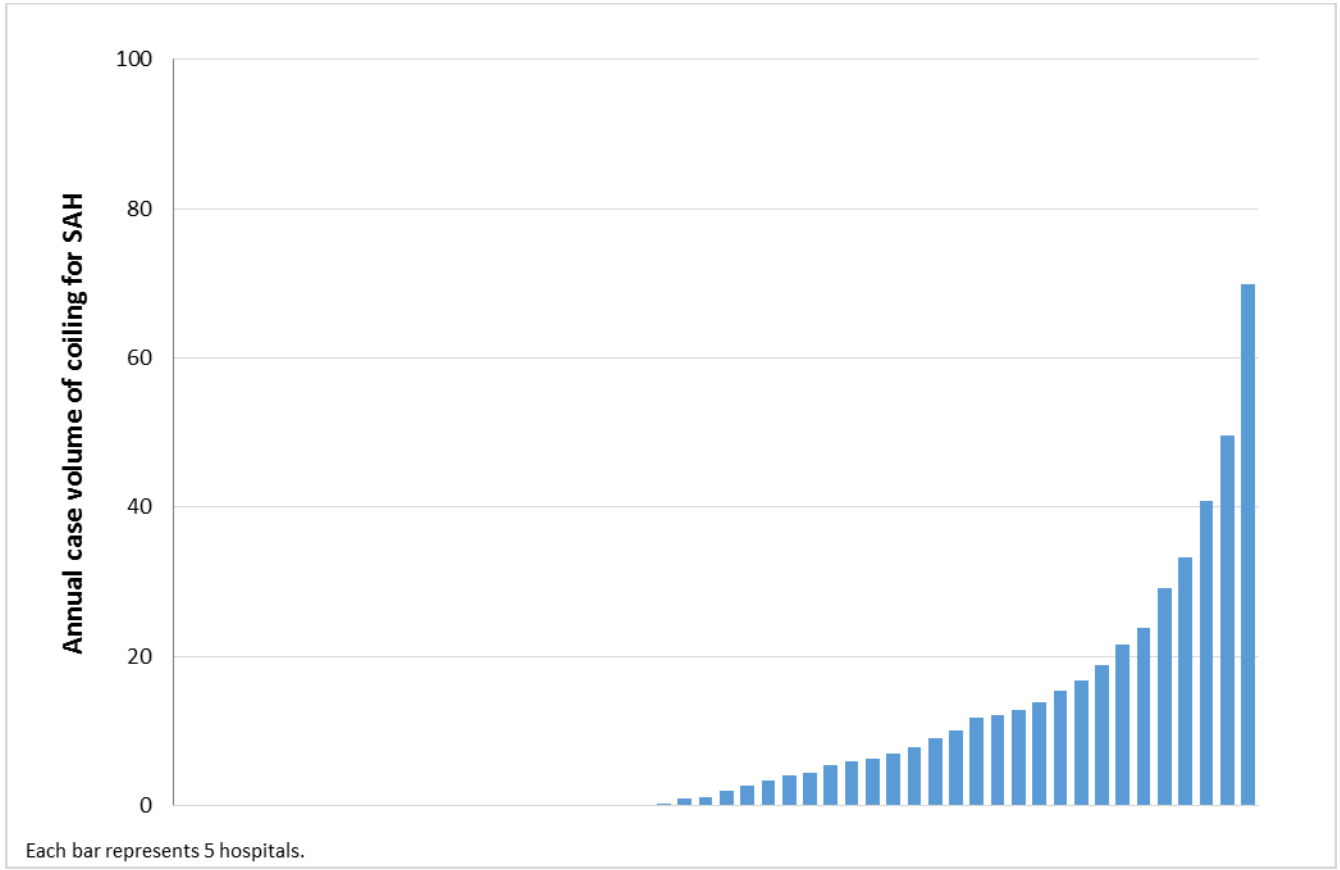


Figure S4. Distribution of annual case volume of coiling for SAH, among hospitals that performed at least one coiling or clipping for SAH or UCA. 117 hospitals (45%) did not perform coiling for SAH during the study period.

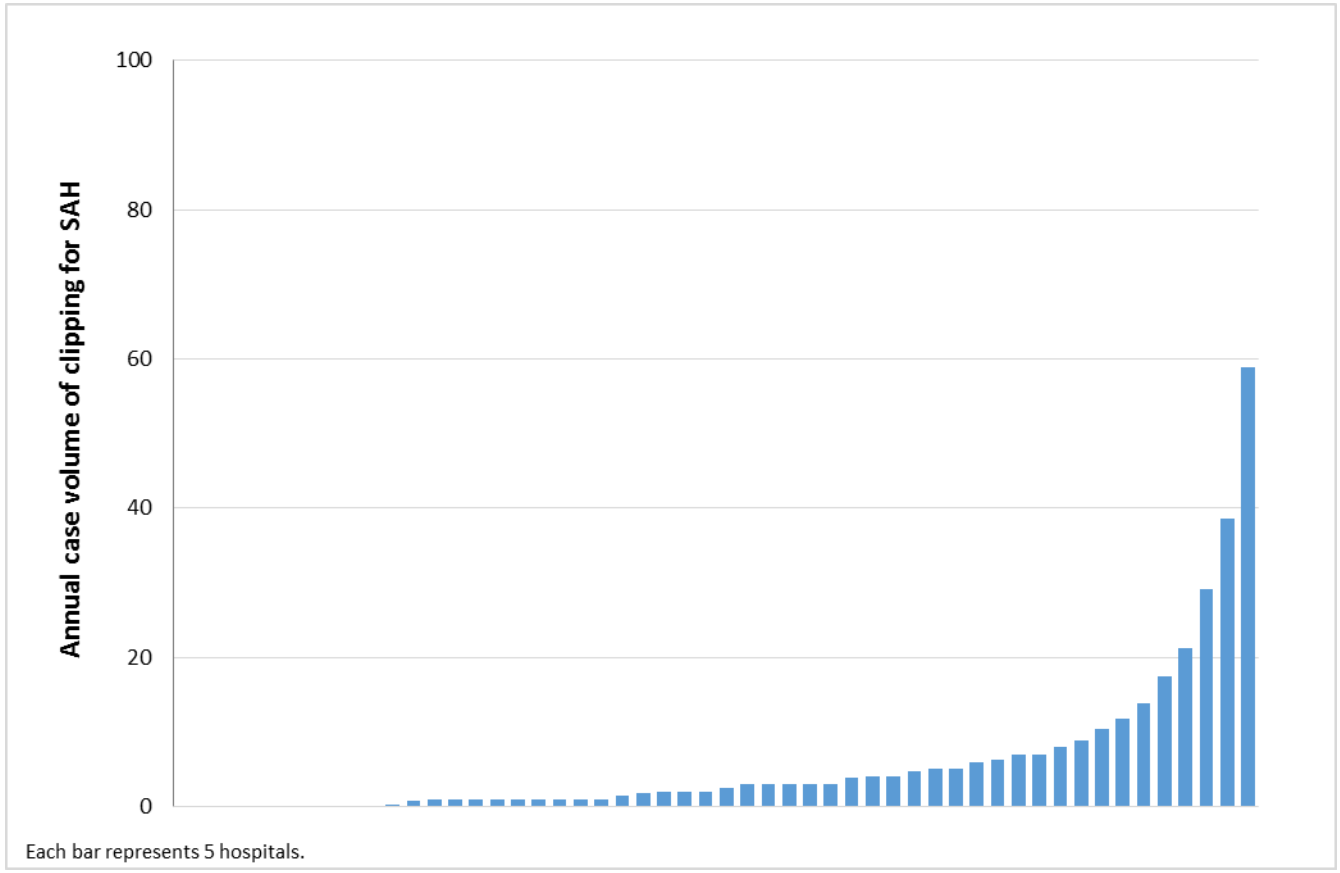


Figure S5. Distribution of annual case volume of clipping for SAH, among hospitals that performed at least one coiling or clipping for SAH or UCA. 53 hospitals (20%) did not perform clipping for SAH during the study period.

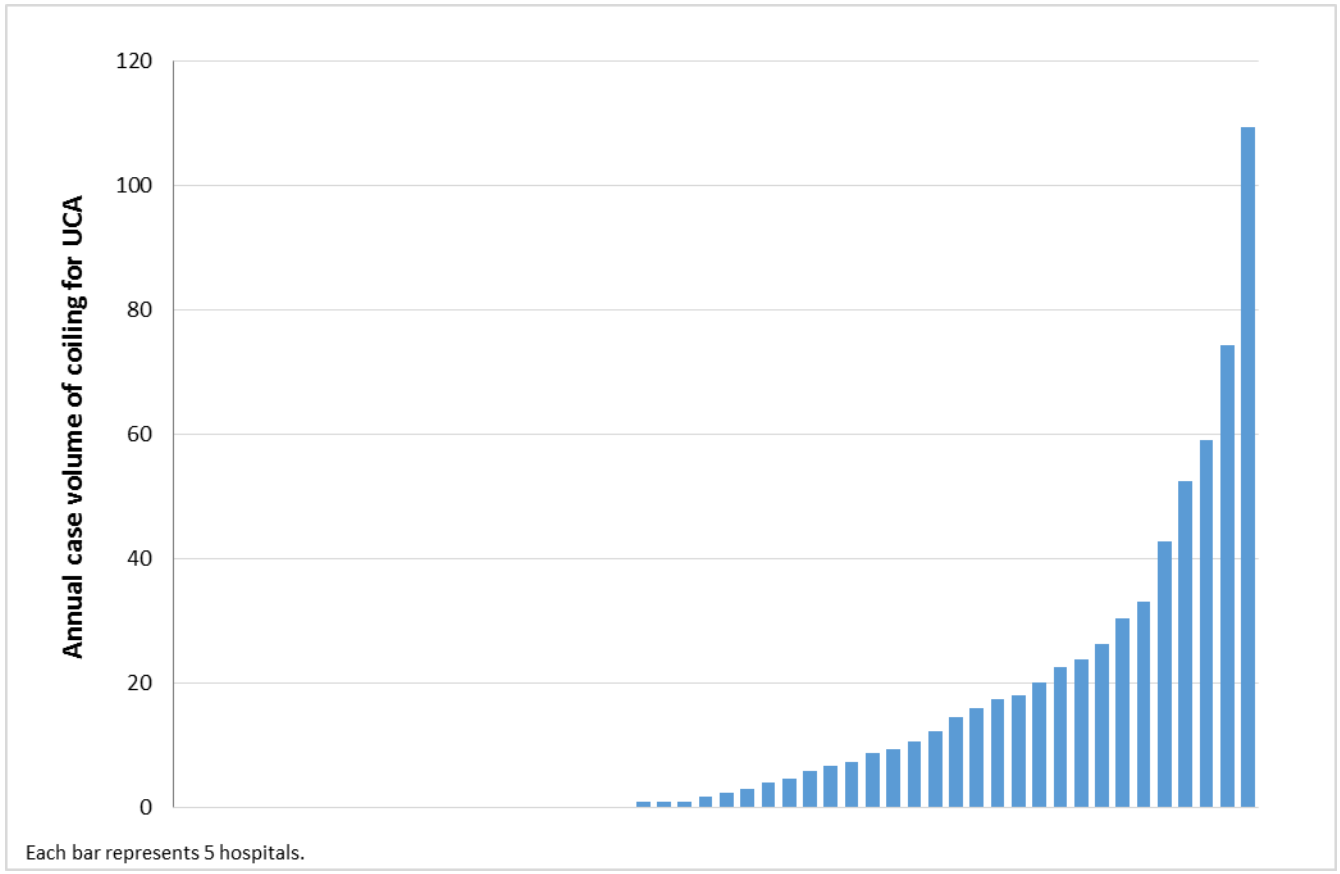


Figure S6. Distribution of annual case volume of coiling for UCA, among hospitals that performed at least one coiling or clipping for SAH or UCA. 109 hospitals (42%) did not perform coiling for UCA during the study period

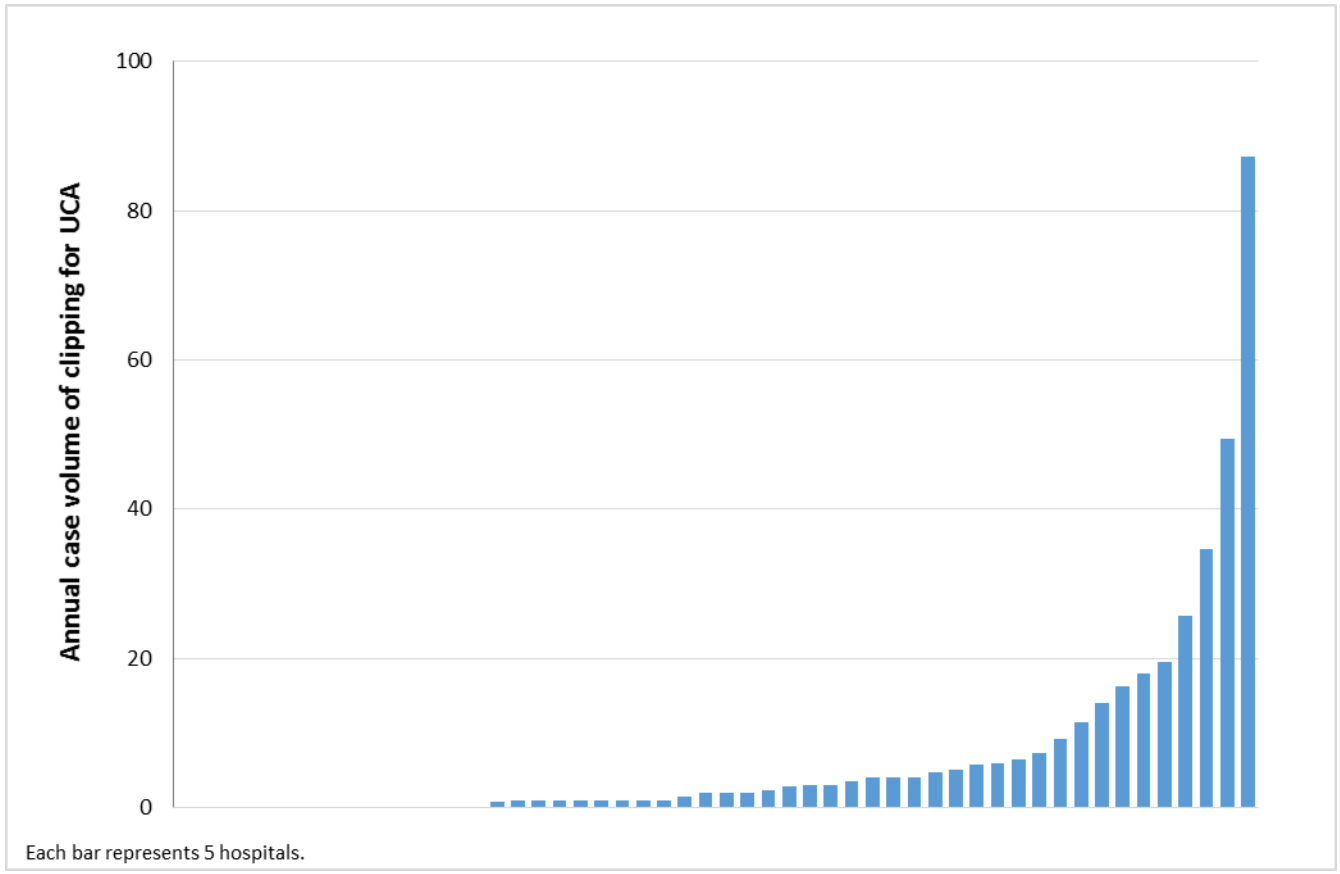
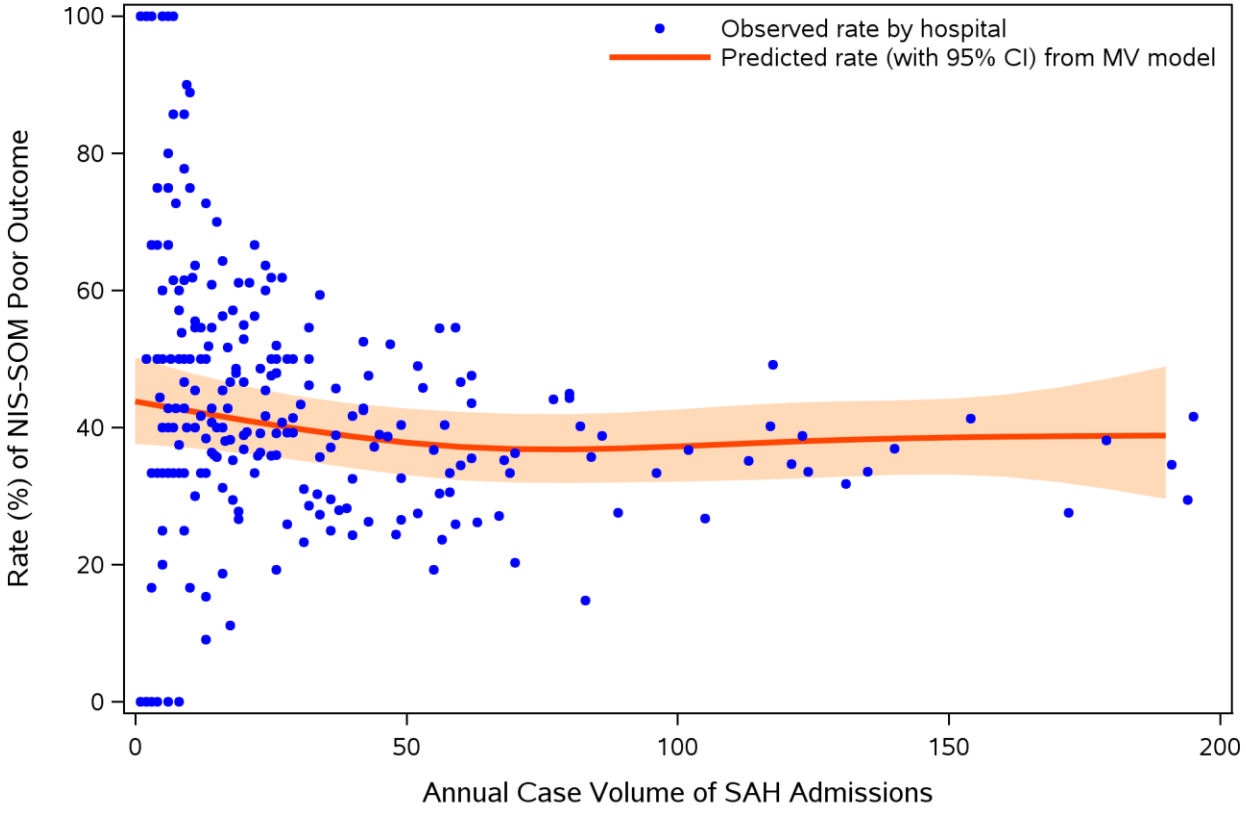
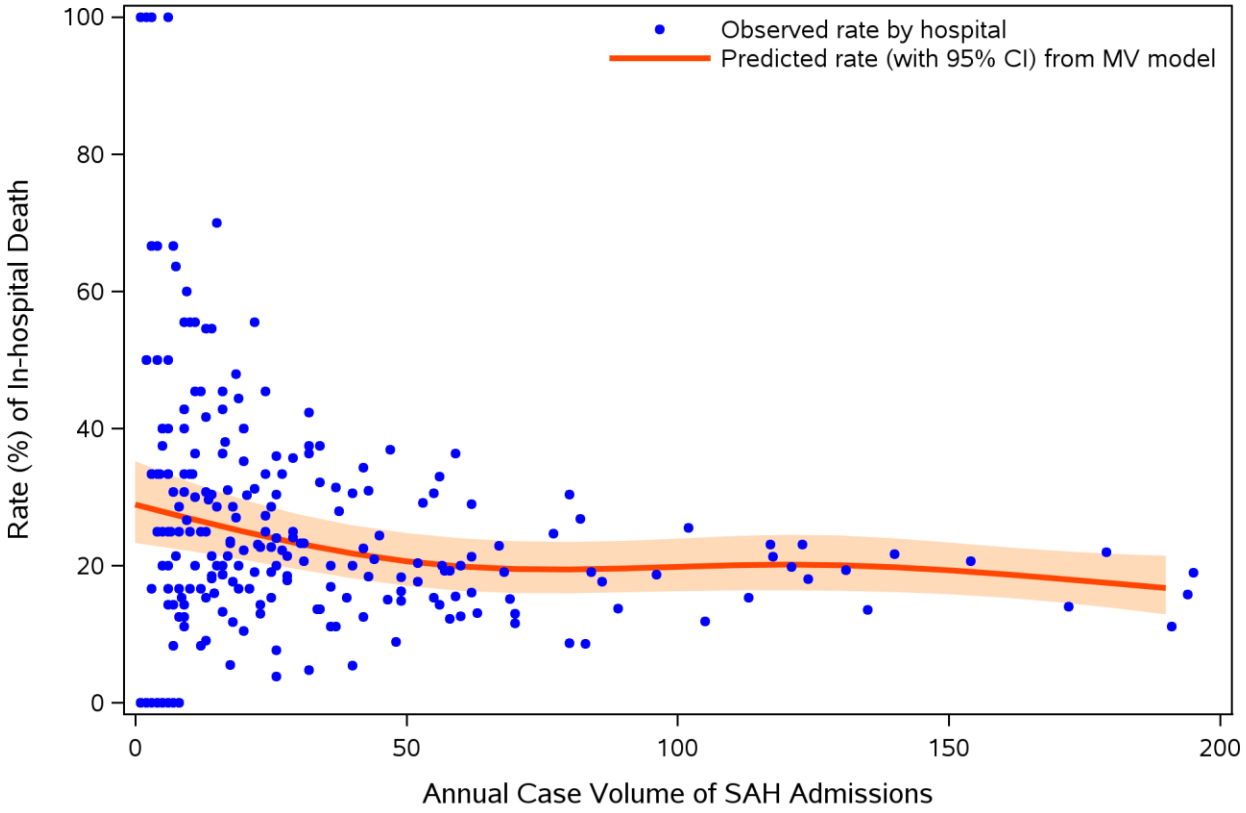


Figure S7. Distribution of annual case volume of clipping for UCA, among hospitals that performed at least one coiling or clipping for SAH or UCA. 74 hospitals (28%) did not perform clipping for UCA during the study period.



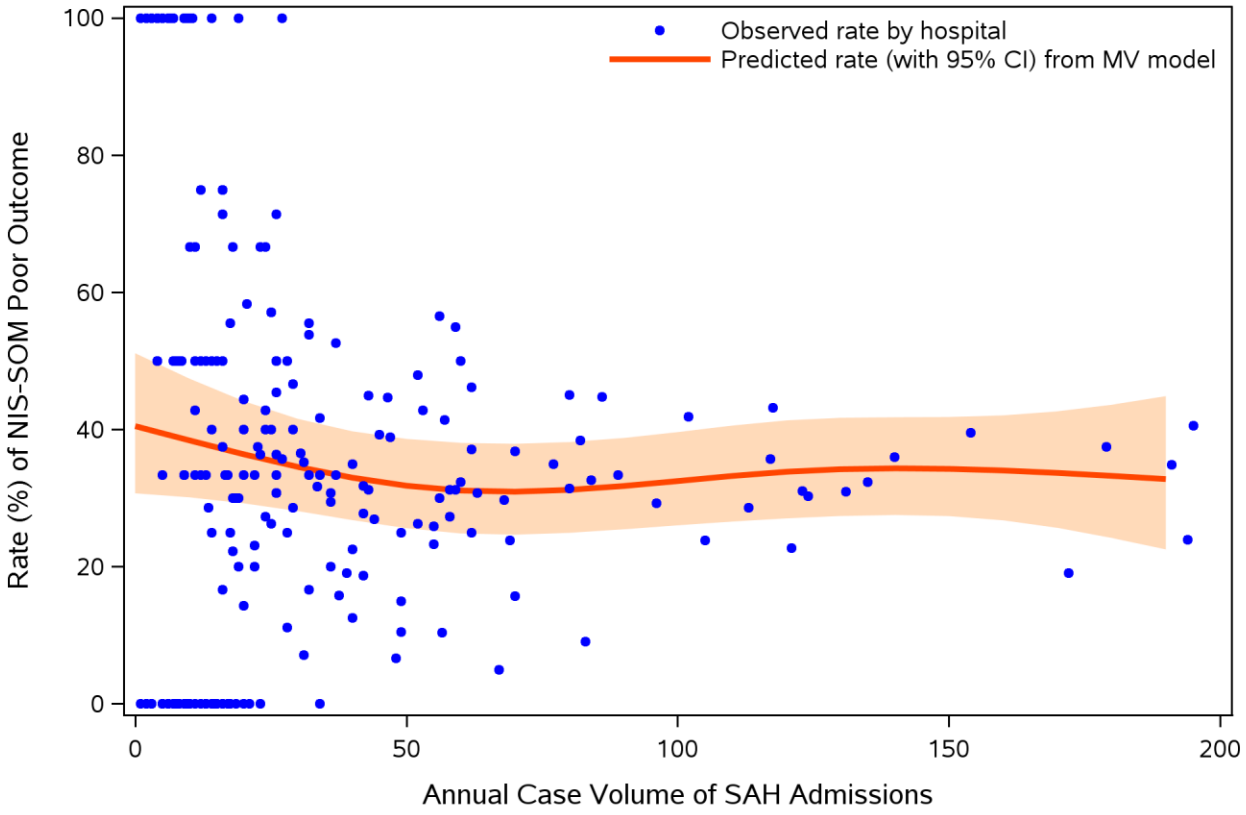
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S8. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (primary cohort).



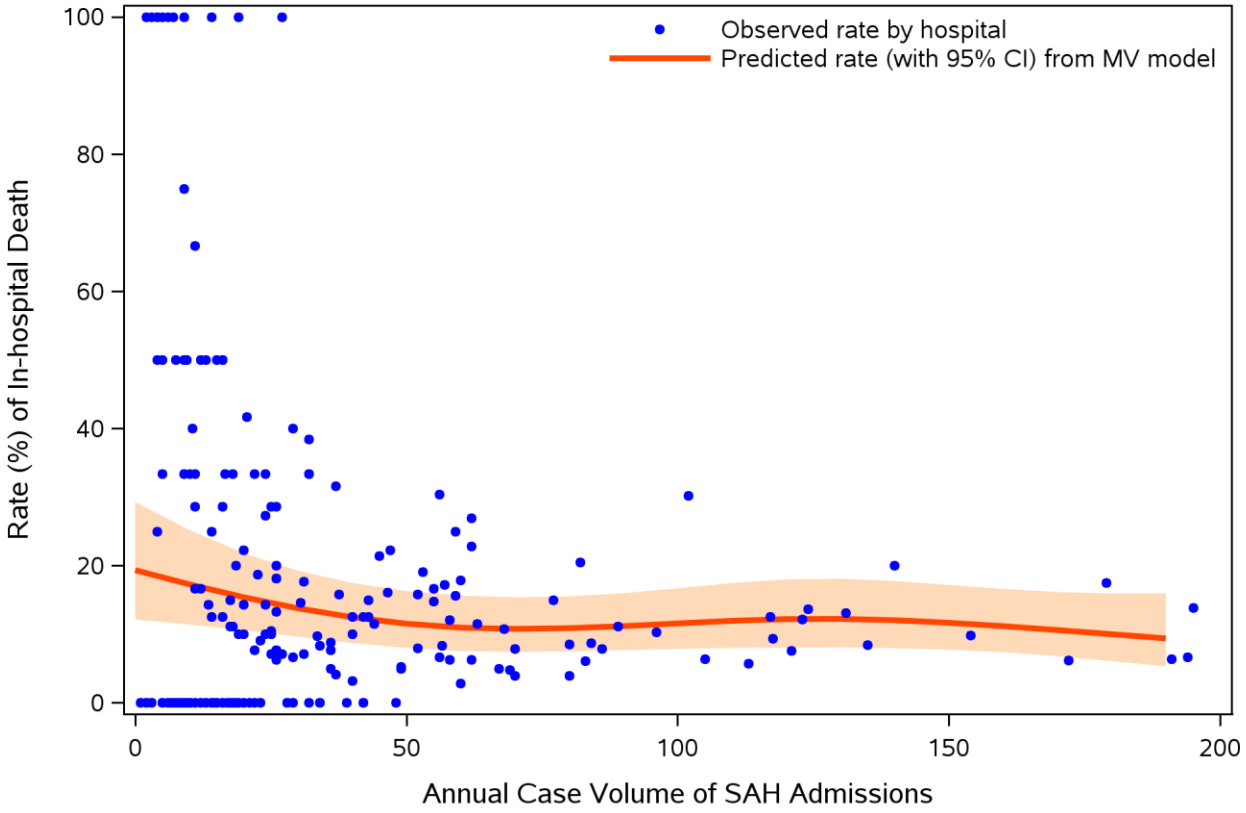
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S9. Observed and predicted rates of in-hospital death by ACV of SAH admissions (primary cohort).



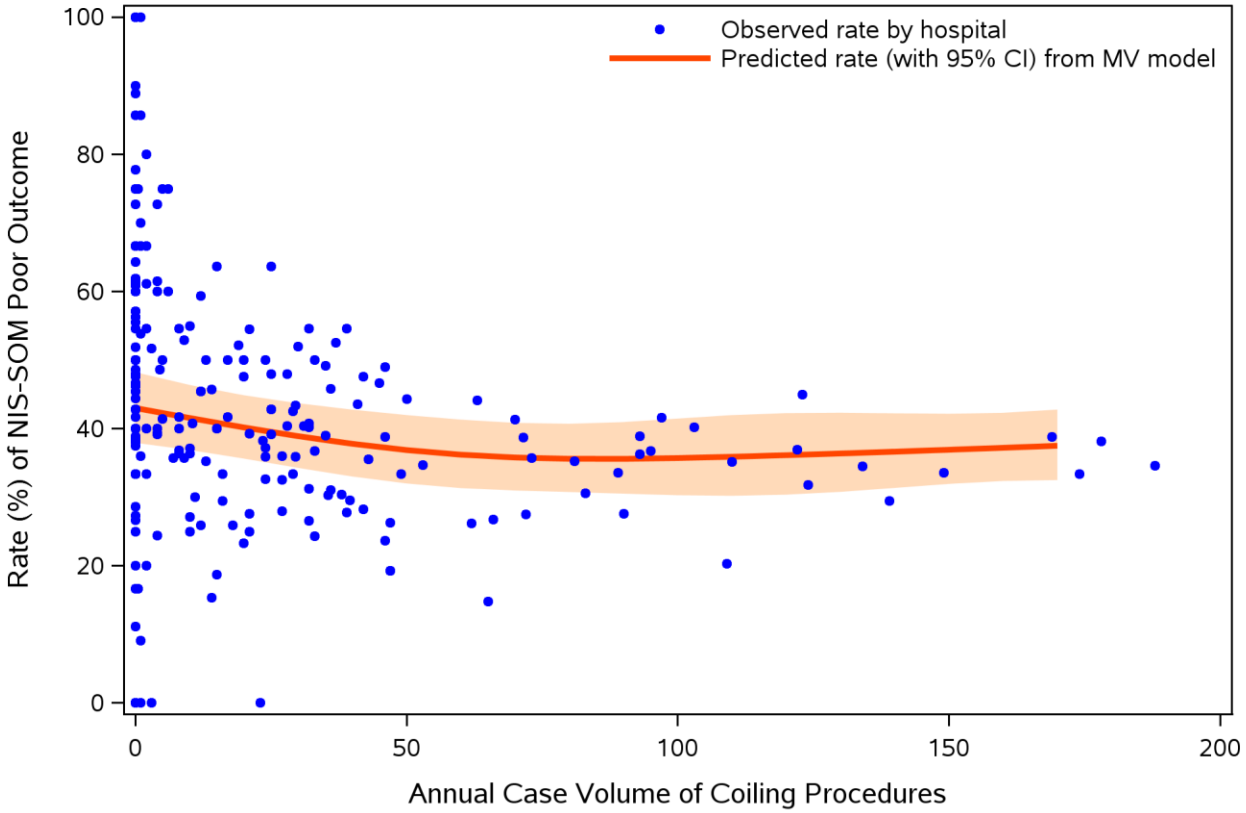
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S10. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (secondary cohort).



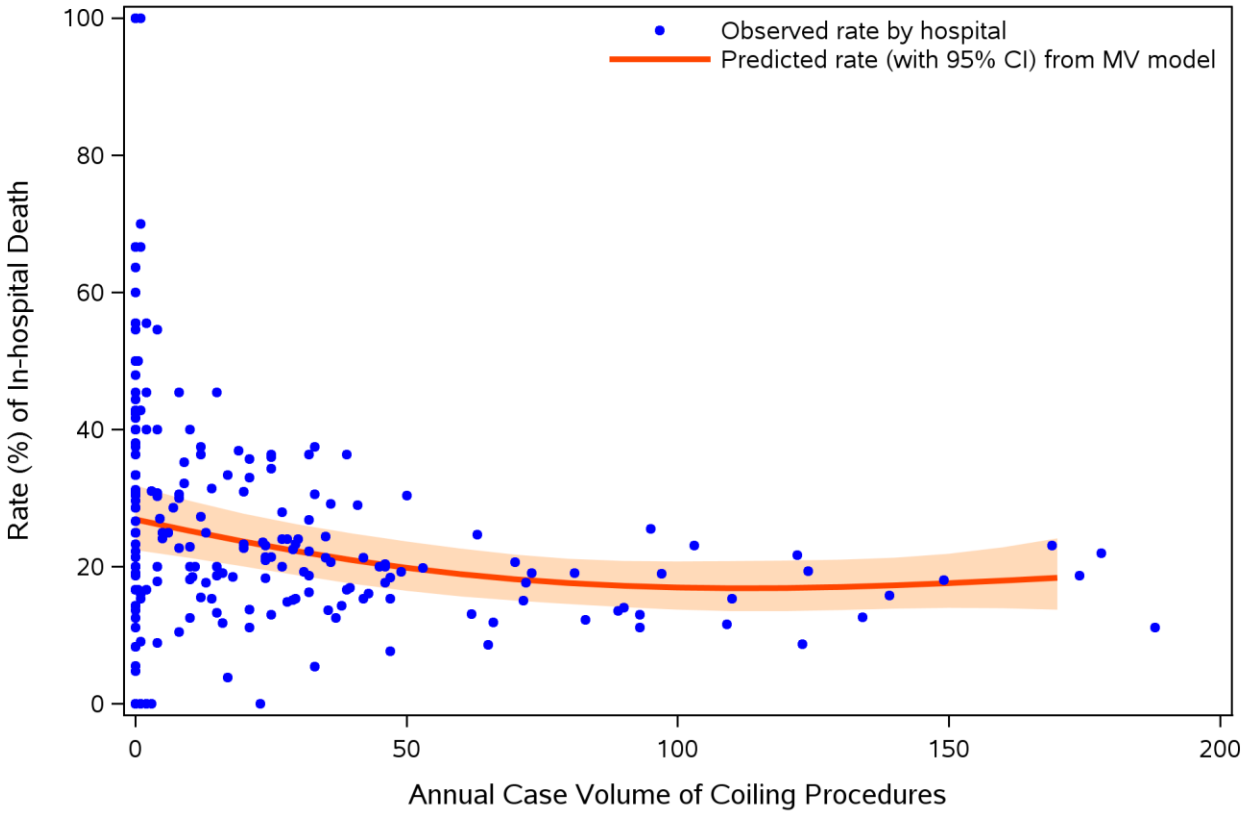
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S11. Observed and predicted rates of in-hospital death by ACV of SAH admissions (secondary cohort).



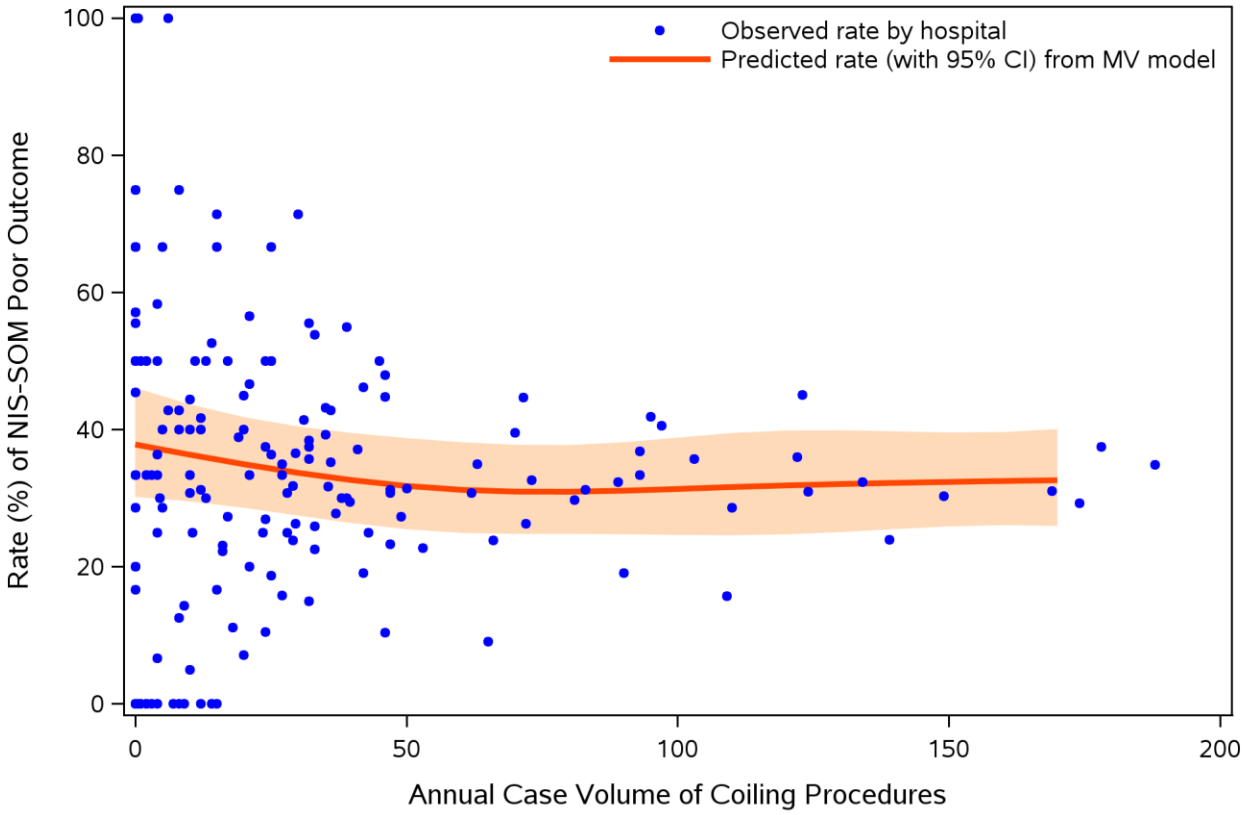
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S12. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling (primary cohort).



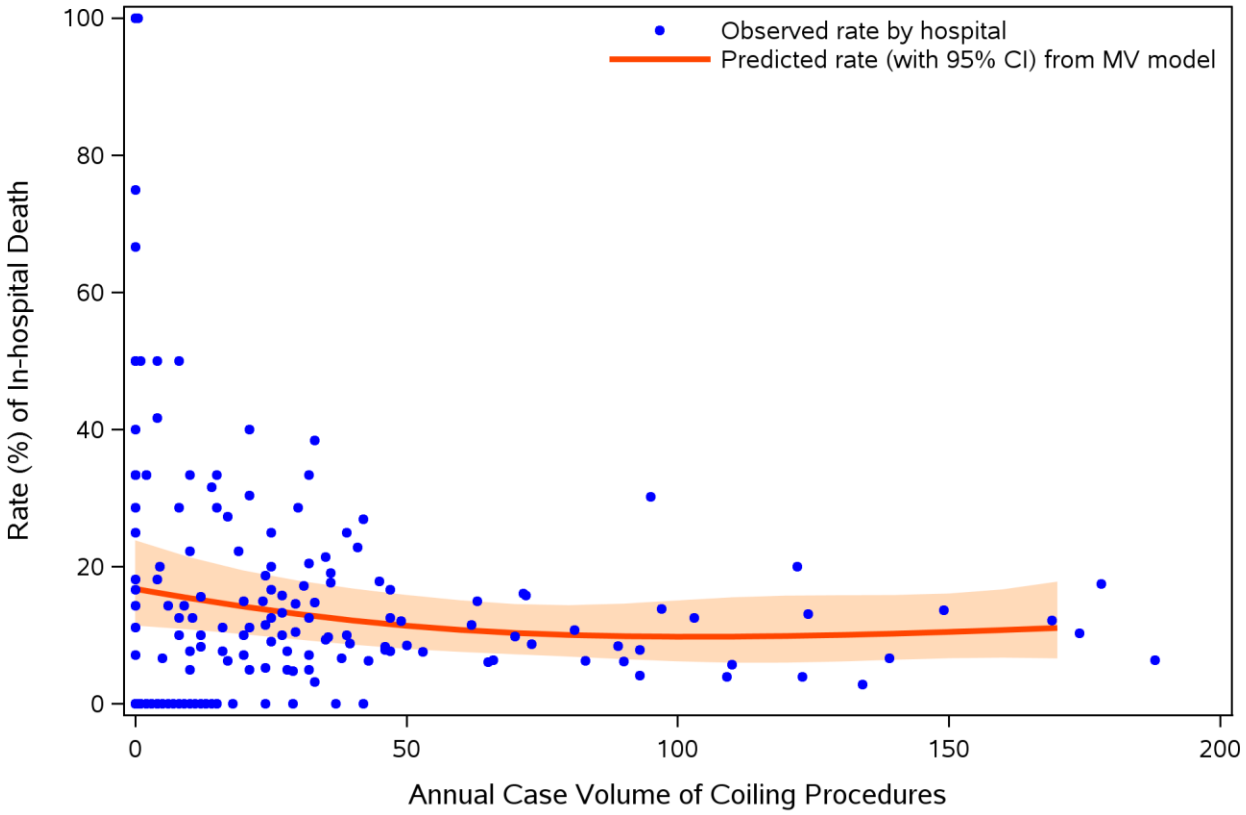
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S13. Observed and predicted rates of in-hospital death by ACV of coiling (primary cohort).



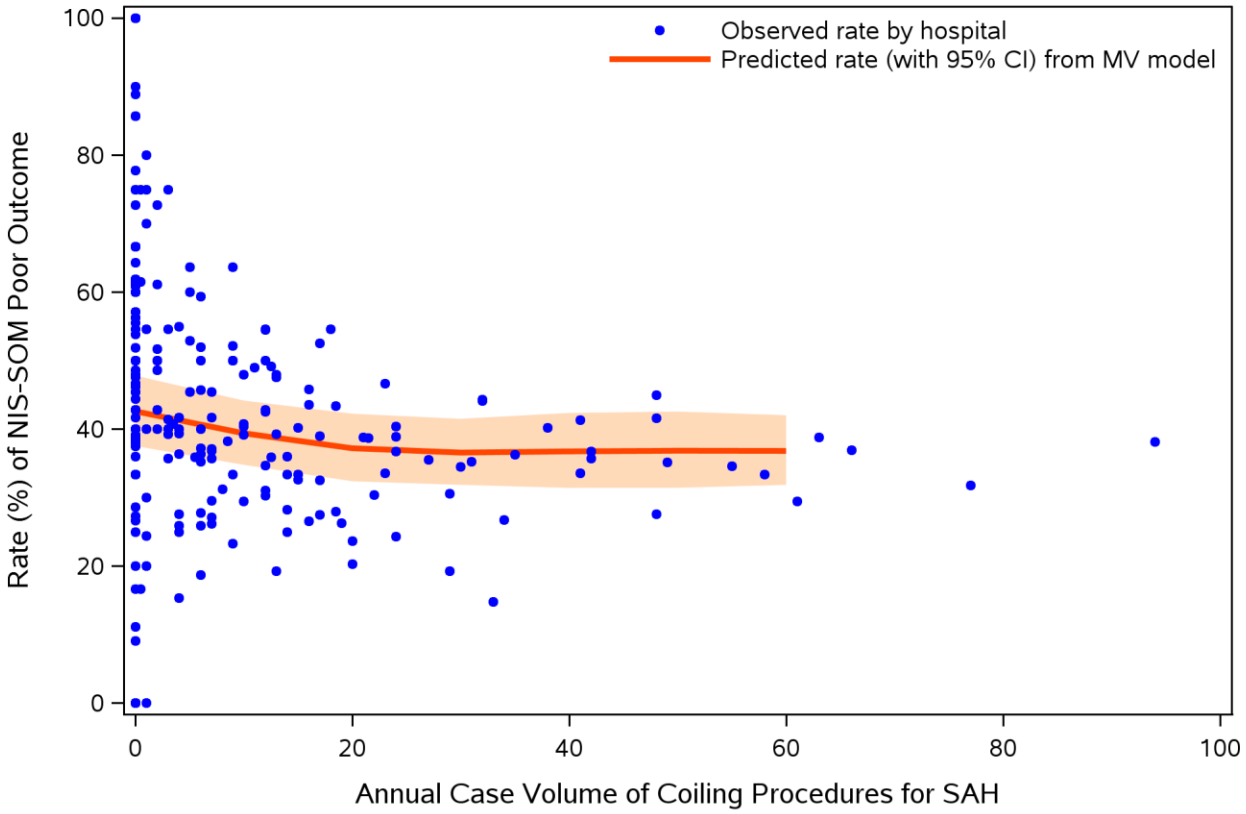
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S14. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling (secondary cohort).



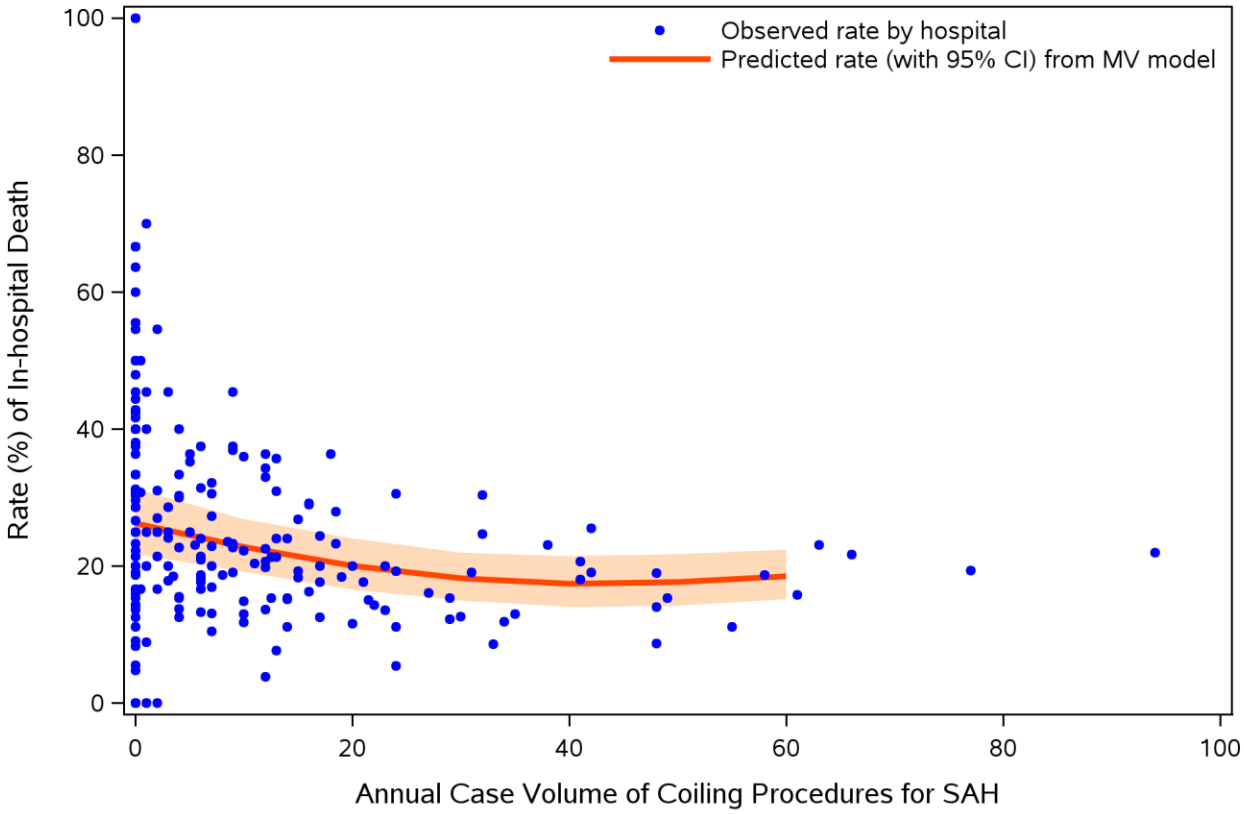
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S15. Observed and predicted rates of in-hospital death by ACV of coiling (secondary cohort).



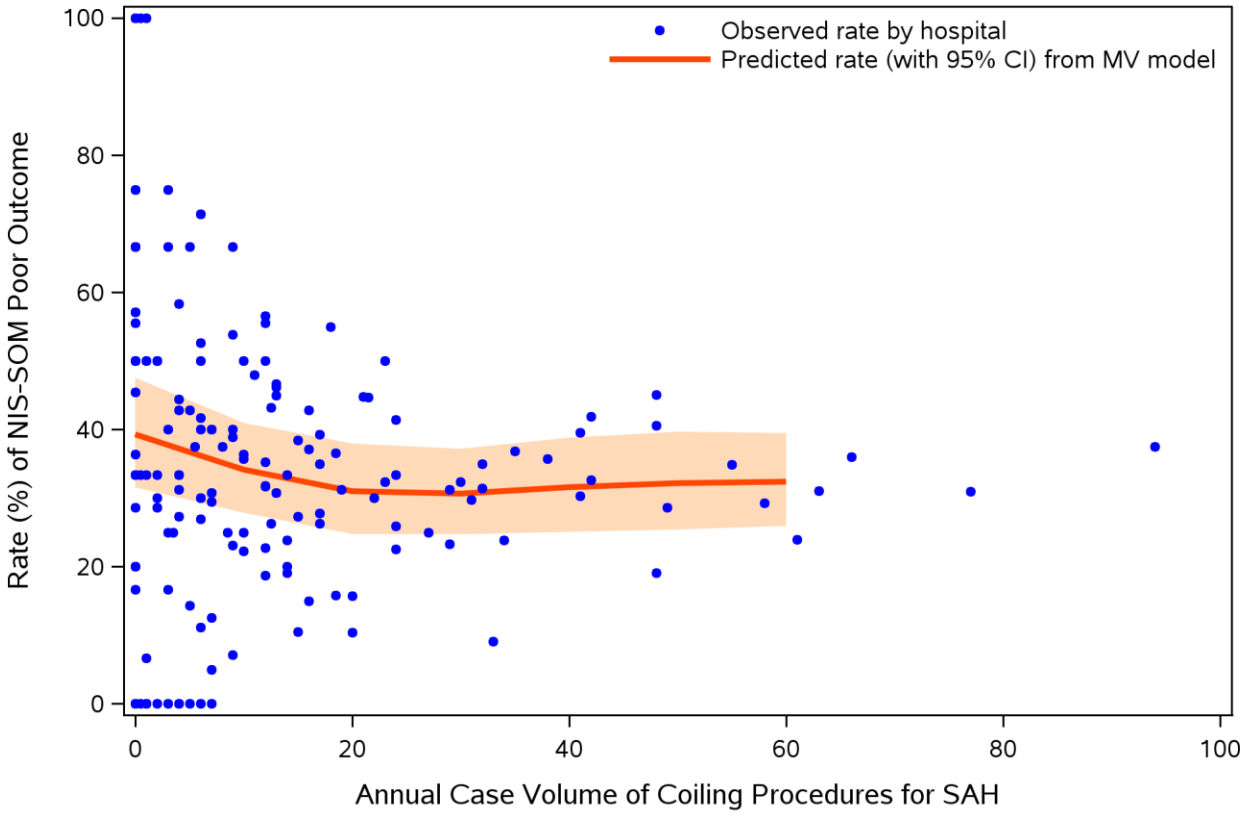
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S16. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling for SAH (primary cohort).



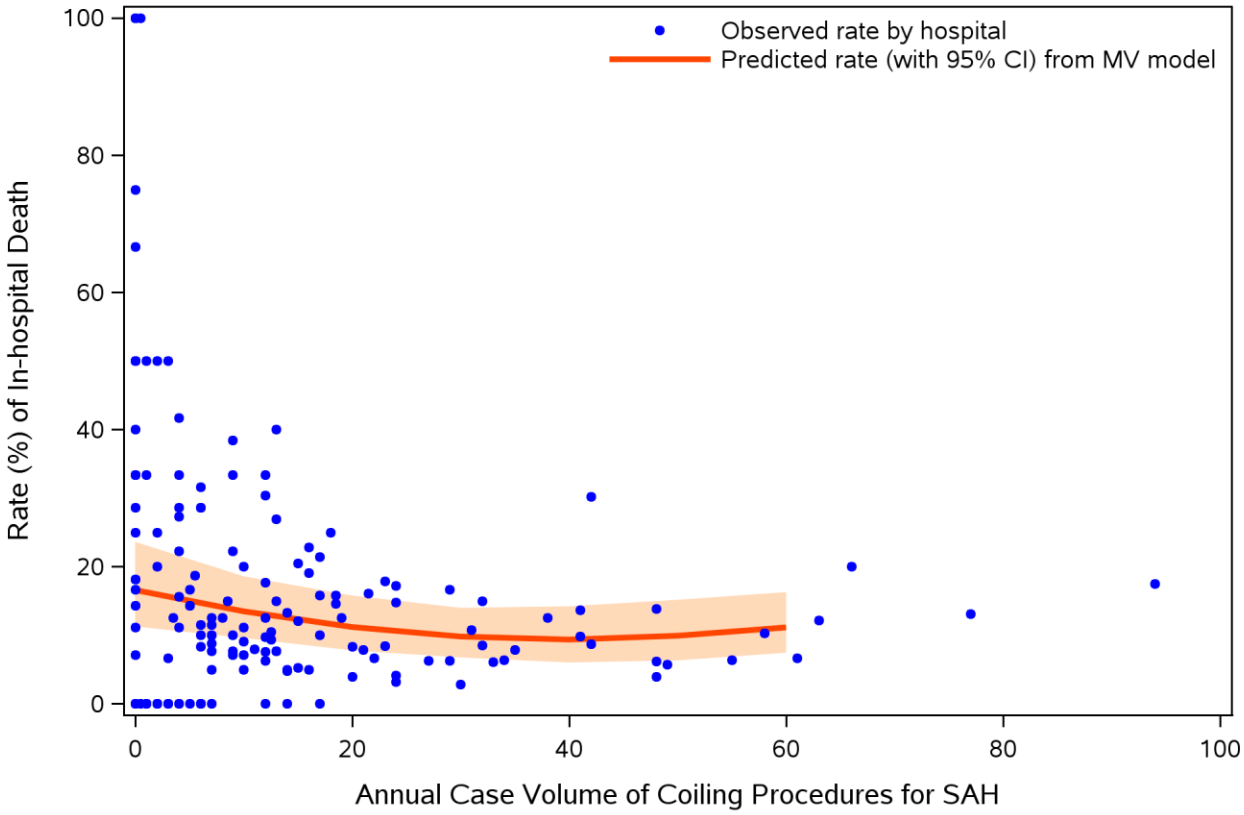
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S17. Observed and predicted rates of in-hospital death by ACV of coiling for SAH (primary cohort).



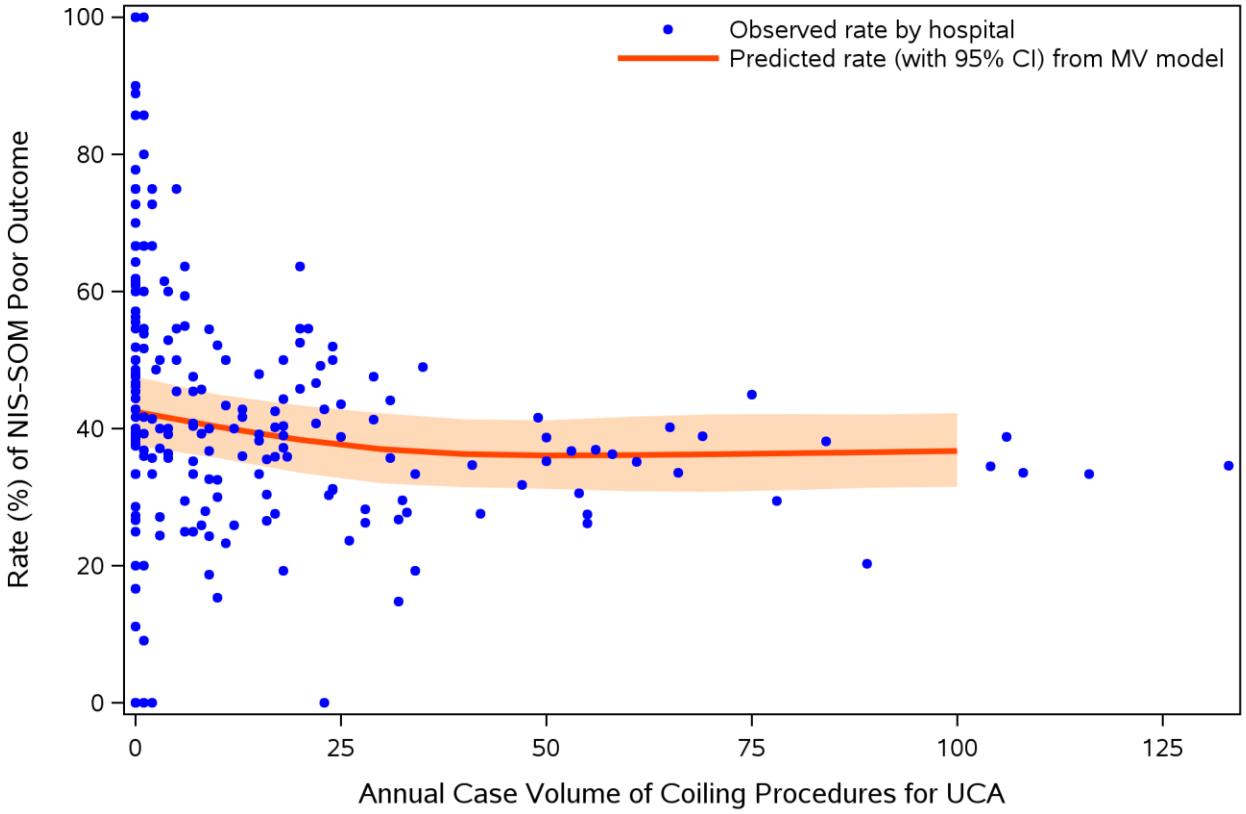
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S18. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling for SAH (secondary cohort).



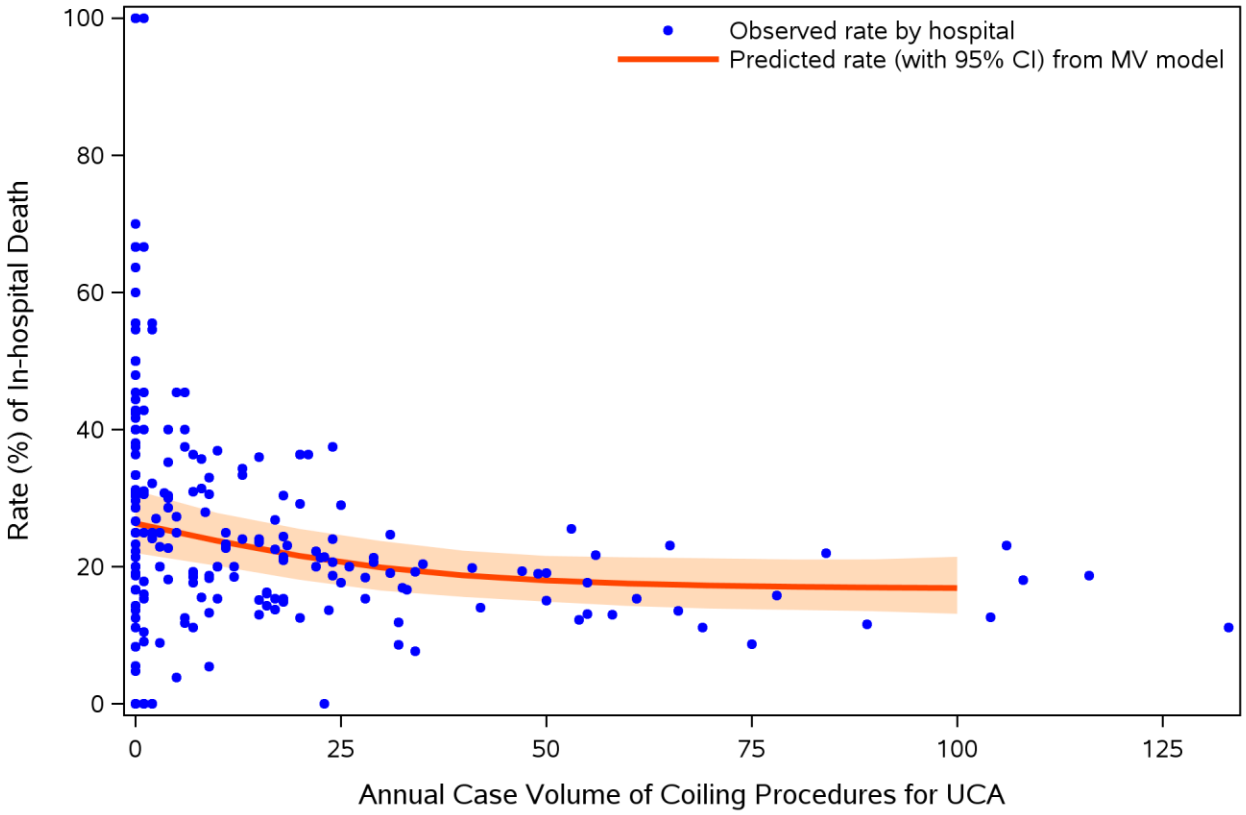
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S19. Observed and predicted rates of in-hospital death by ACV of coiling for SAH (secondary cohort).



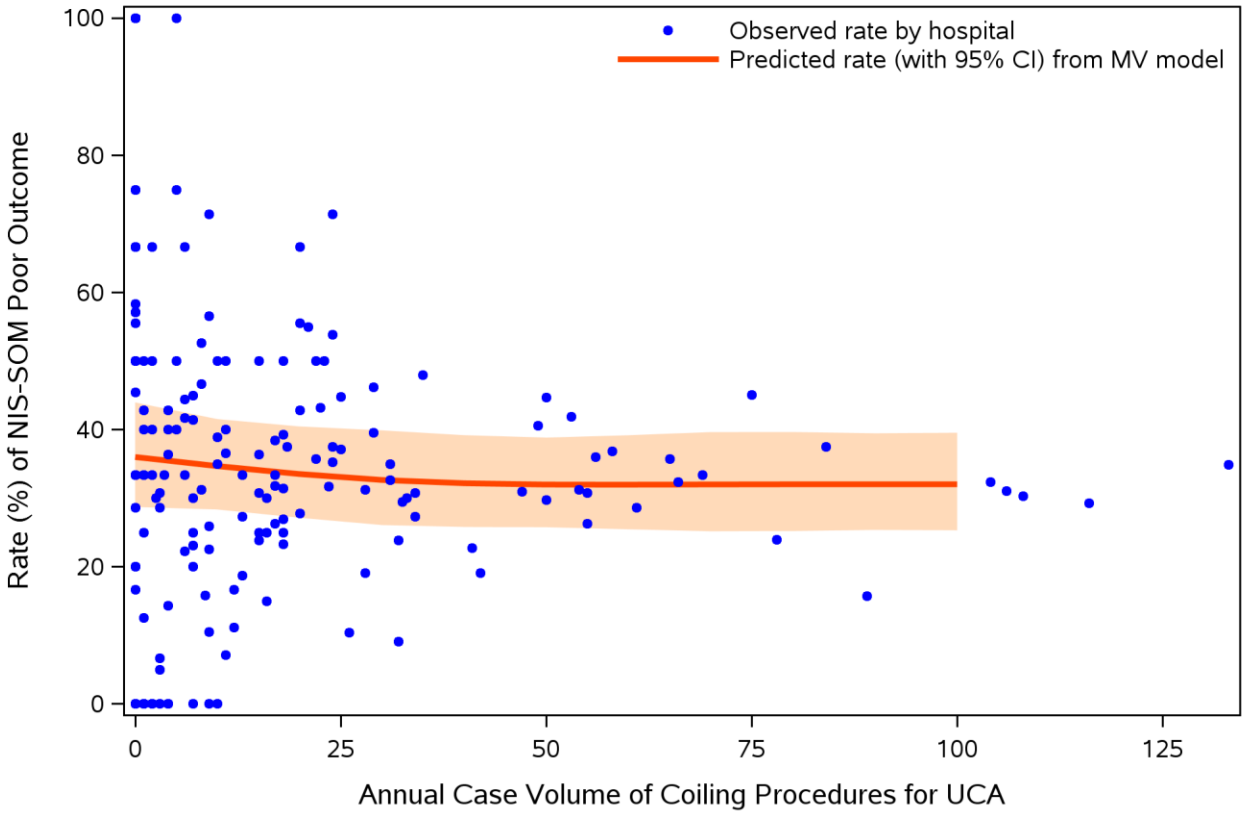
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S20. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling for UCA (primary cohort).



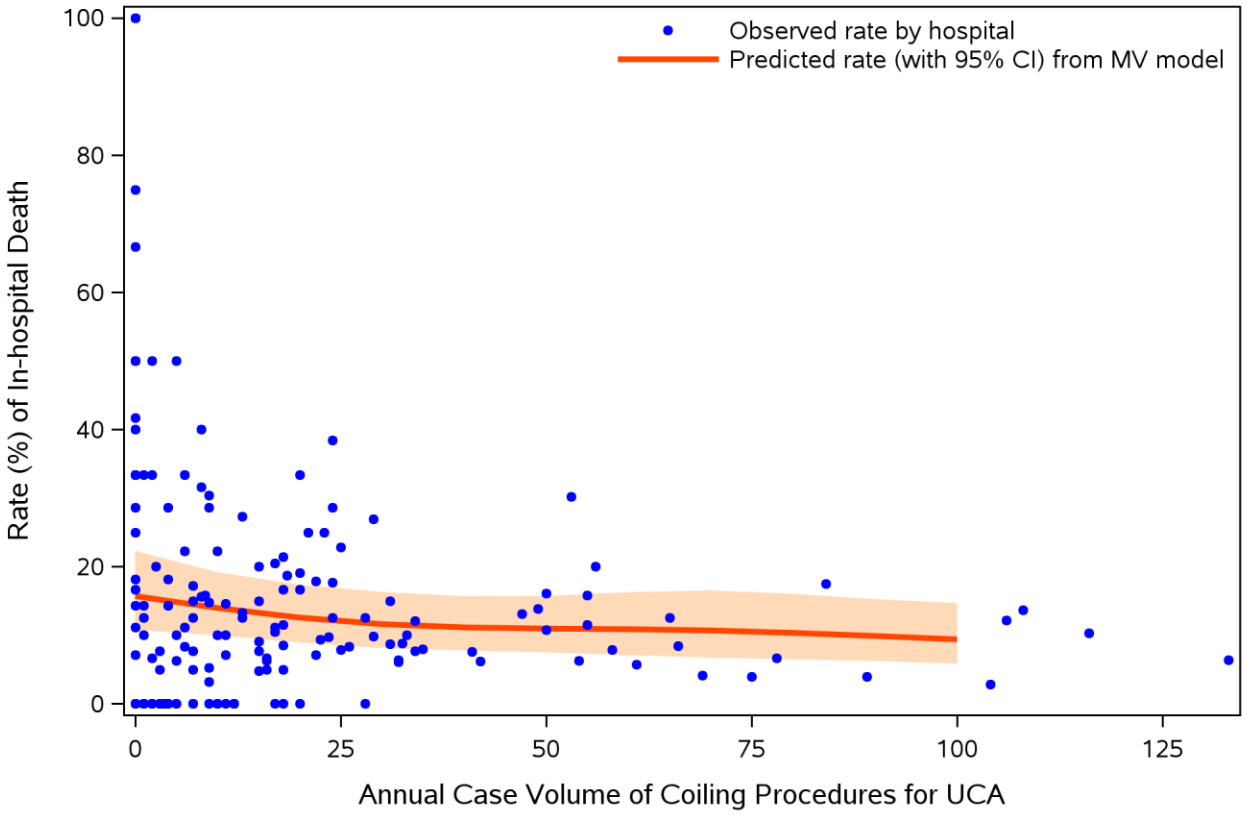
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S21. Observed and predicted rates of in-hospital death by ACV of Coiling for UCA (primary cohort).



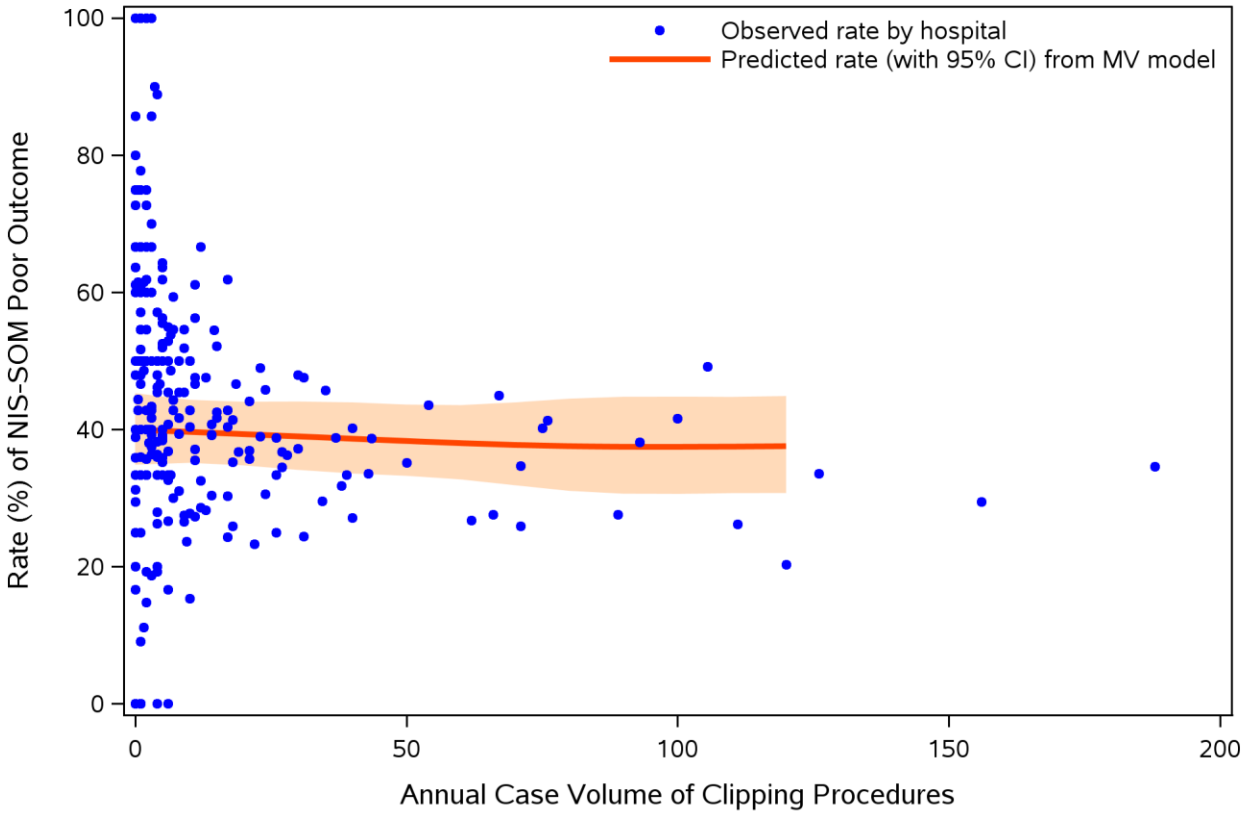
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S22. Observed and predicted rates of NIS-SOM poor outcome by ACV of coiling for UCA (secondary cohort).



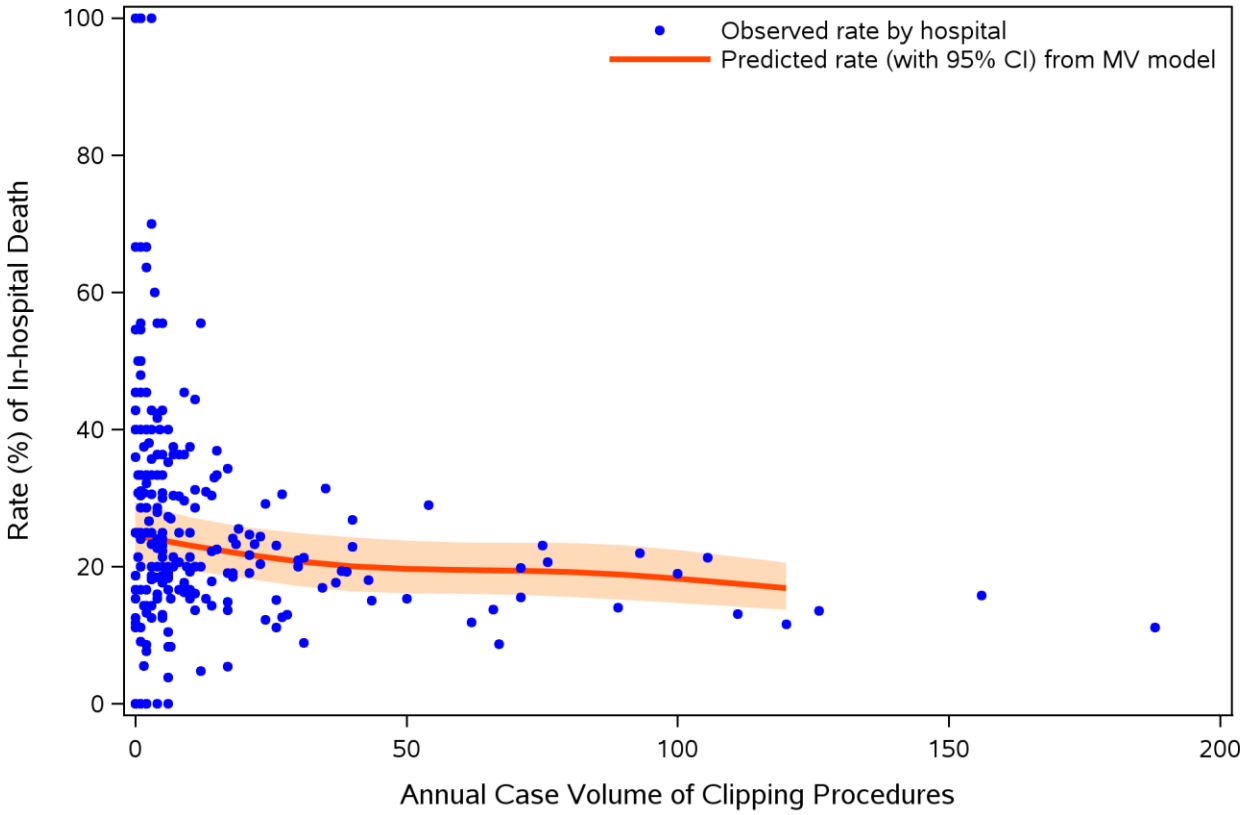
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S23. Observed and predicted rates of in-hospital death by ACV of coiling for UCA (secondary cohort).



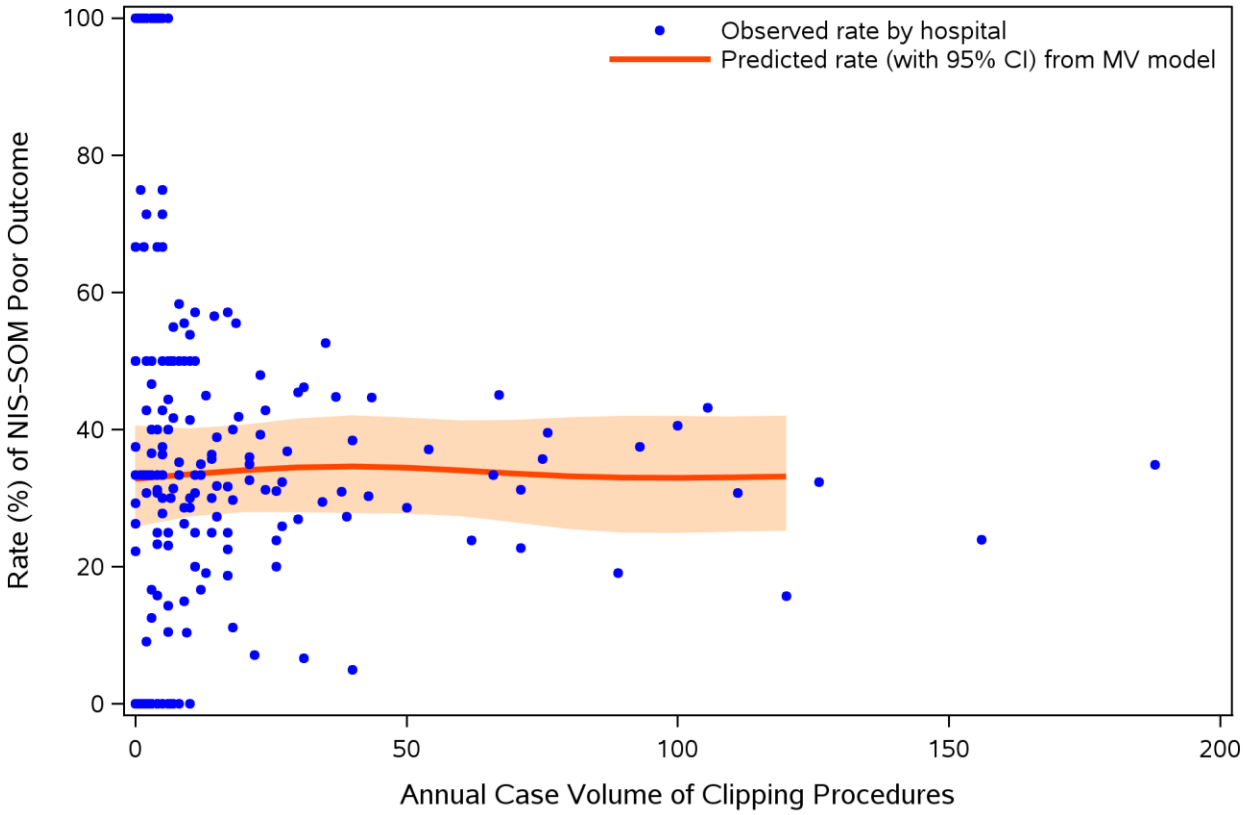
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S24. Observed and predicted rates of NIS-SOM poor outcome by ACV of clipping (primary cohort).



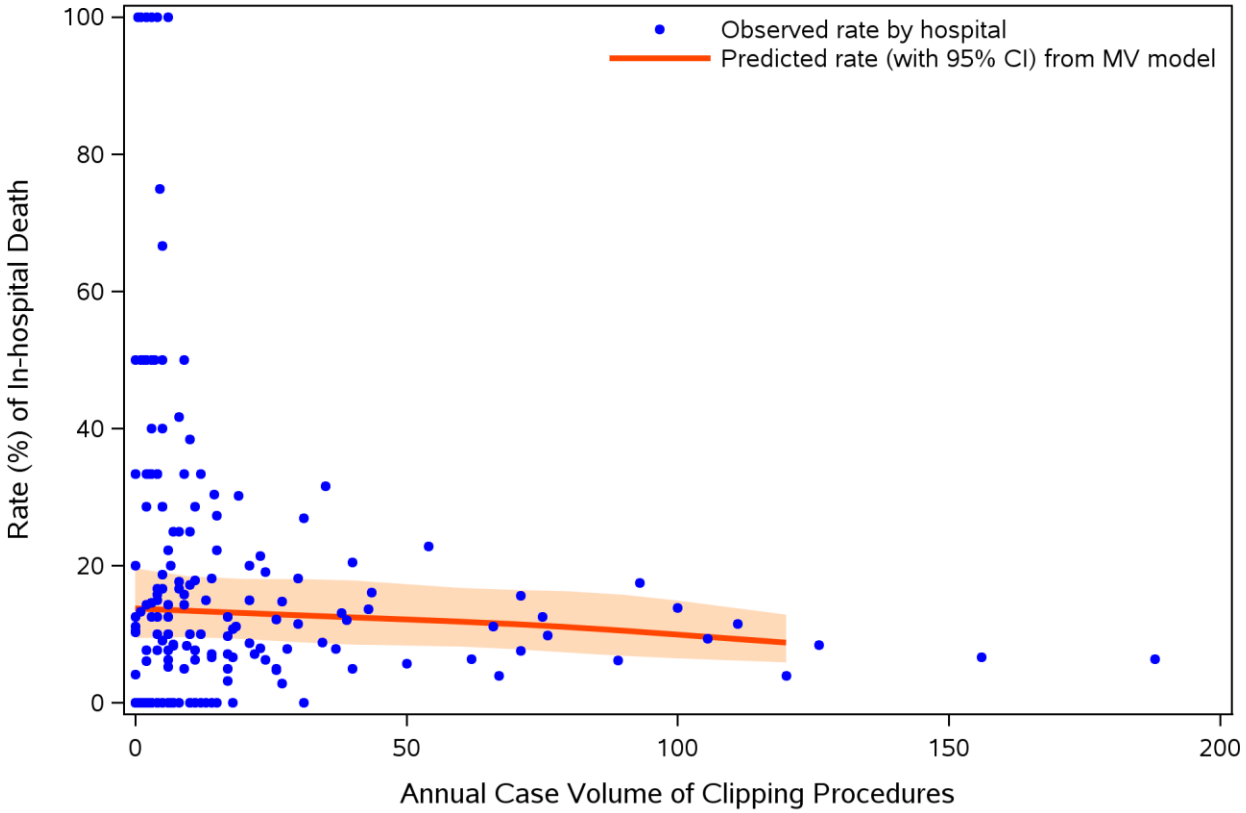
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S25. Observed and predicted rates of in-hospital death by ACV of clipping (primary cohort).



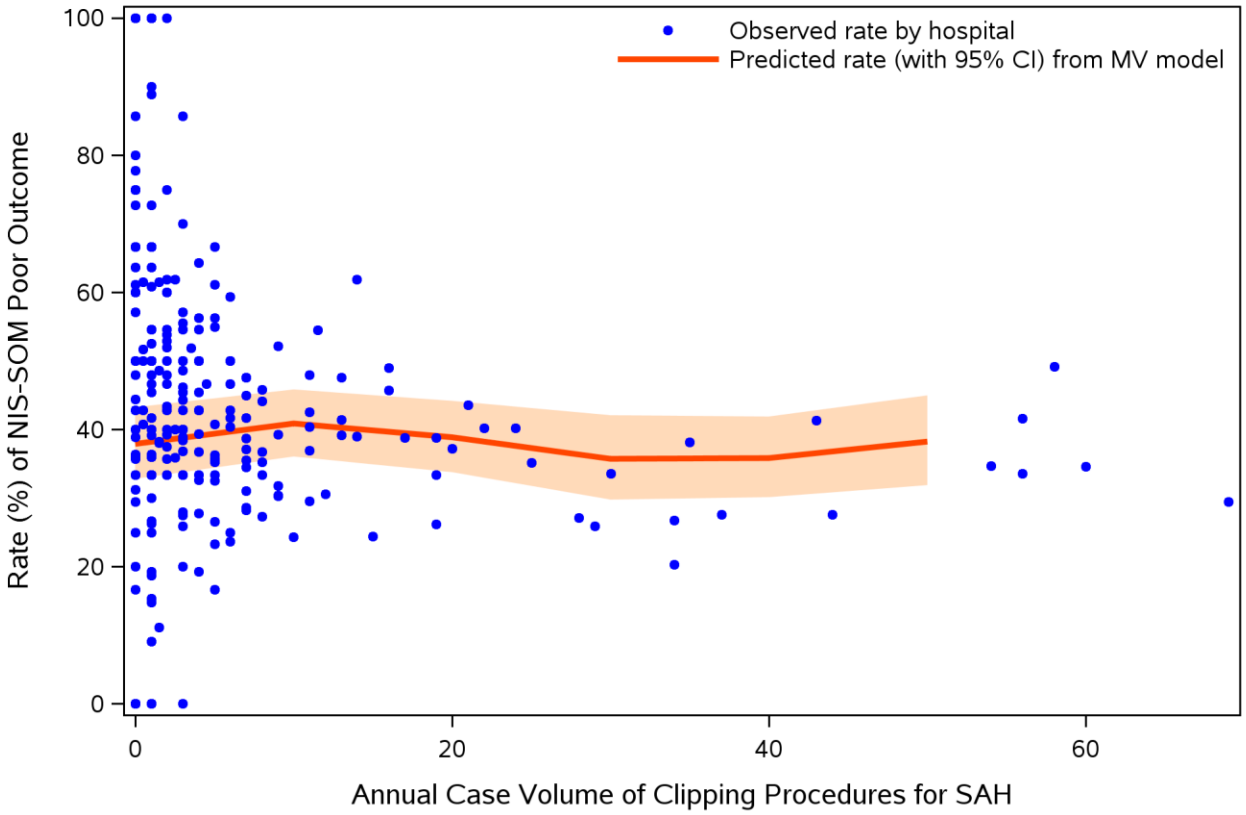
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S26. Observed and predicted rates of NIS-SOM poor outcome by ACV of clipping (secondary cohort).



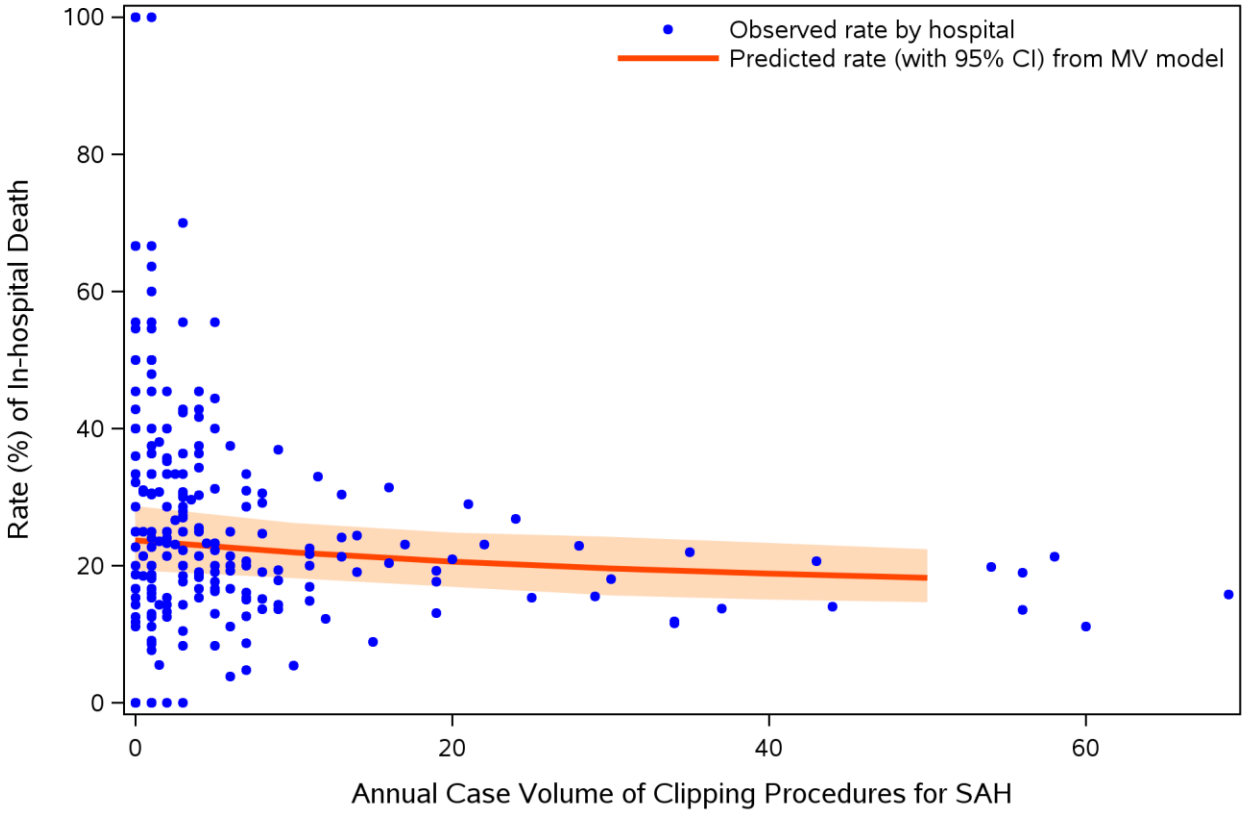
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S27. Observed and predicted rates of in-hospital death by ACV of Clipping (secondary cohort).



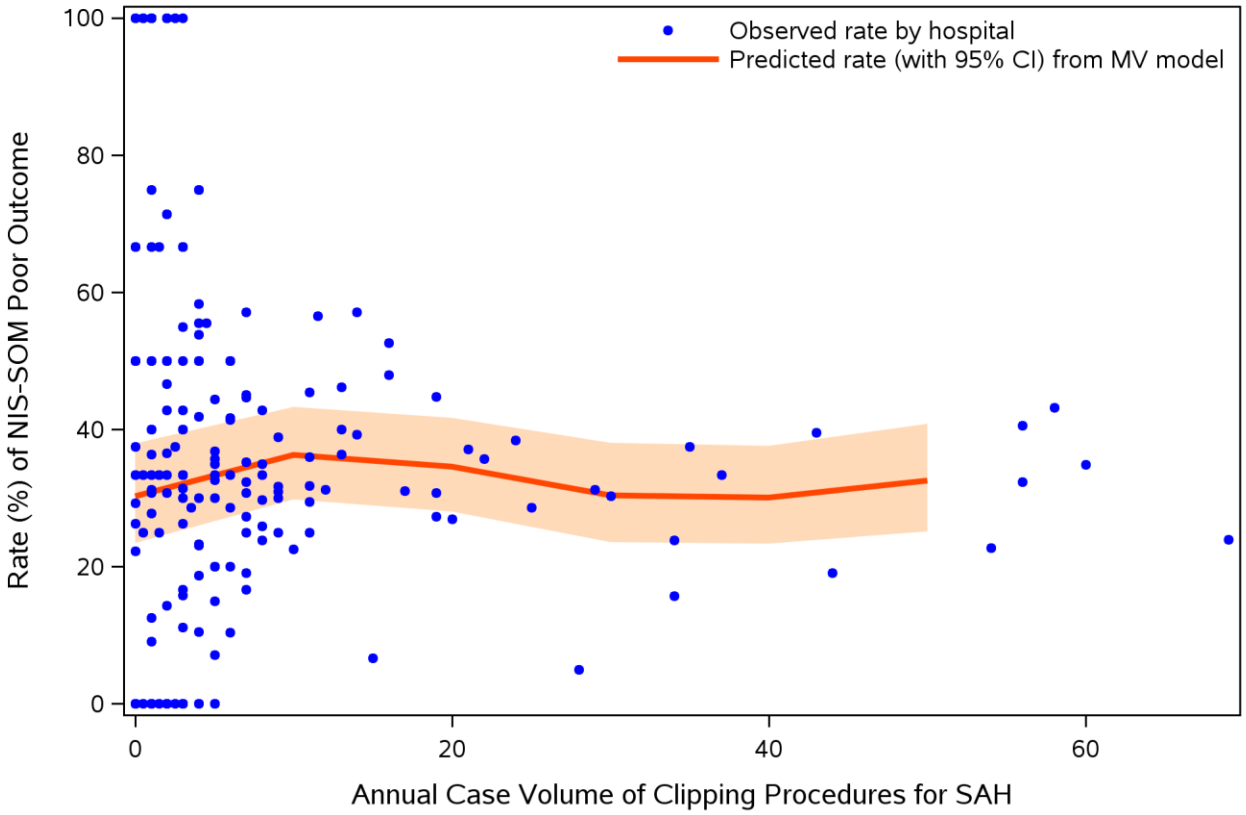
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S28. Observed and predicted rates of NIS-SOM poor outcome by ACV of clipping for SAH (primary cohort).



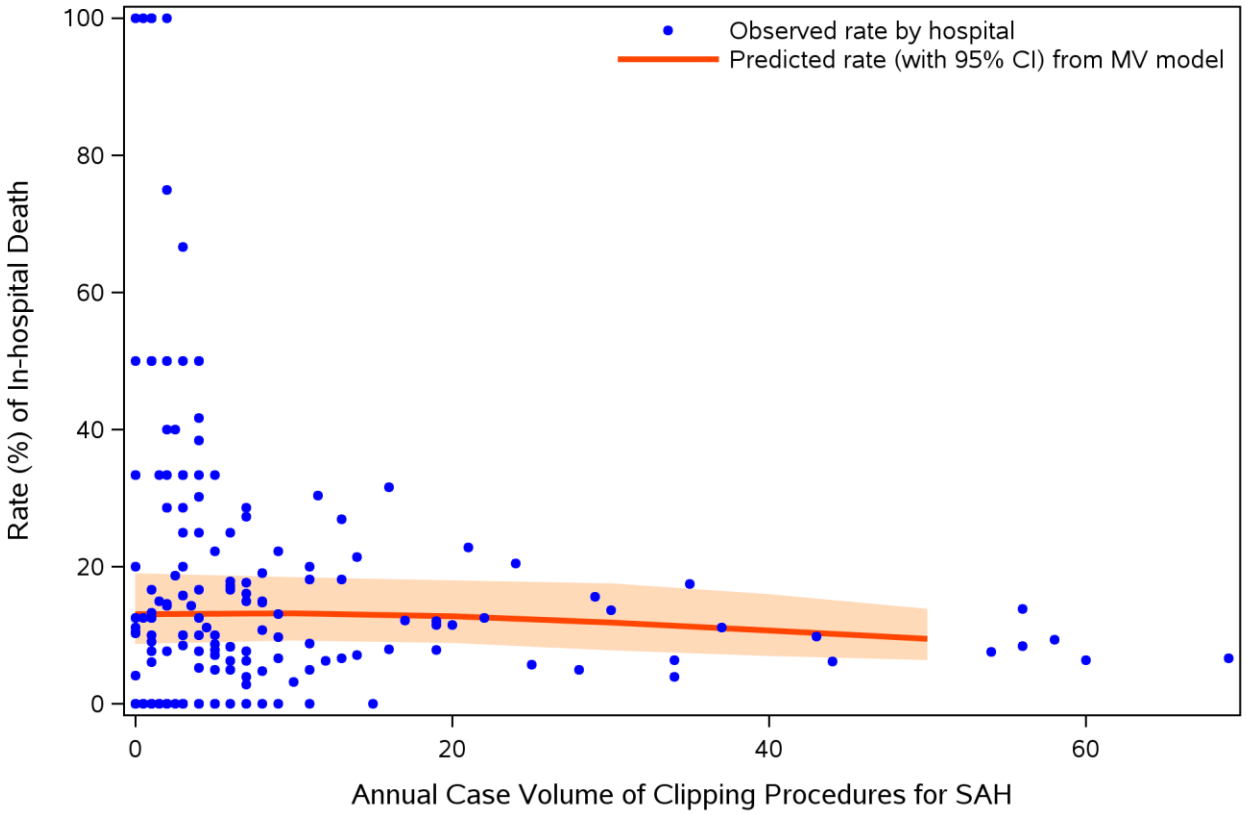
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S29. Observed and predicted rates of in-hospital death by ACV of clipping for SAH (primary cohort).



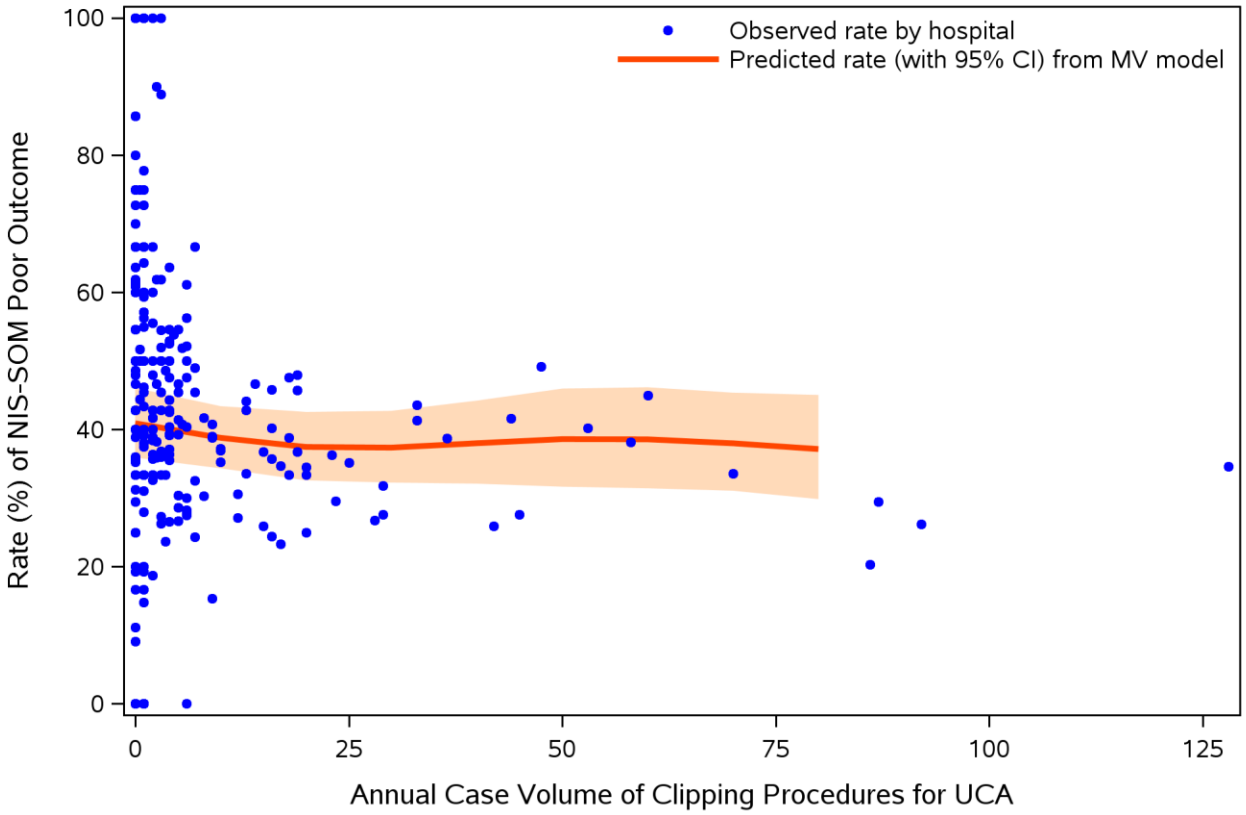
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S30. Observed and predicted rates of NIS-SOM poor outcome by ACV of clipping for SAH (secondary cohort).



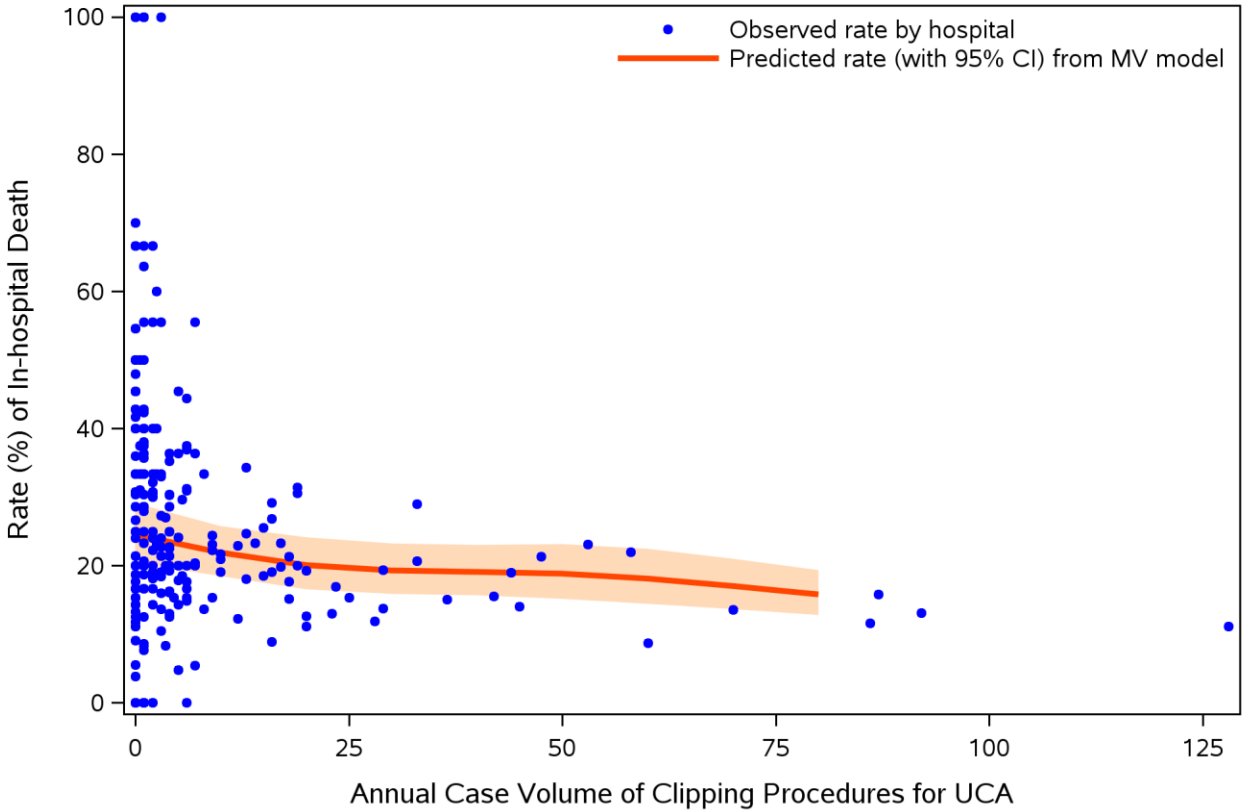
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S31. Observed and predicted rates of in-hospital death by ACV of clipping for SAH (secondary cohort).



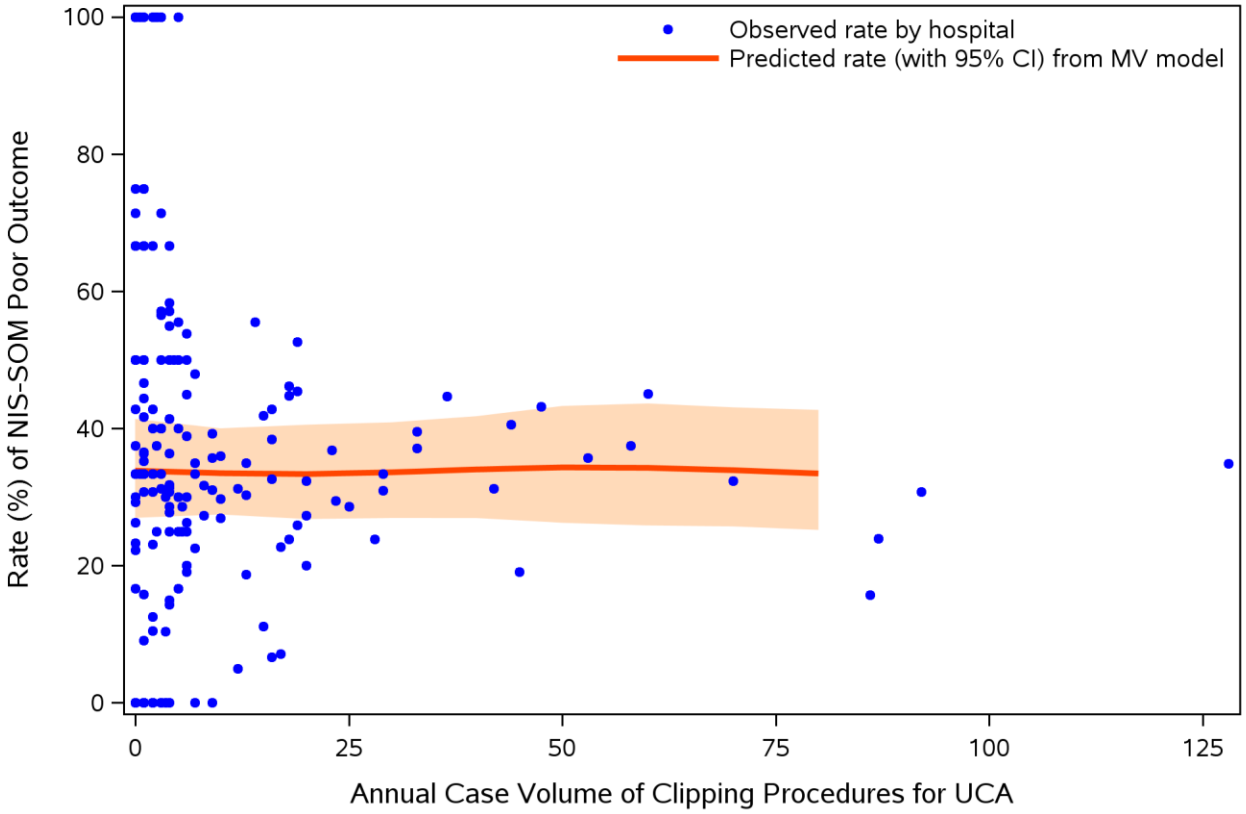
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S32. Observed and predicted rates of NIS-SOM poor outcome by ACV of clipping for UCA (primary cohort).



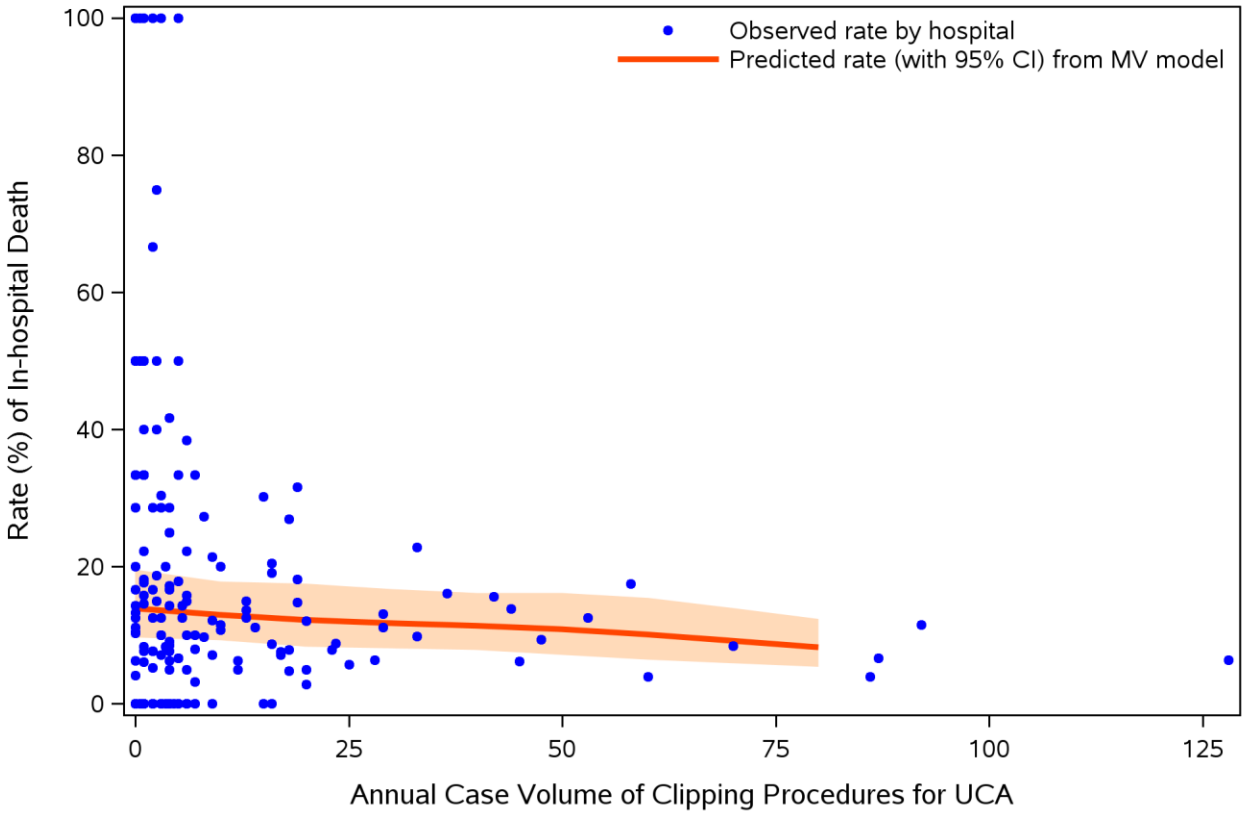
Results for primary analysis cohort: all SAH admissions
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S33. Observed and predicted rates of in-hospital death by ACV of clipping for UCA (primary cohort).



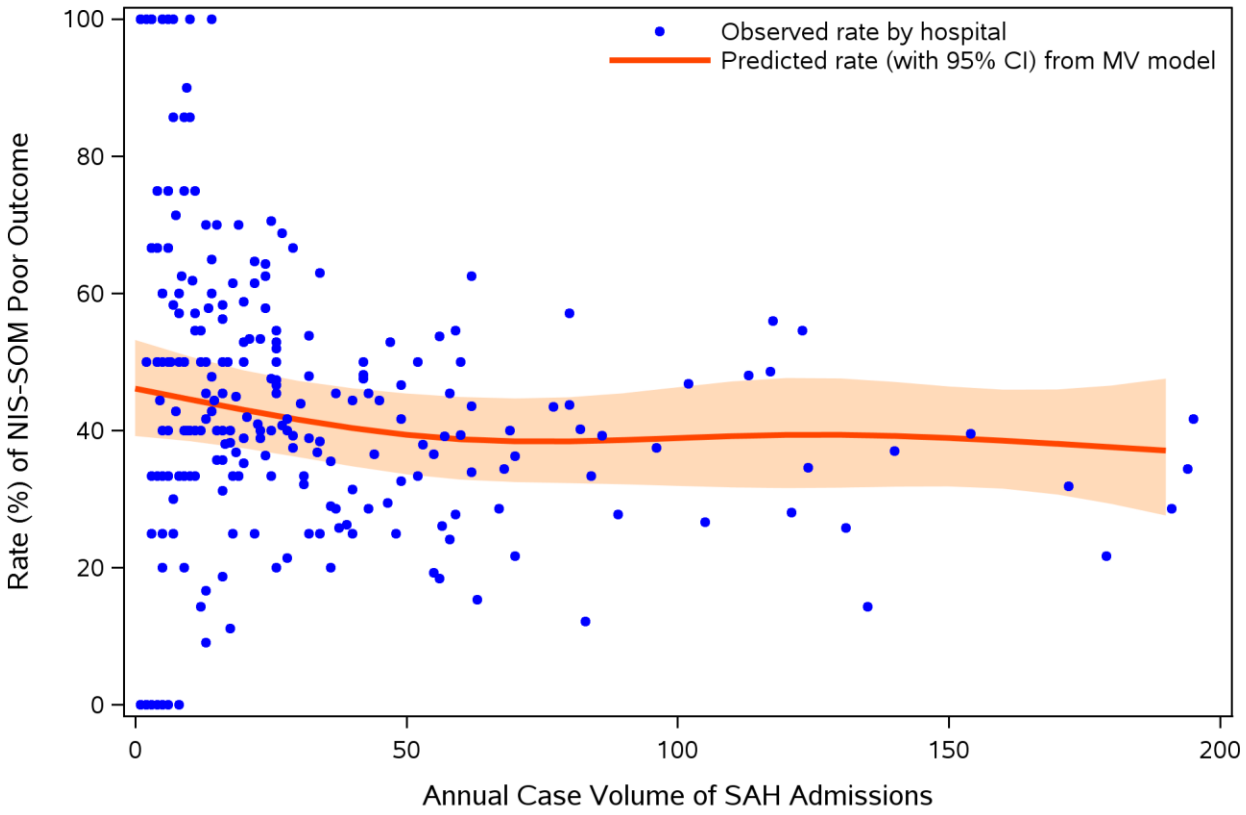
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S34. Observed and predicted rates of NIS-SOM poor outcome by ACV of Clipping for UCA (secondary cohort).



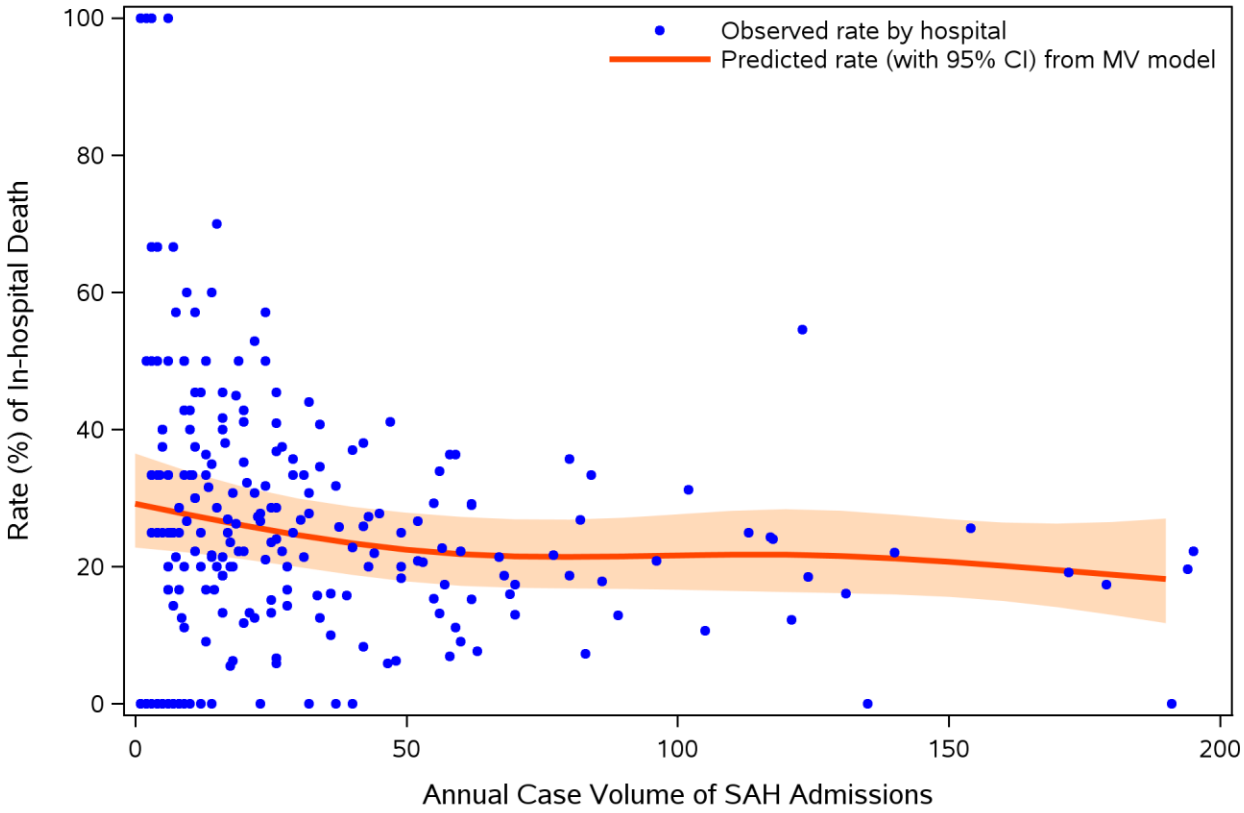
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S35. Observed and predicted rates of in-hospital death by ACV of clipping for UCA (secondary cohort).



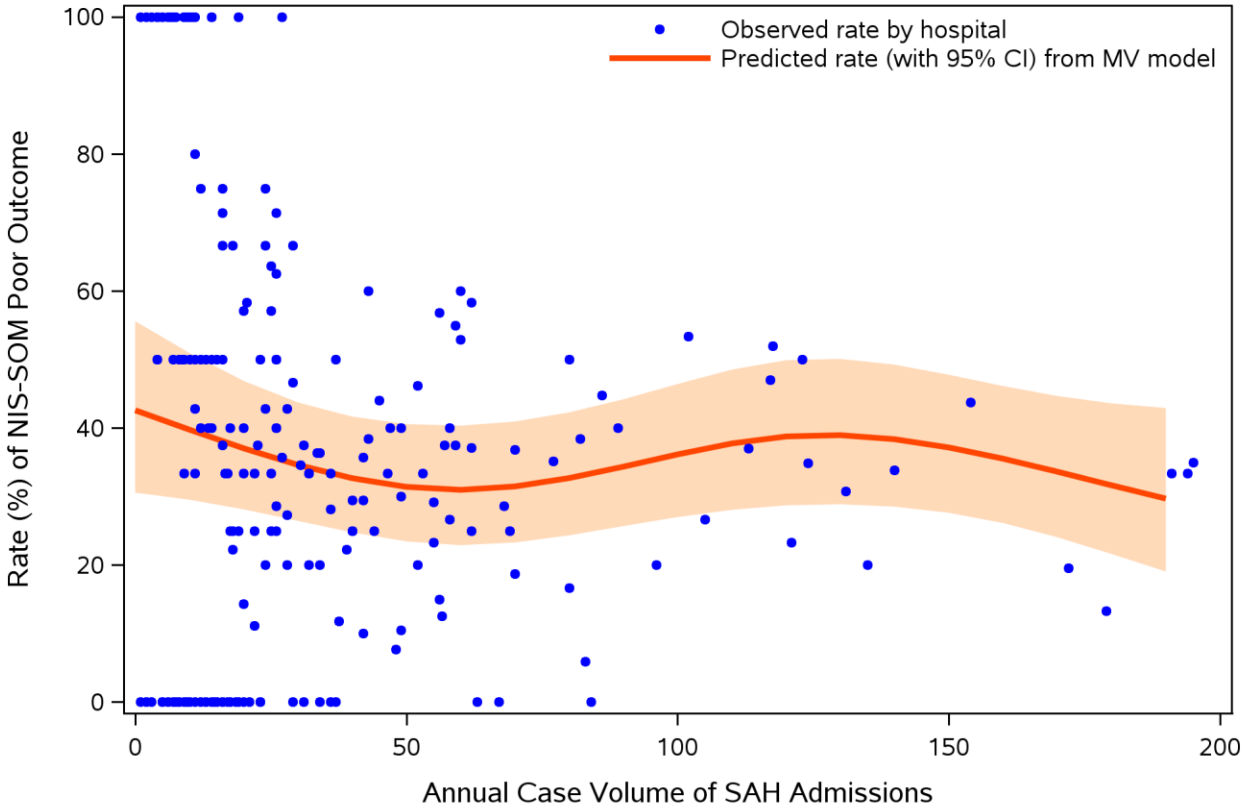
Results for primary analysis cohort: all SAH admissions, excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S36. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (primary cohort), excluding patients who transfer in from another acute care facility.



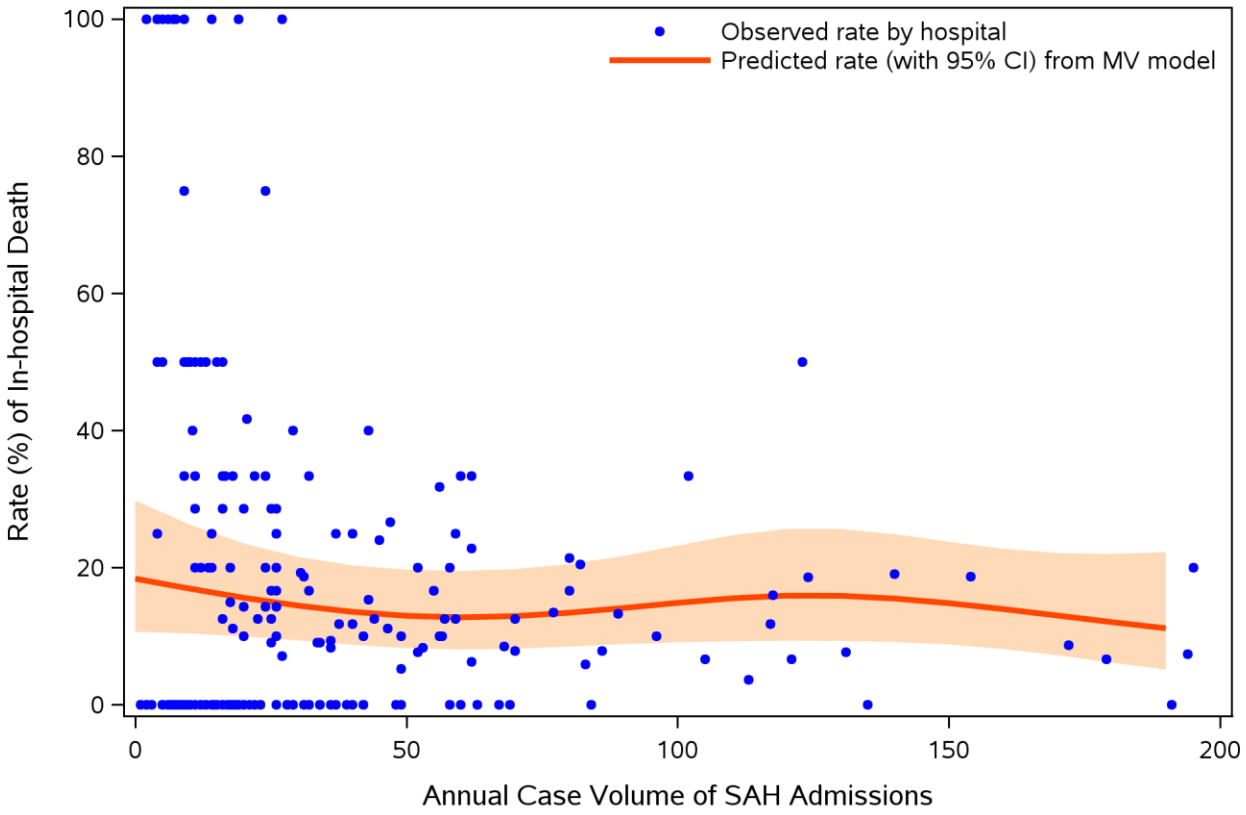
Results for primary analysis cohort: all SAH admissions, excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S37. Observed and predicted rates of in-hospital death by ACV of SAH admissions (primary cohort), excluding patients who transfer in from another acute care facility.



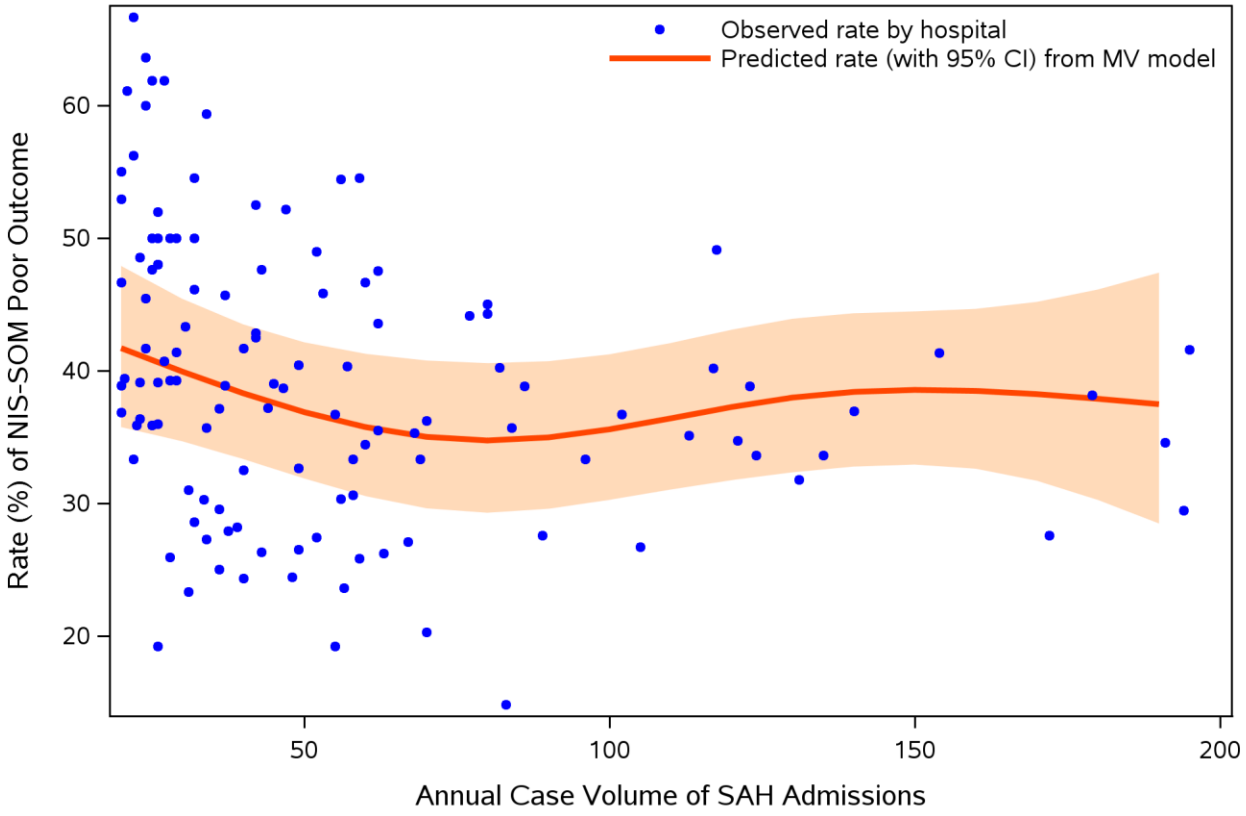
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling, excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S38. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (secondary cohort), excluding patients who transfer in from another acute care facility.



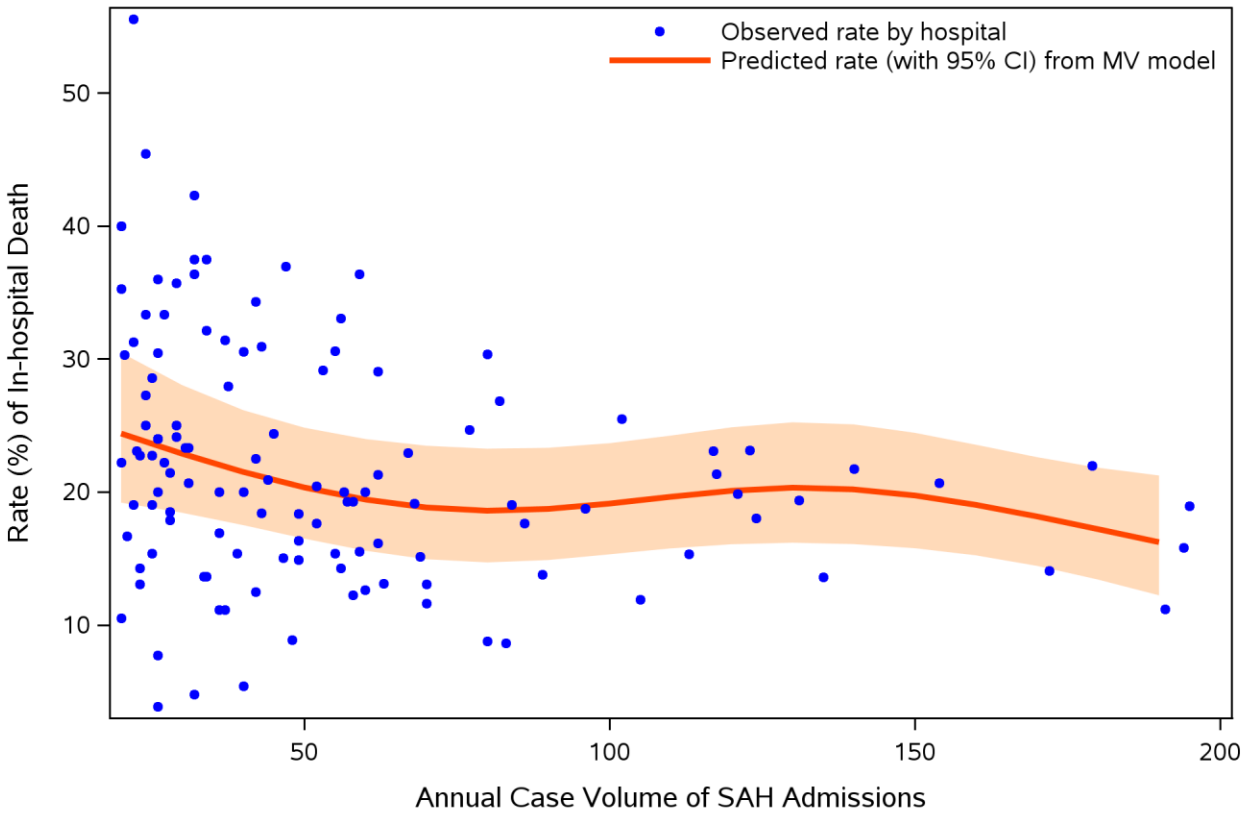
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling, excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S39. Observed and predicted rates of in-hospital death by ACV of SAH admissions (secondary cohort), excluding patients who transfer in from another acute care facility.



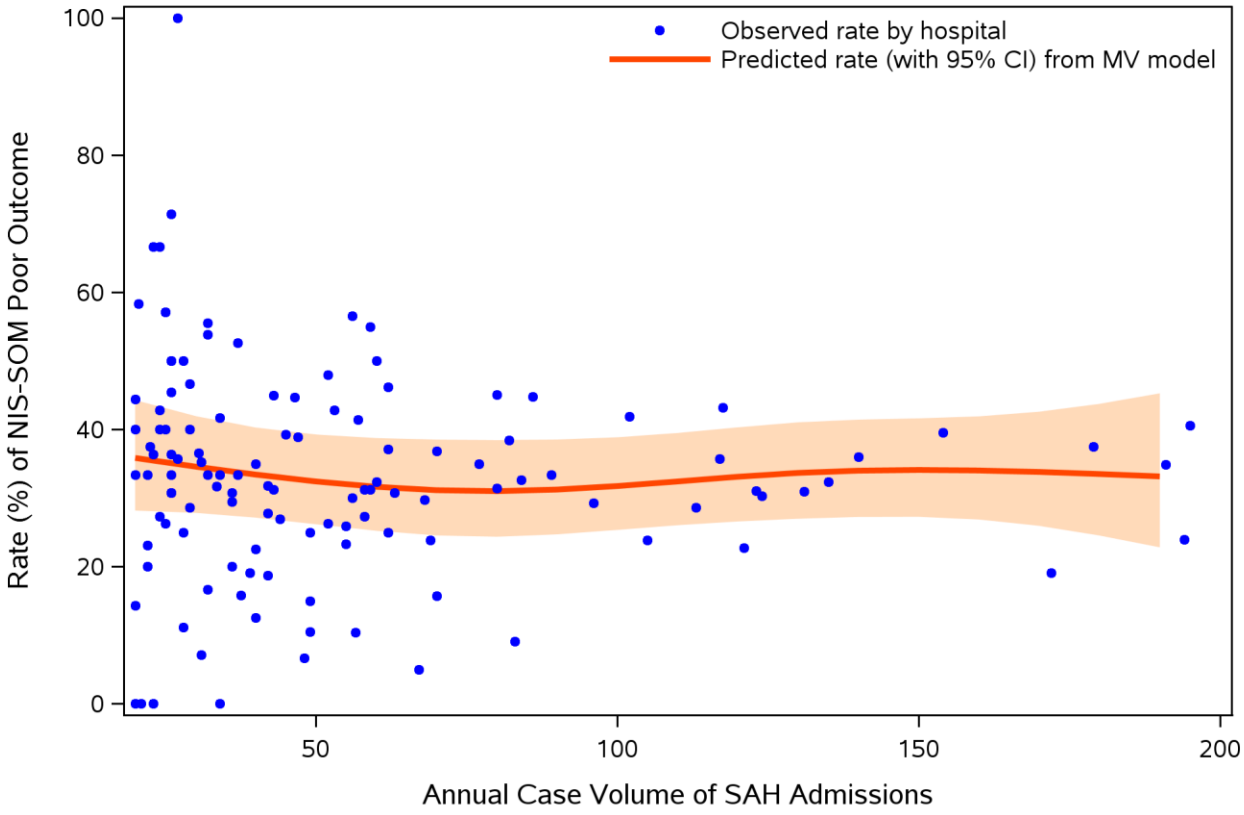
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 20 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S40. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (primary cohort), among hospitals with SAH ACV ≥ 20.



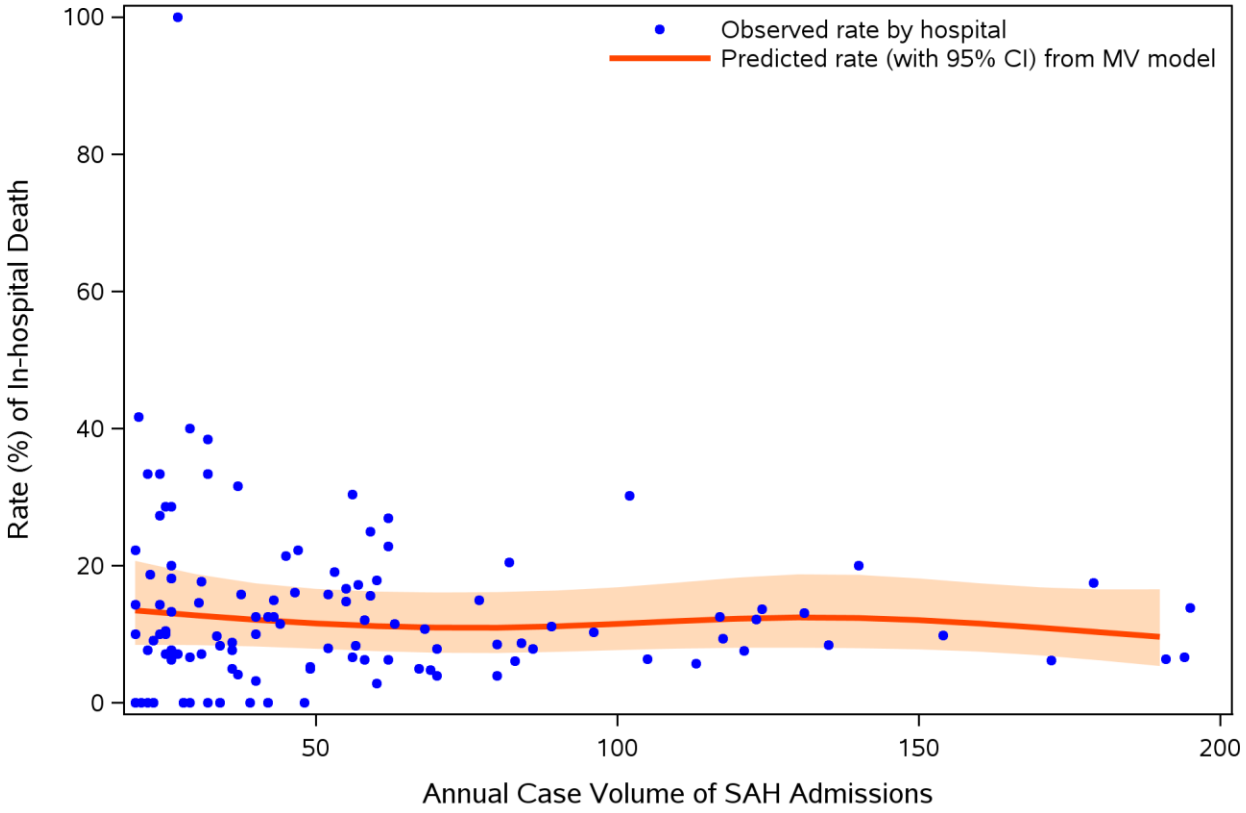
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 20 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S41. Observed and predicted rates of in-hospital death by ACV of SAH admissions (primary cohort), among hospitals with SAH ACV ≥ 20.



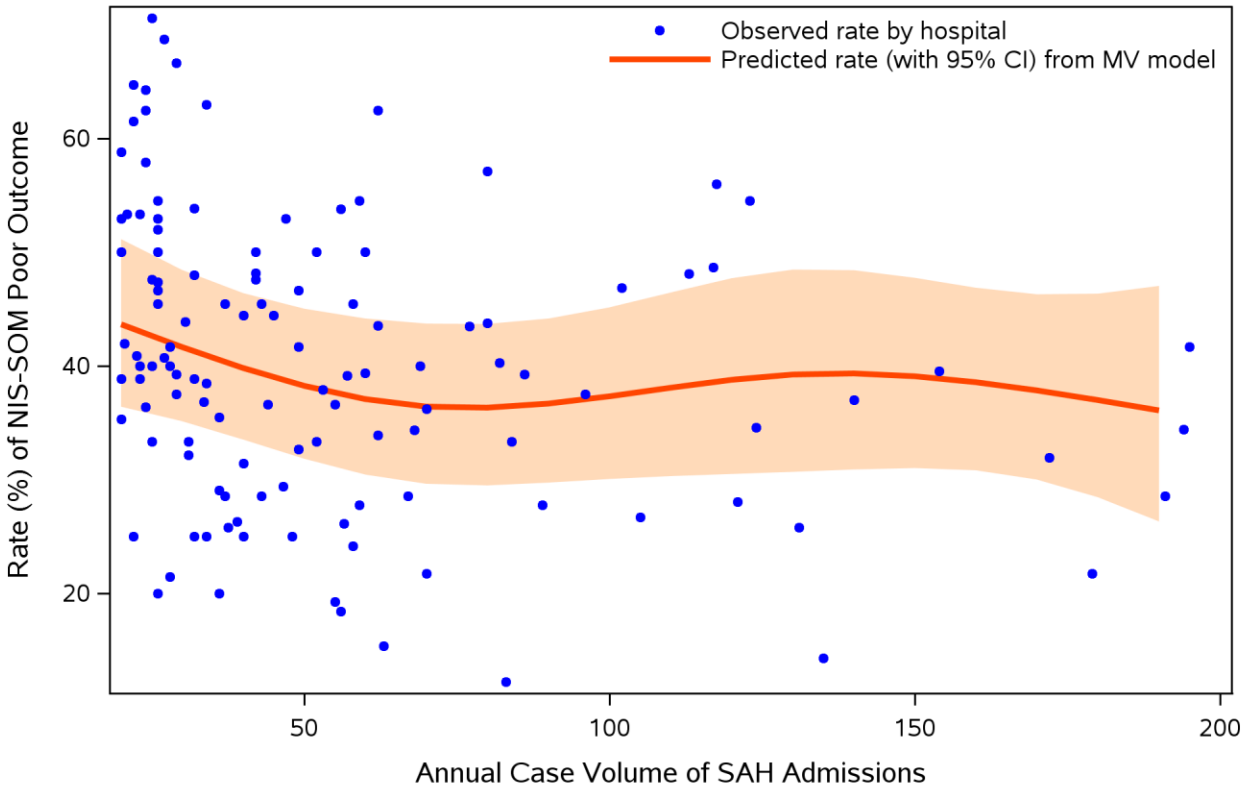
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling, among hospitals with SAH ACV of 20 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S42. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (secondary cohort), among hospitals with SAH ACV ≥ 20.



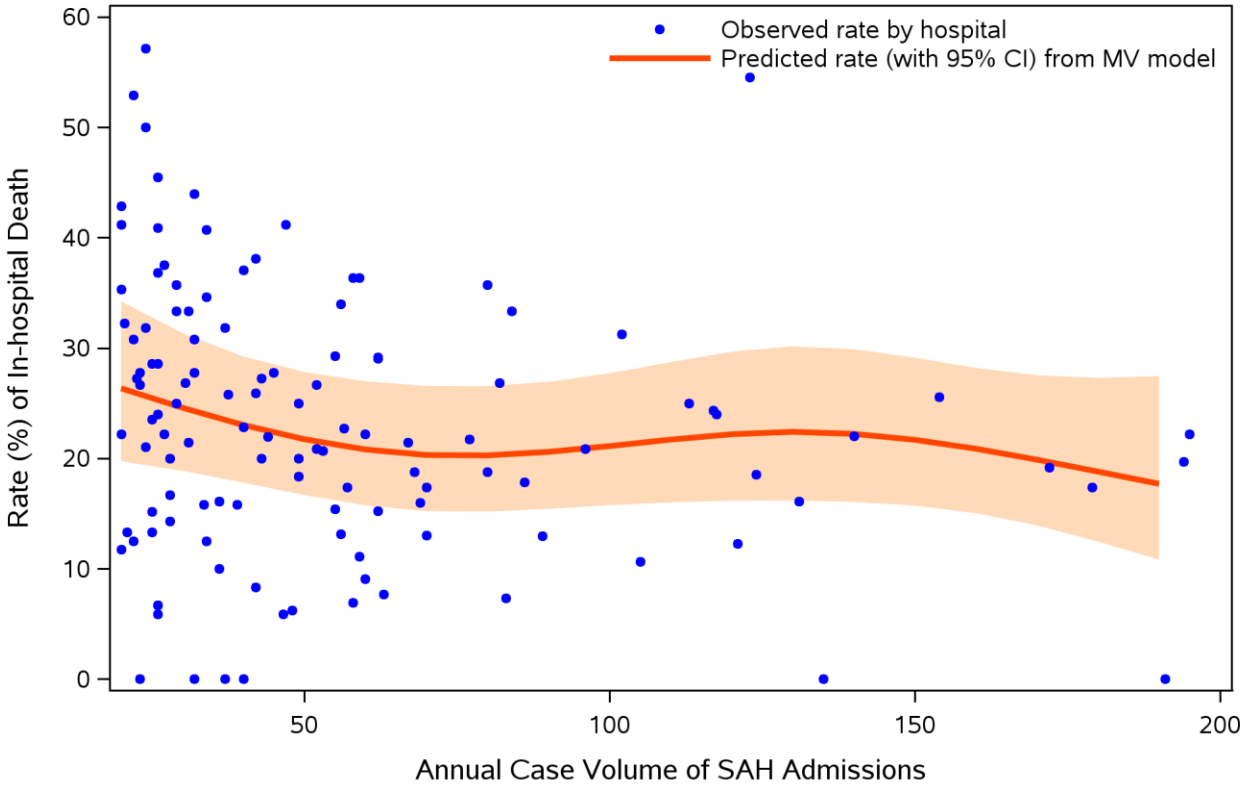
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling, among hospitals with SAH ACV of 20 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S43. Observed and predicted rates of in-hospital death by ACV of SAH admissions (secondary cohort), among hospitals with SAH ACV ≥ 20.



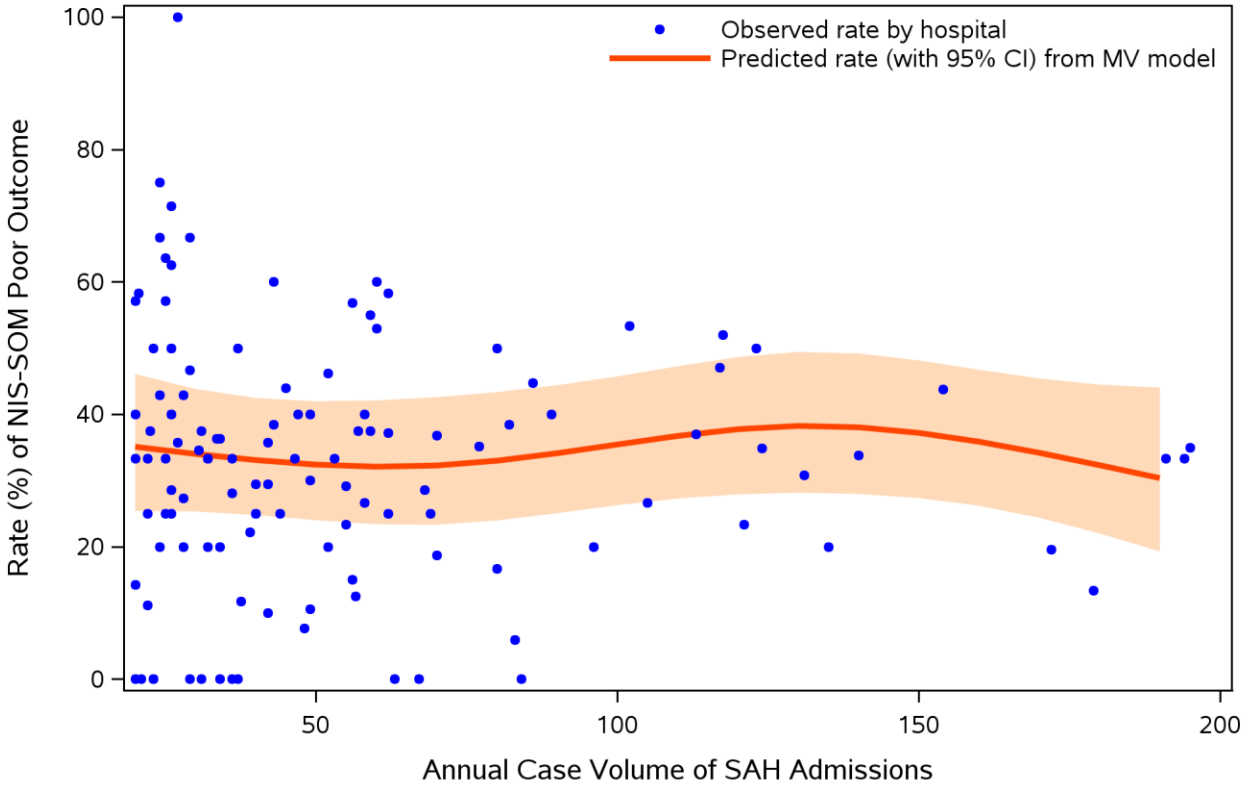
Results for primary analysis cohort: all SAH admissions
Among hospitals with SAH ACV of 20 or higher and excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S44. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (primary cohort), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer in.



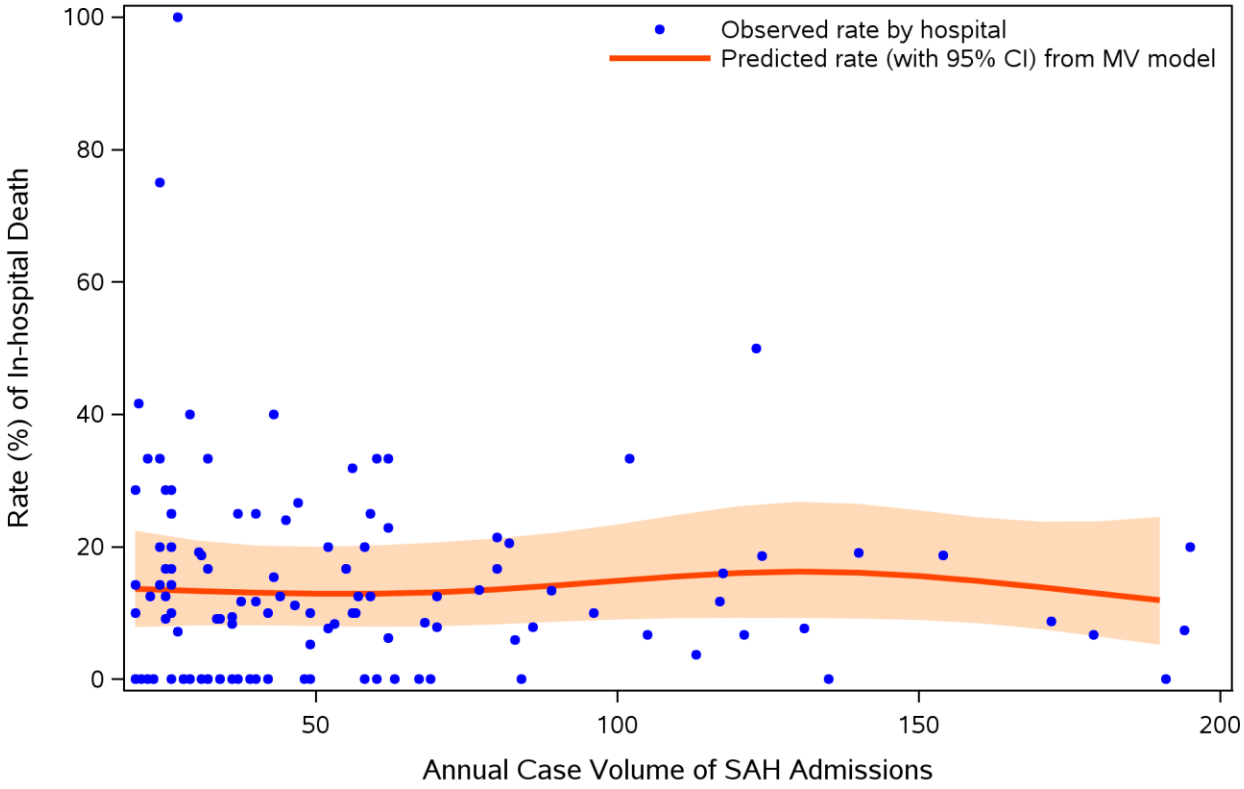
Results for primary analysis cohort: all SAH admissions
Among hospitals with SAH ACV of 20 or higher and excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S45. Observed and predicted rates of in-hospital death by ACV of SAH admissions (primary cohort), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer in.



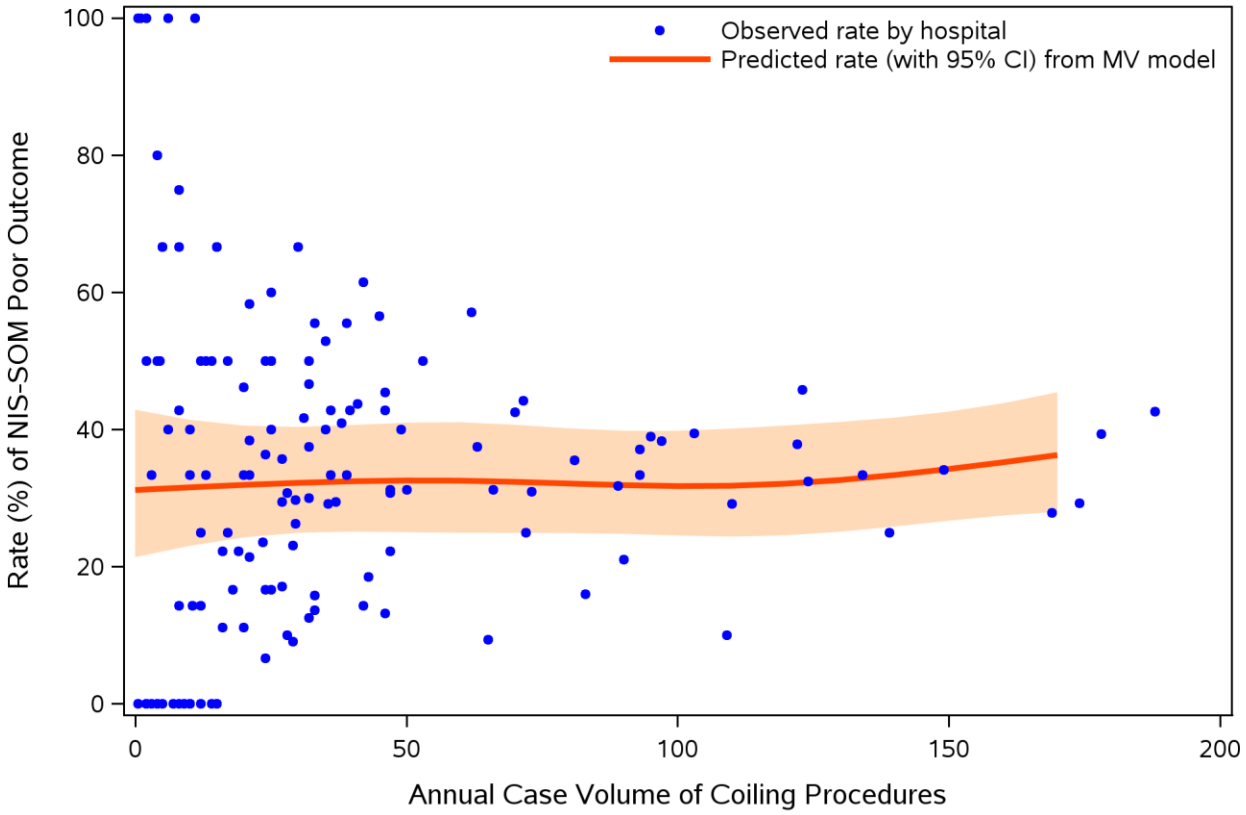
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
Among hospitals with SAH ACV of 20 or higher and excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S46. Observed and predicted rates of NIS-SOM poor outcome by ACV of SAH admissions (secondary cohort), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer in.



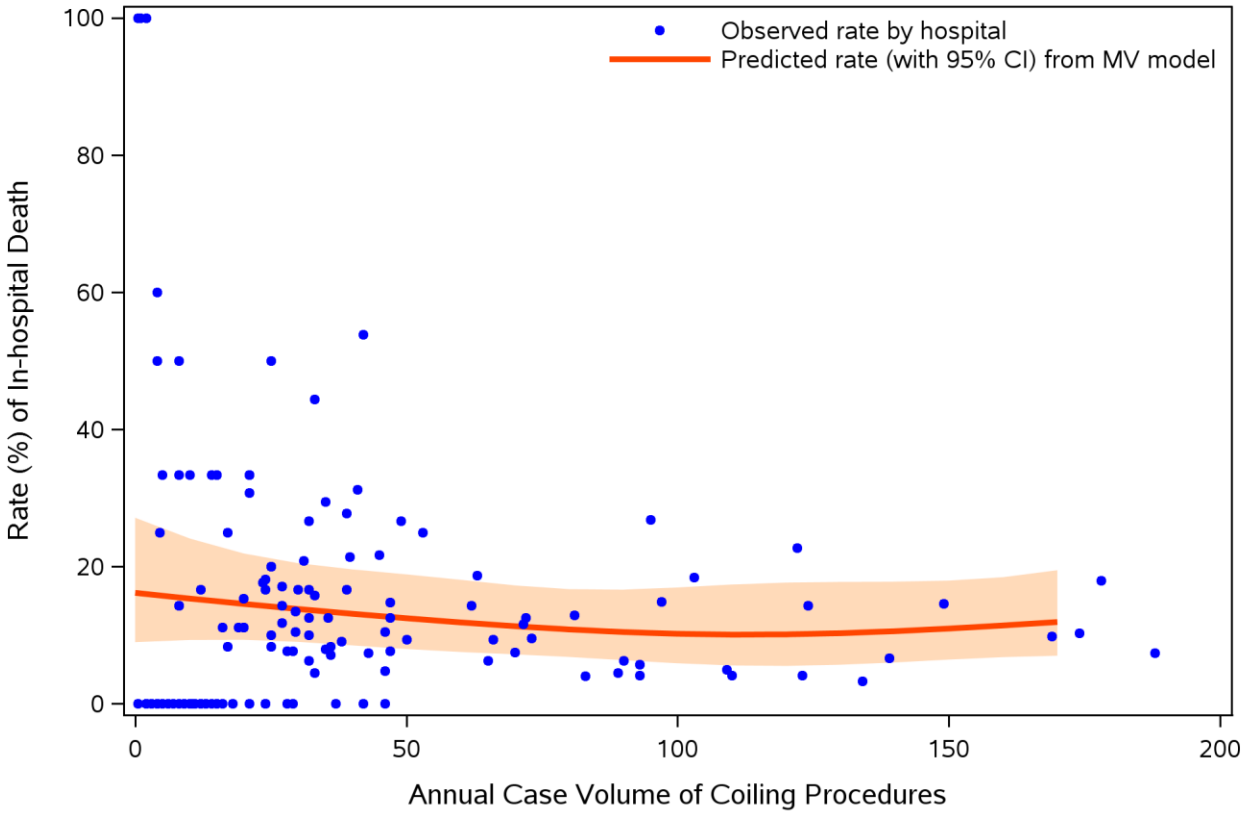
Results for secondary analysis cohort: SAH admissions who underwent clipping or coiling
Among hospitals with SAH ACV of 20 or higher and excluding patients who transfer from acute care
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 20 to the 99th percentile of the ACV distribution.

Figure S47. Observed and predicted rates of in-hospital death by ACV of SAH admissions (secondary cohort), among hospitals with SAH ACV ≥ 20 and excluding patients who transfer in.



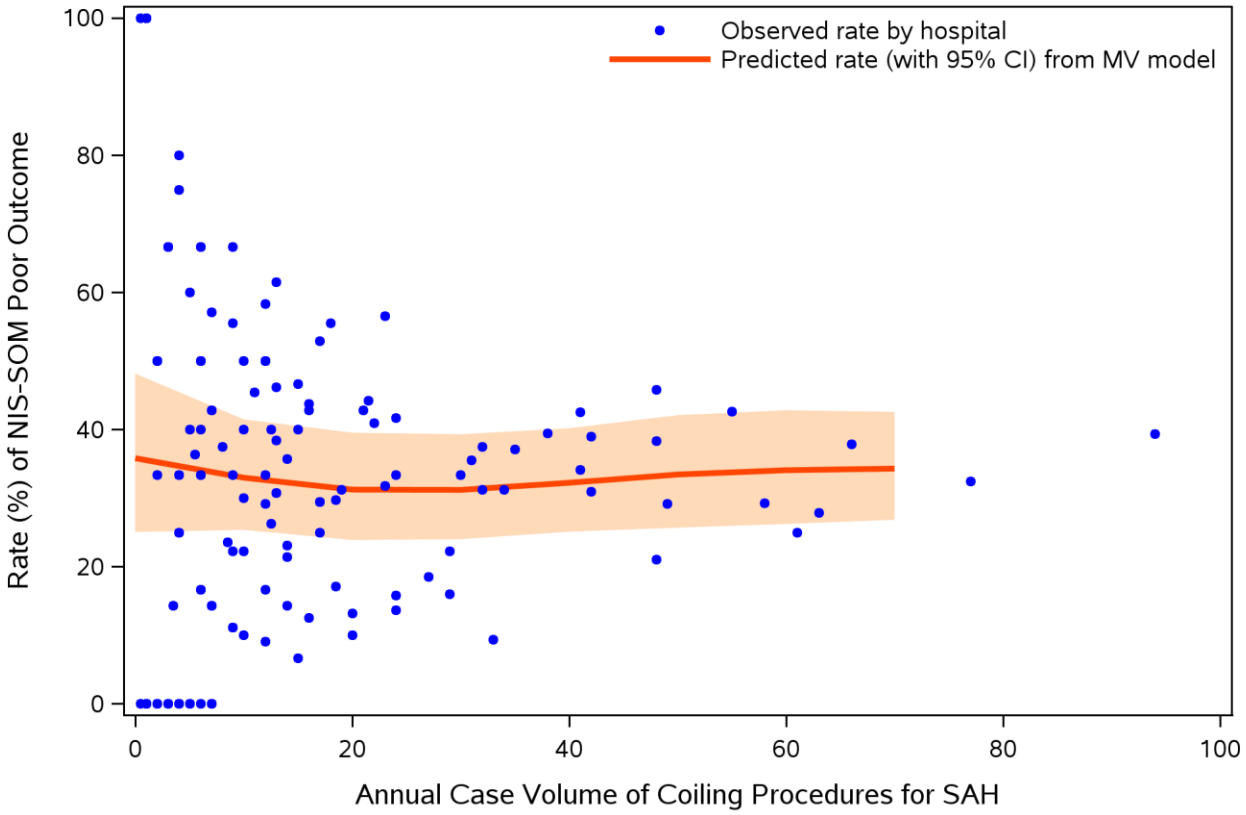
Results for subgroup: SAH admissions who underwent coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S48. NIS-SOM by Coiling ACV, for SAH pts who undergo coiling.



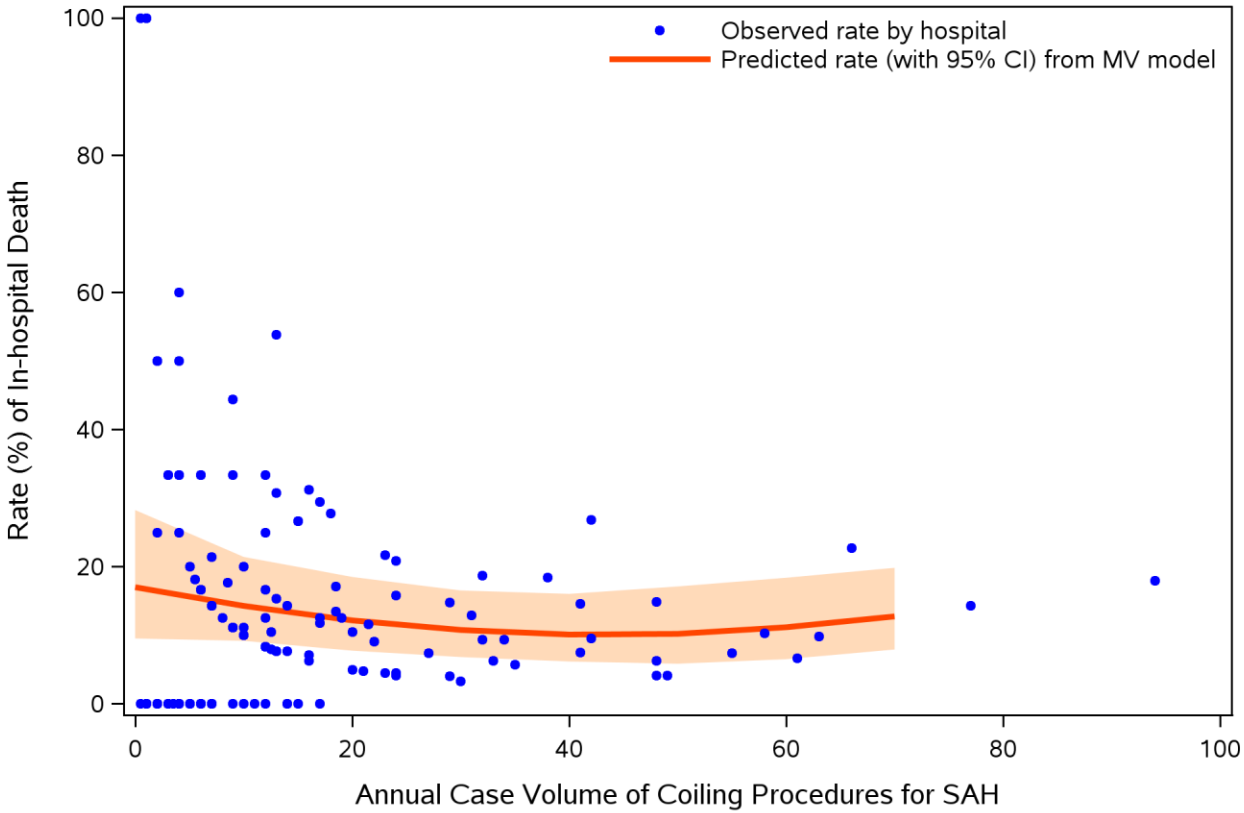
Results for subgroup: SAH admissions who underwent coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S49. In-hospital mortality by Coiling ACV, for SAH pts who undergo coiling.



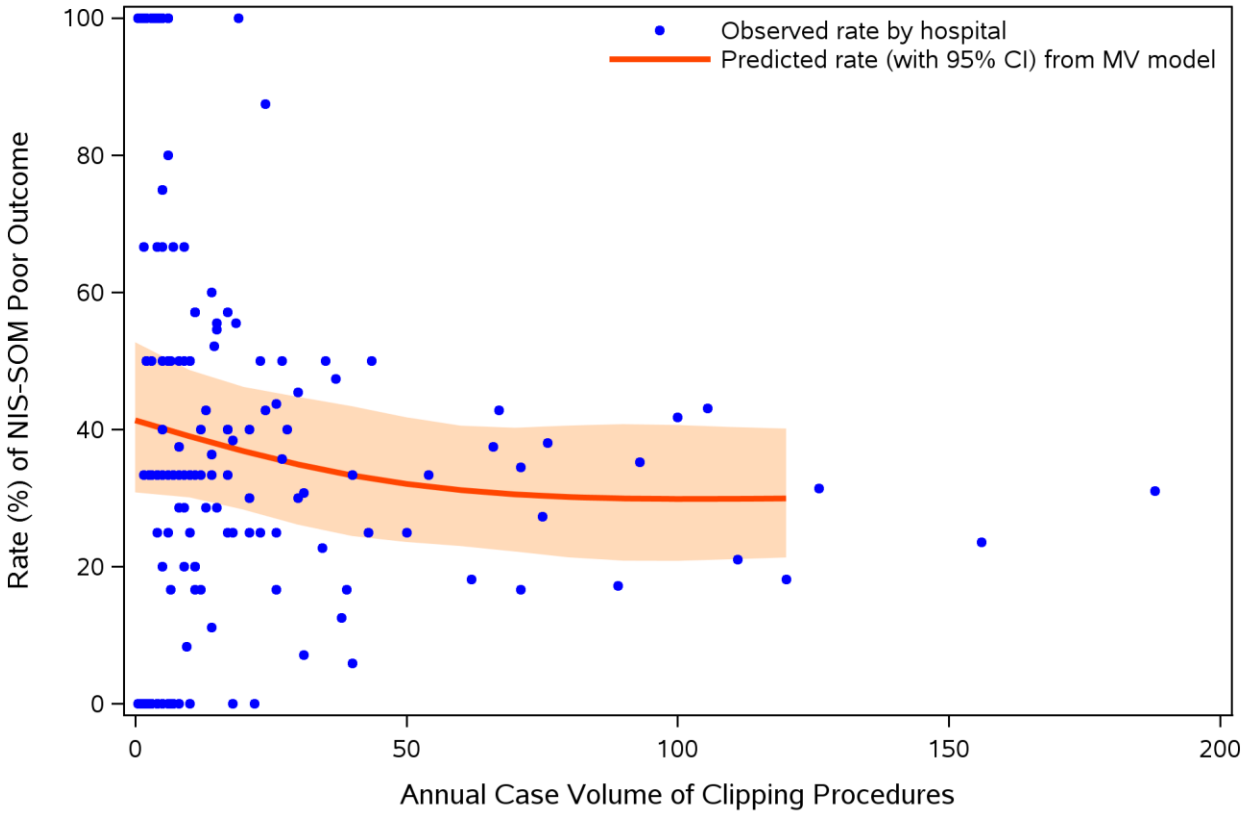
Results for subgroup: SAH admissions who underwent coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S50. NIS-SOM by SAH Coiling ACV, for SAH pts who undergo coiling.



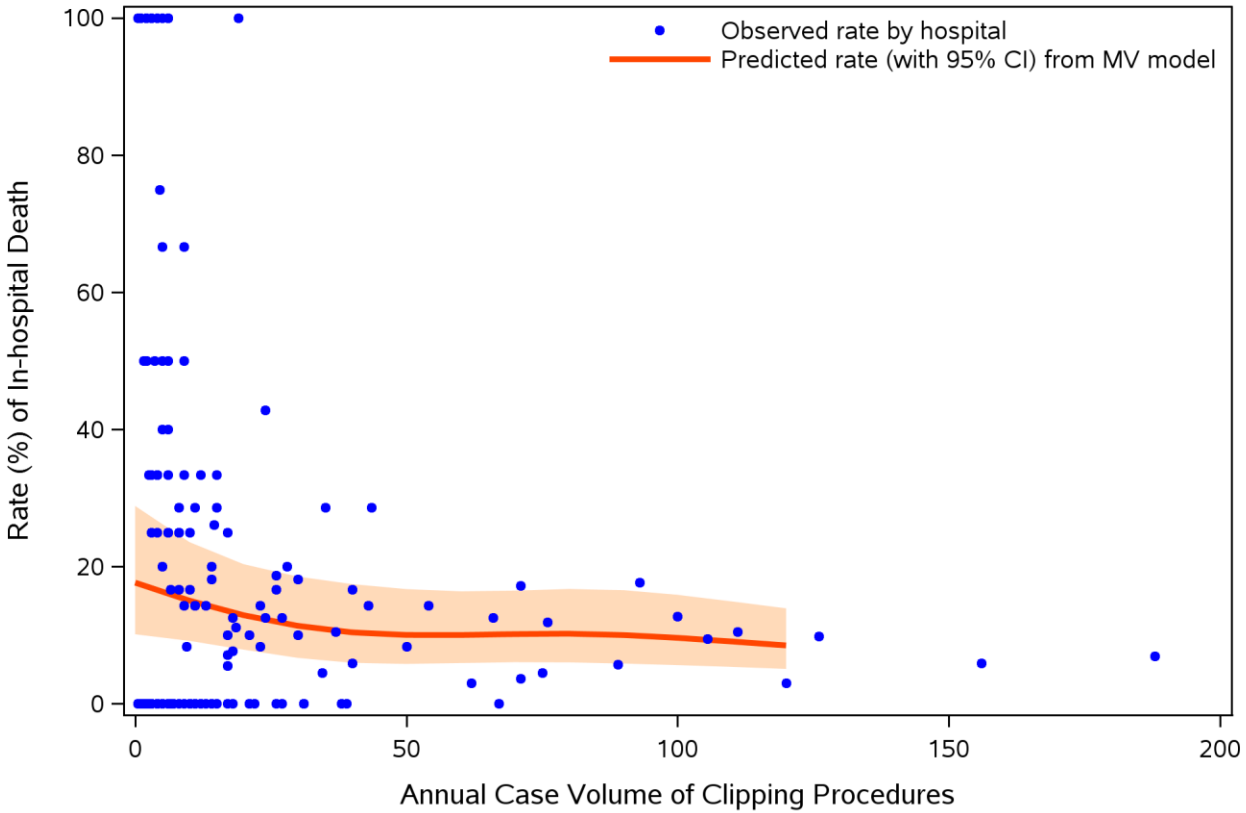
Results for subgroup: SAH admissions who underwent coiling
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S51. In-hospital mortality by SAH Coiling ACV, for SAH pts who undergo coiling.



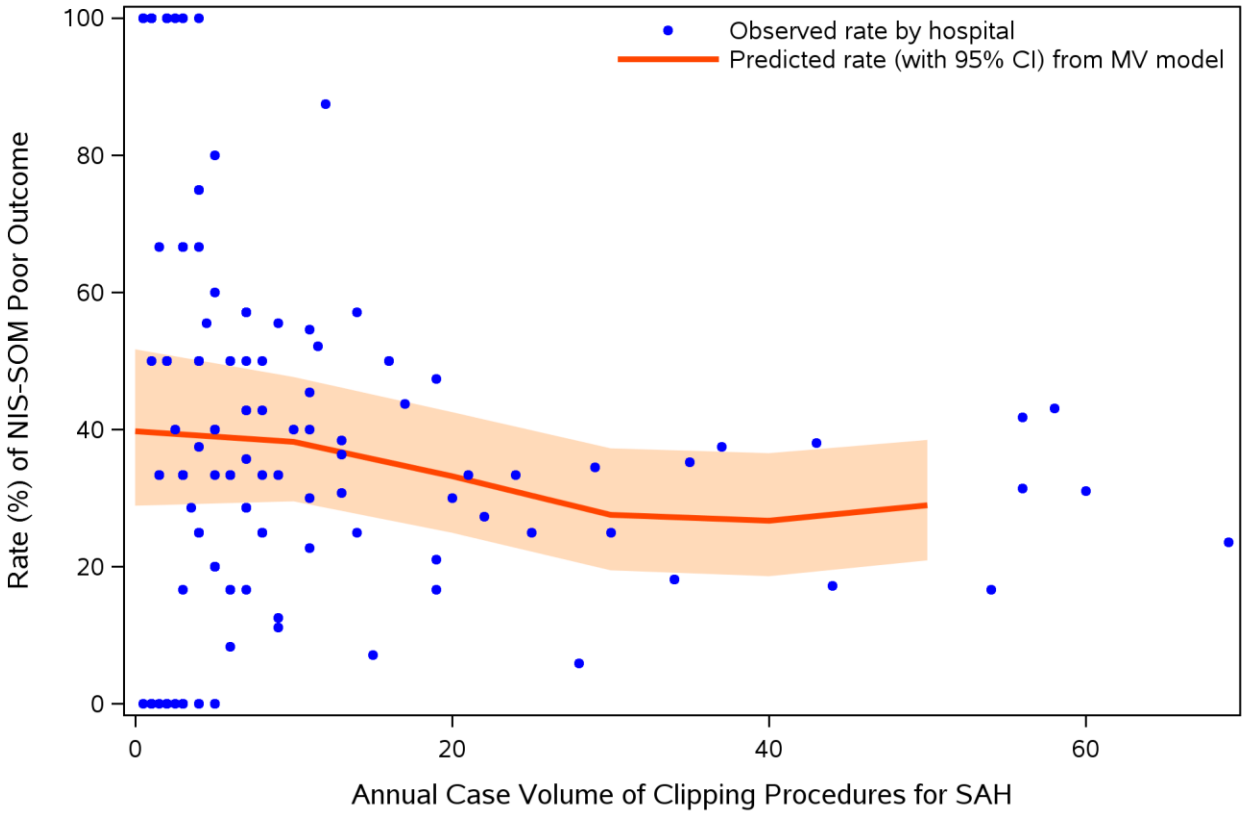
Results for subgroup: SAH admissions who underwent clipping
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S52. NIS-SOM by Clipping ACV, for SAH pts who undergo clipping.



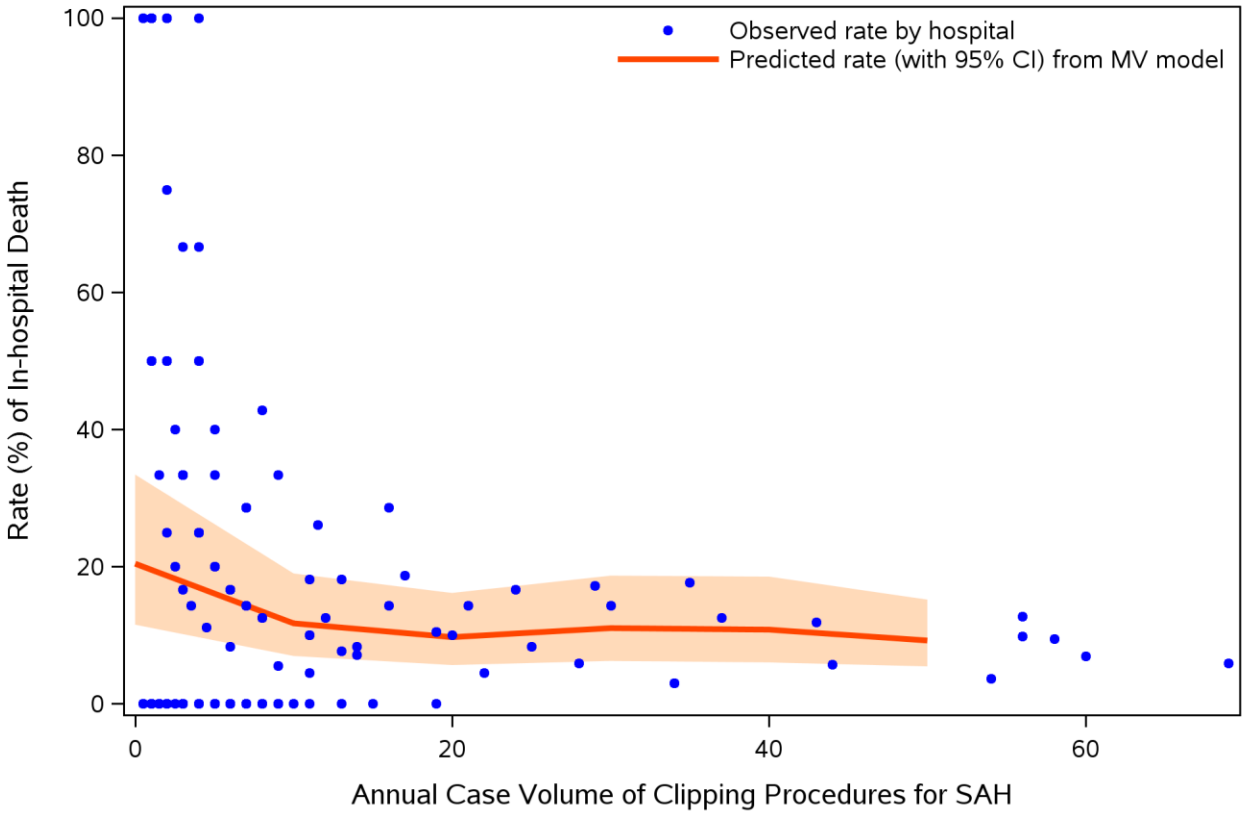
Results for subgroup: SAH admissions who underwent clipping
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S53. In-hospital mortality by Clipping ACV, for SAH pts who undergo clipping.



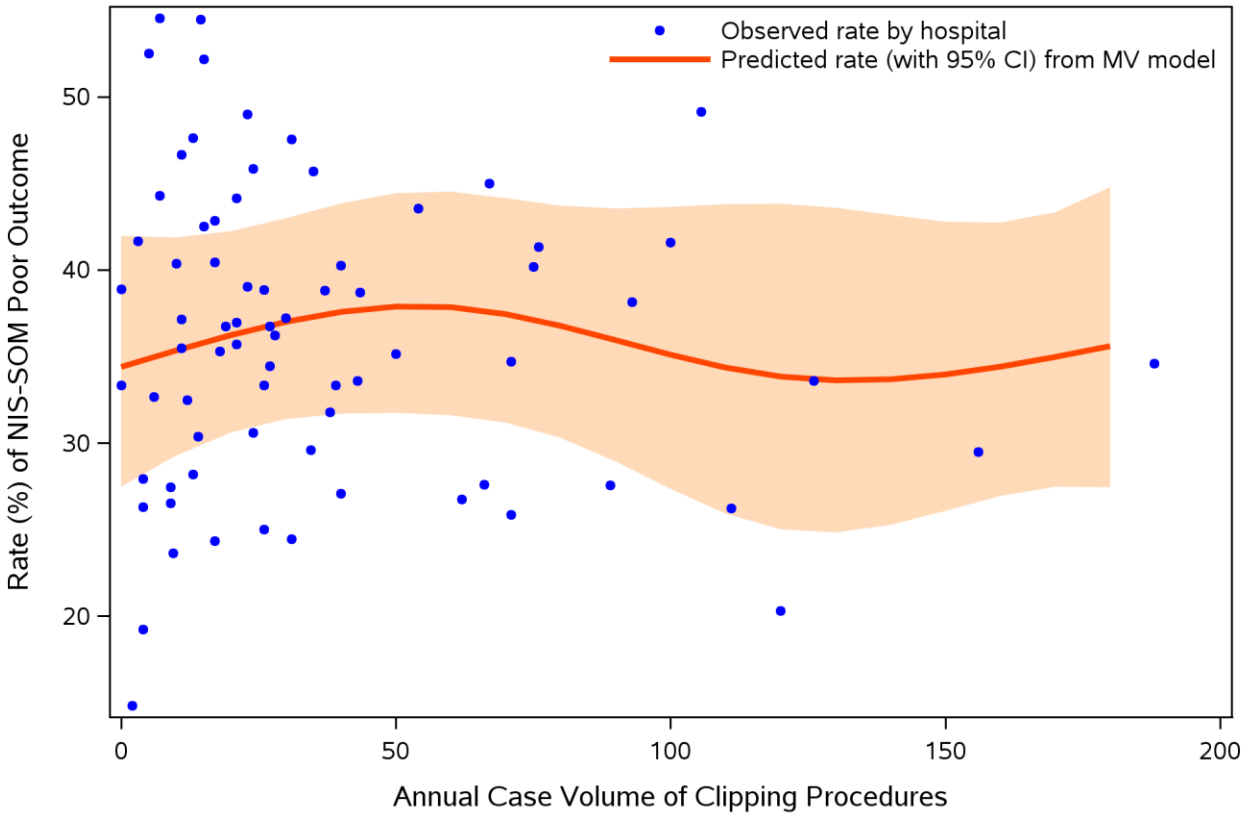
Results for subgroup: SAH admissions who underwent clipping
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S54. NIS-SOM by SAH Clipping ACV, for SAH pts who undergo clipping.



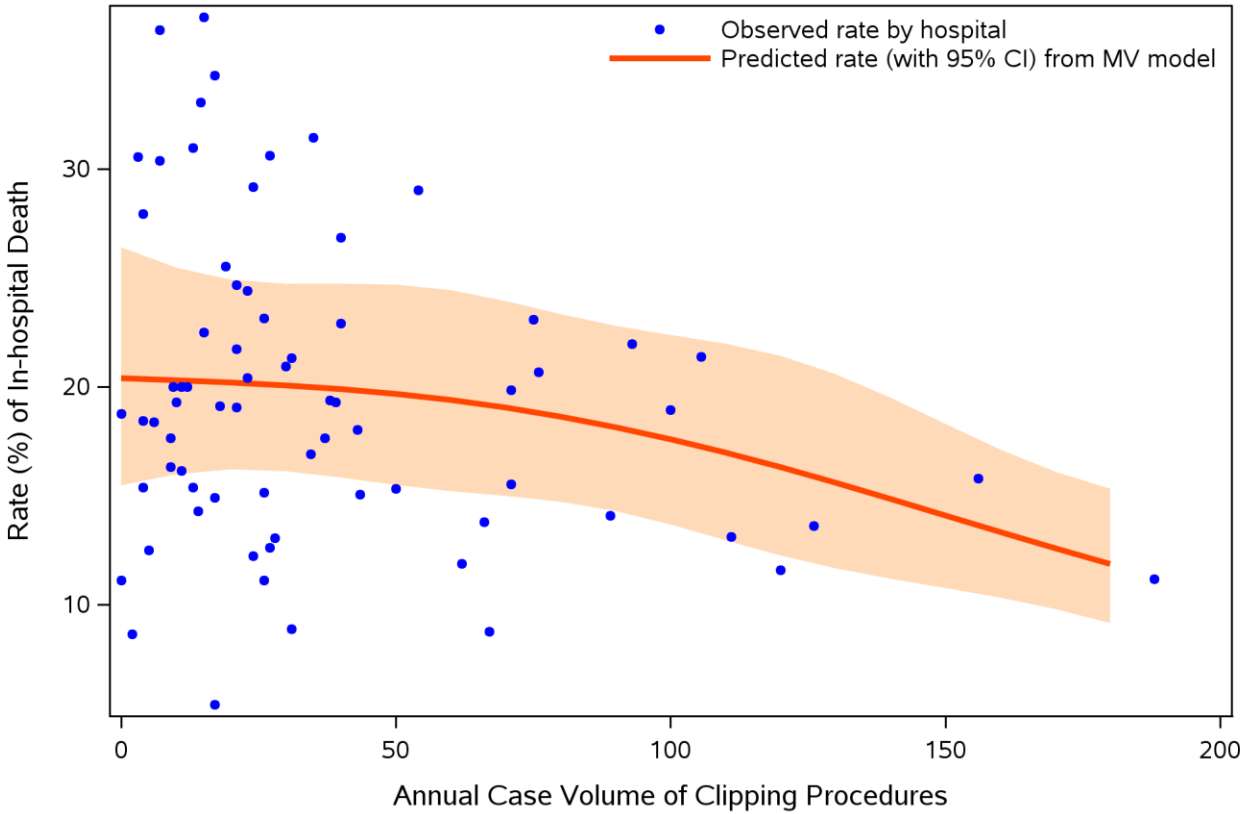
Results for subgroup: SAH admissions who underwent clipping
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S55. In-hospital mortality by SAH Clipping ACV, for SAH pts who undergo clipping.



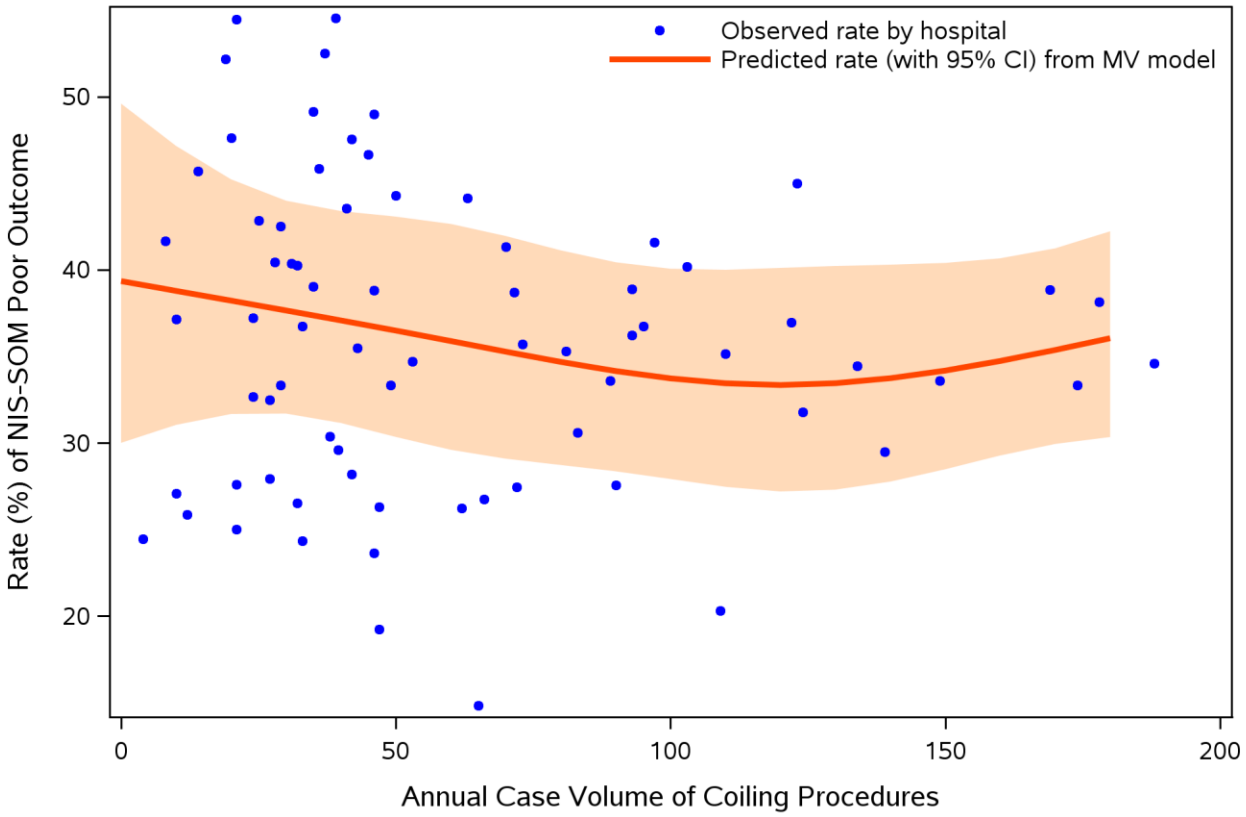
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S56. NIS-SOM by Clipping ACV, at sites with SAH ACV ≥ 35.



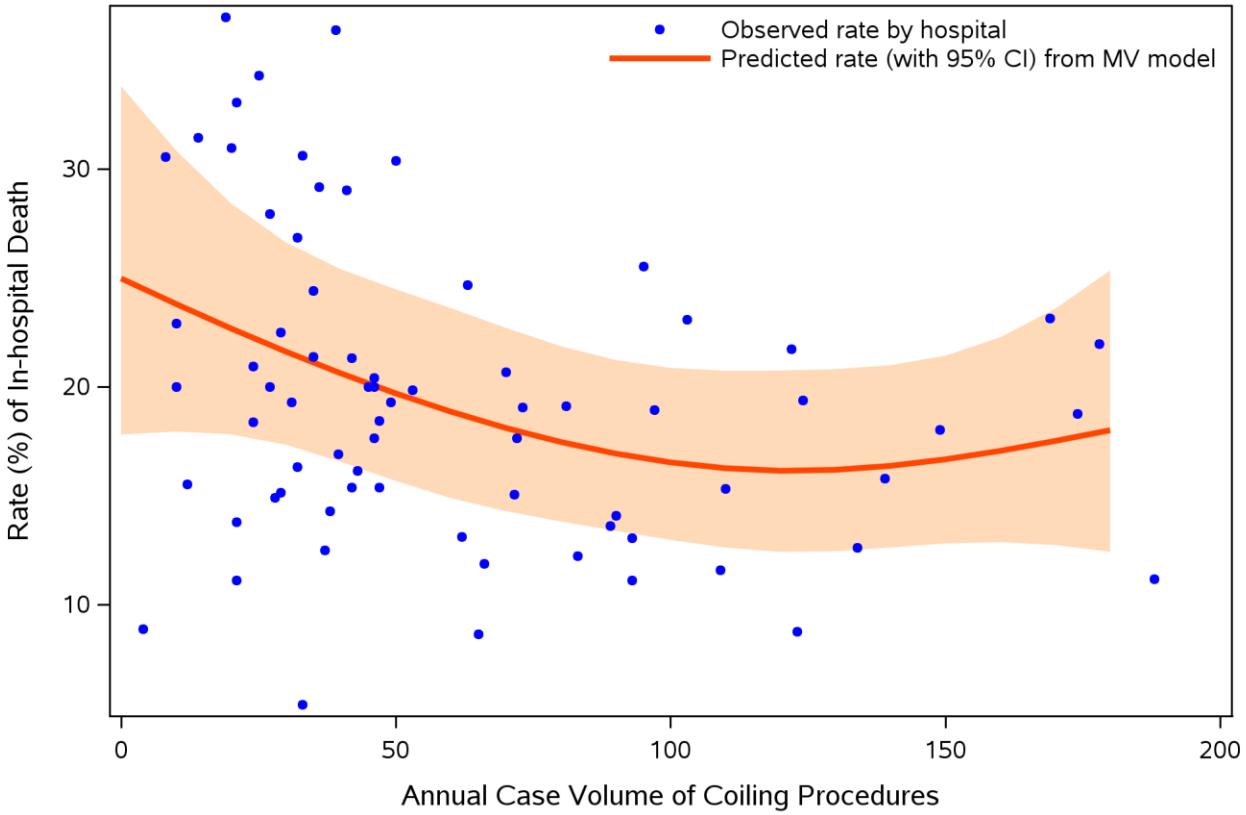
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S57. In-hospital mortality by Clipping ACV, at sites with SAH ACV ≥ 35.



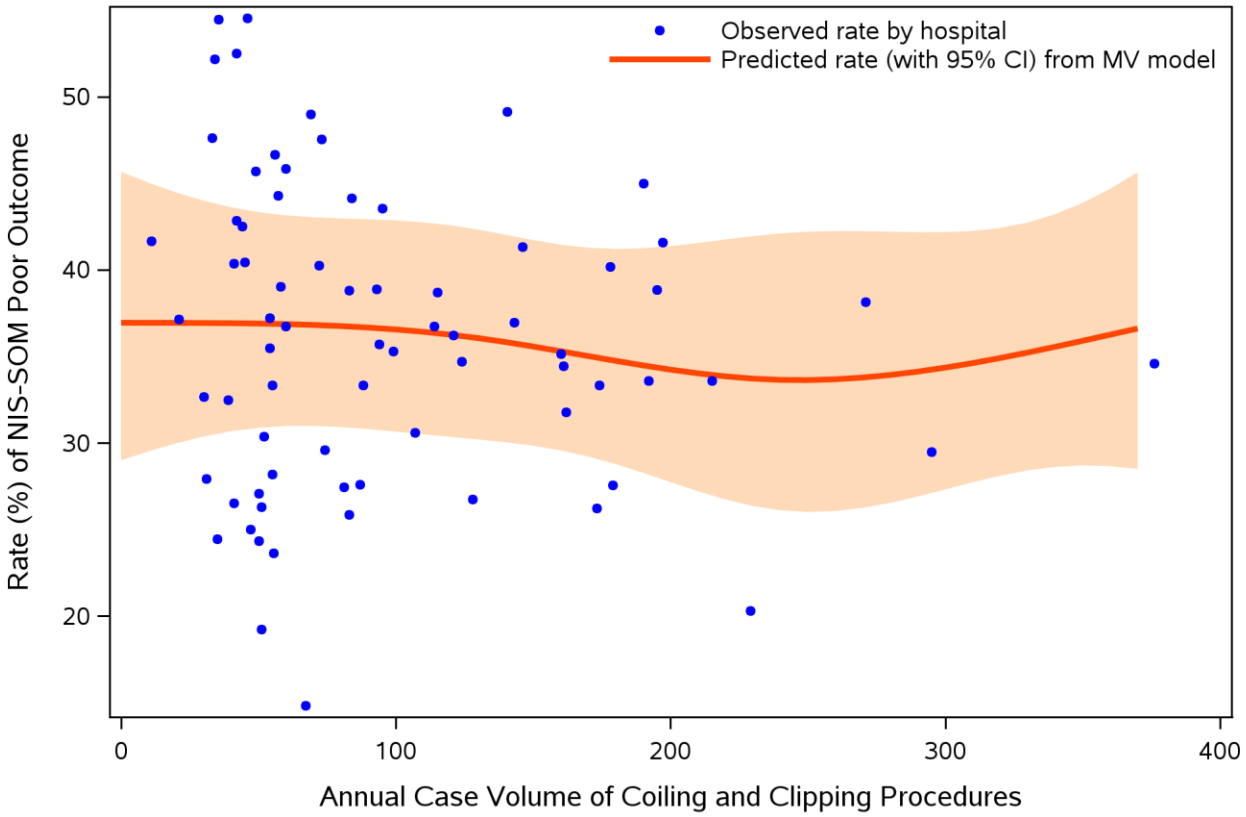
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S58. NIS-SOM by Coiling ACV, at sites with SAH ACV ≥ 35.



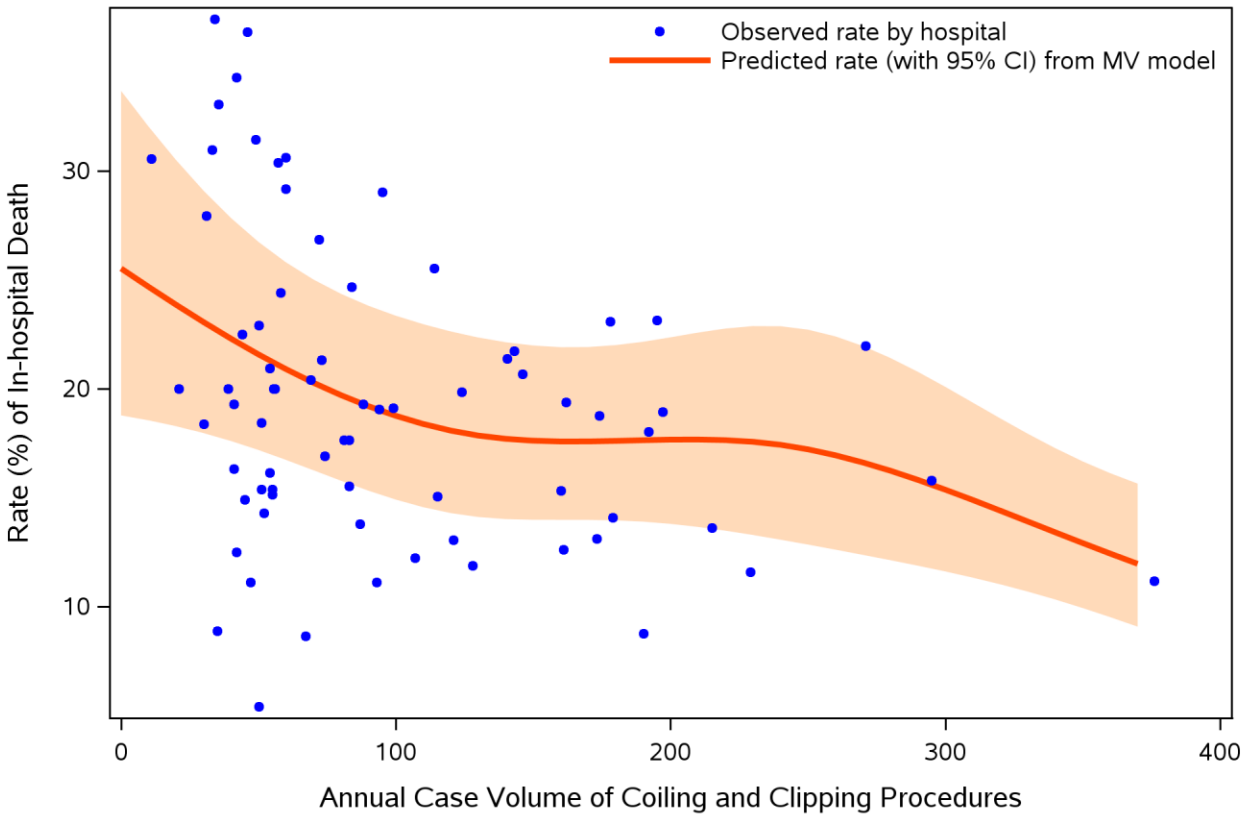
Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S59. In-hospital mortality by Coiling ACV, at sites with SAH ACV ≥ 35.



Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S60. NIS-SOM by Total Coiling + Clipping ACV, at sites with SAH ACV ≥ 35.



Results for primary analysis cohort: all SAH admissions, among hospitals with SAH ACV of 35 or higher
A single blue dot may represent more than 1 hospital with the same ACV and event rate.
Predicted rates are shown from ACV of 0 to the 99th percentile of the ACV distribution.

Figure S61. In-hospital mortality by Total Coiling + Clipping ACV, at sites with SAH ACV ≥ 35.

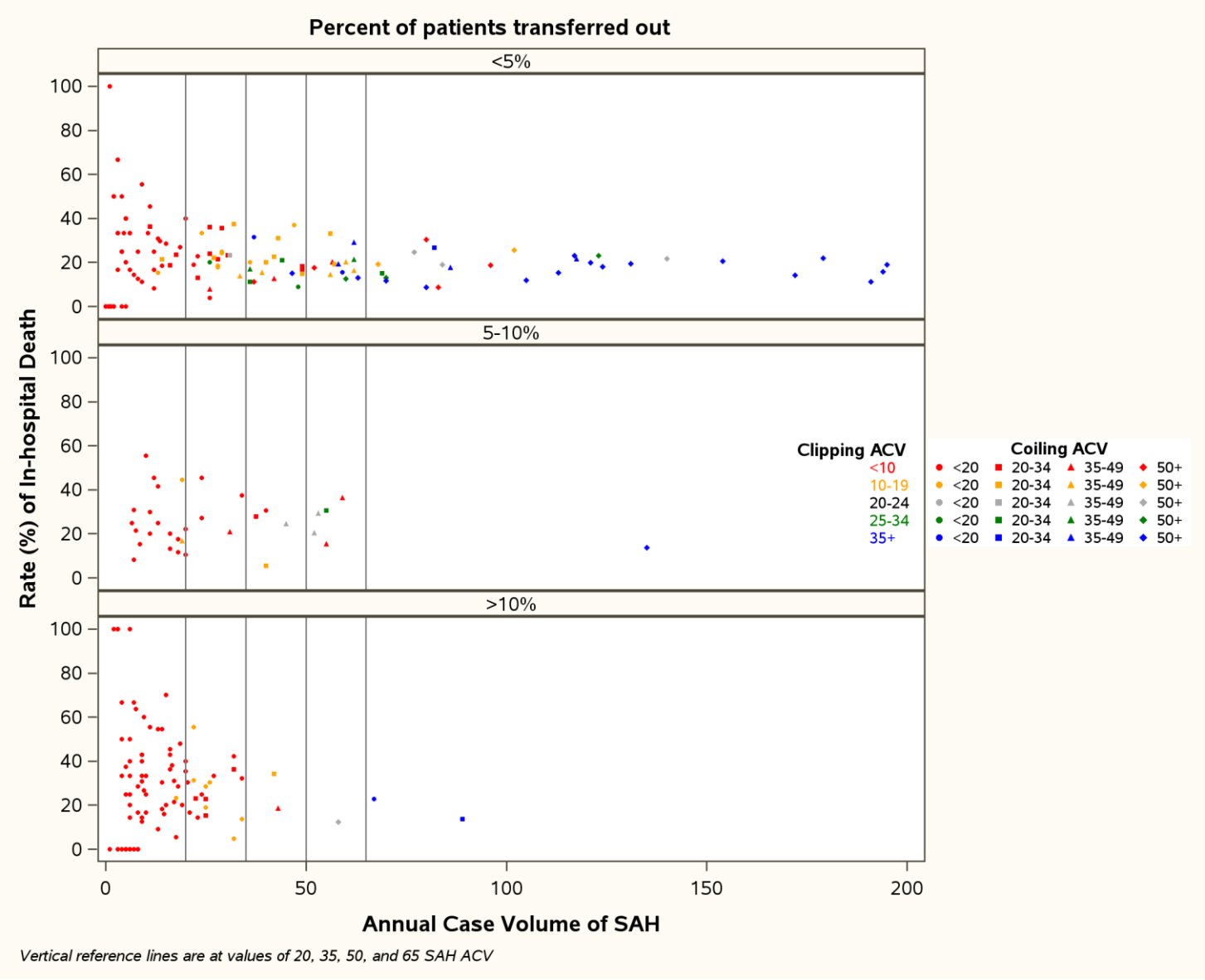


Figure S62. In-hospital mortality by SAH, Clipping, and Coiling ACVs, by transfer-out rate.

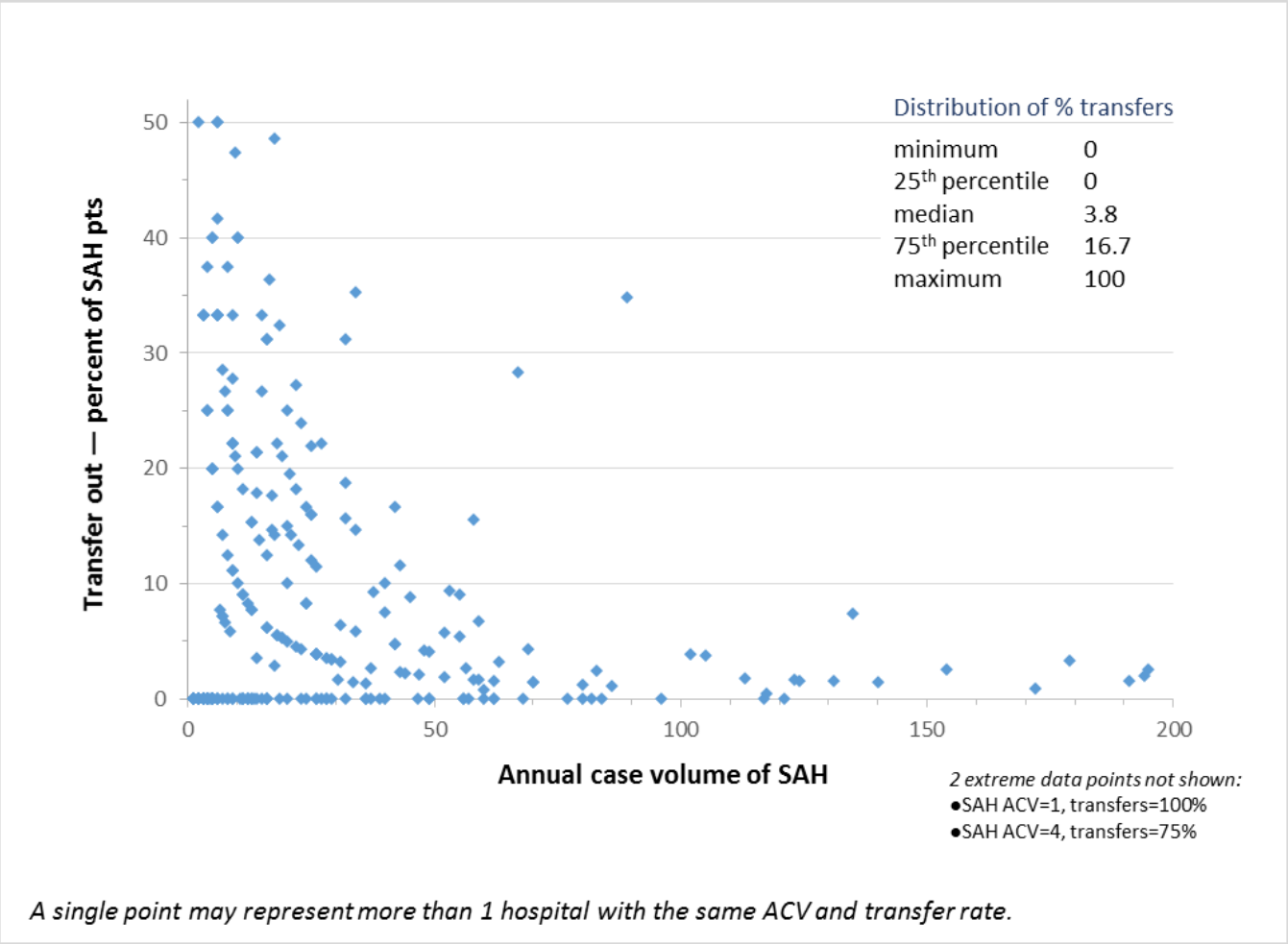


Figure S63. Percent transferred and SAH ACV—all transfers.

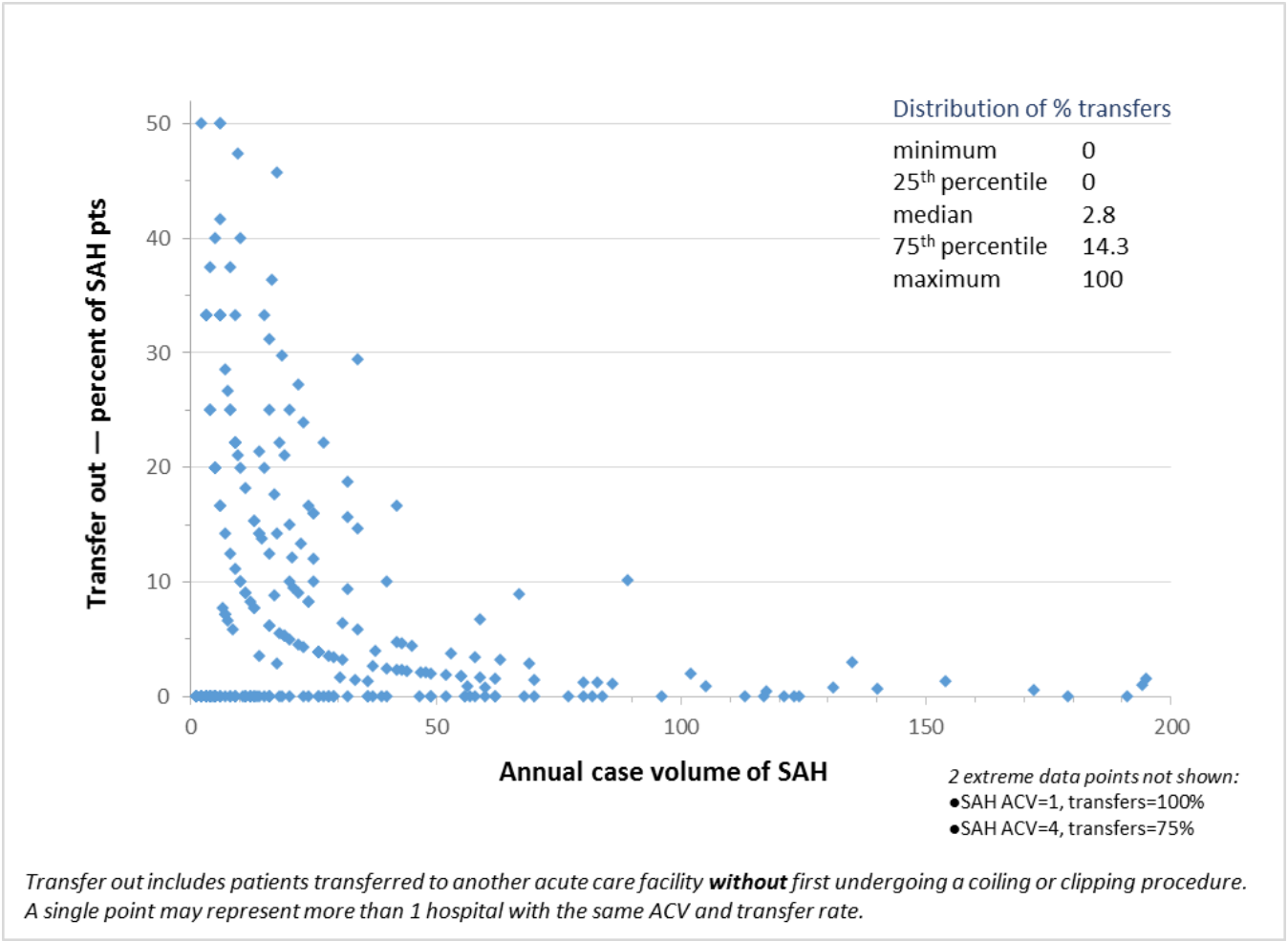


Figure S64. Percent transferred and SAH ACV—without coiling or clipping first.

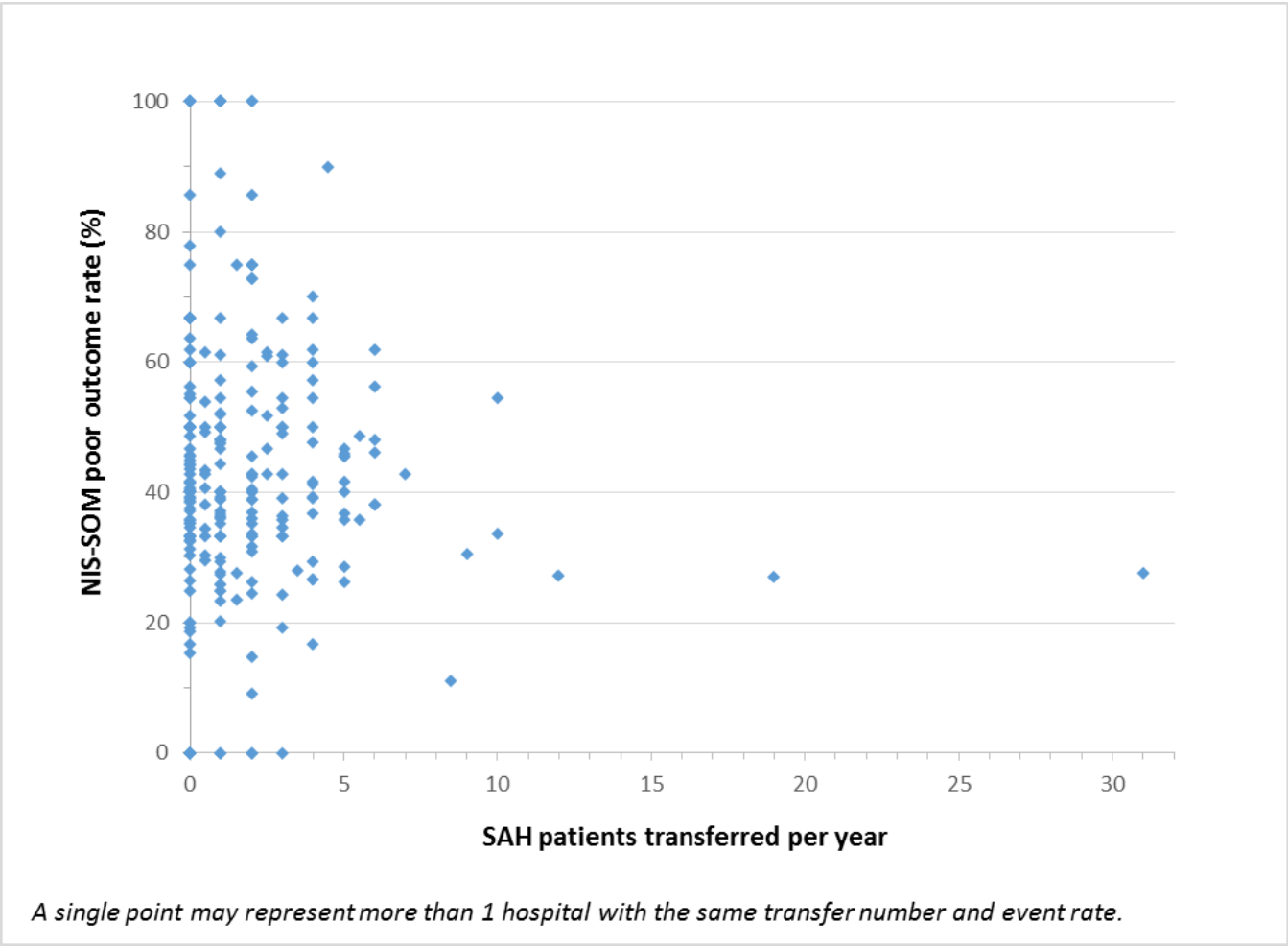


Figure S65. NIS-SOM poor outcome and number of SAH patients transferred (per year).

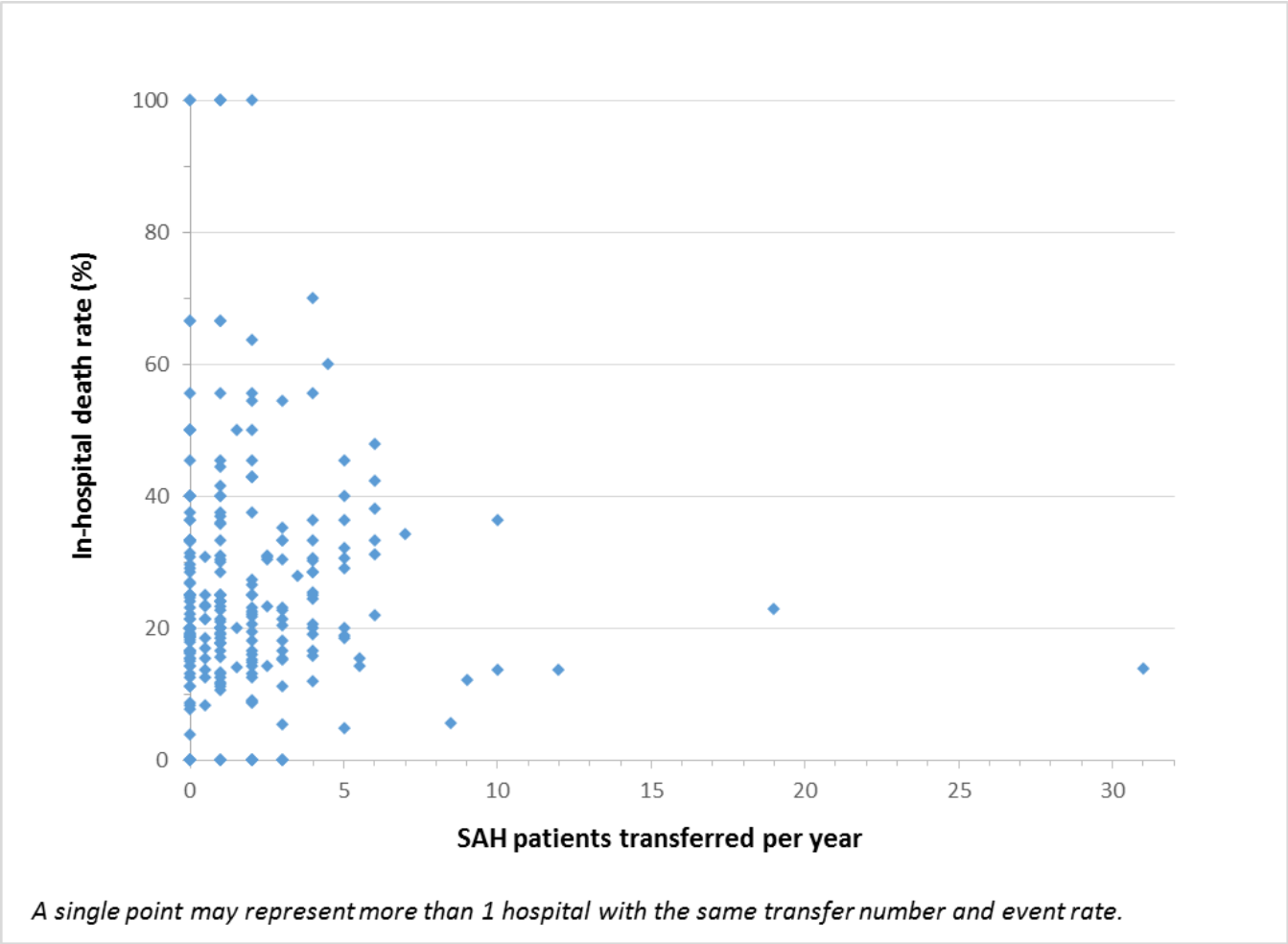


Figure S66. In-hospital mortality rate and number of SAH patients transferred (per year).

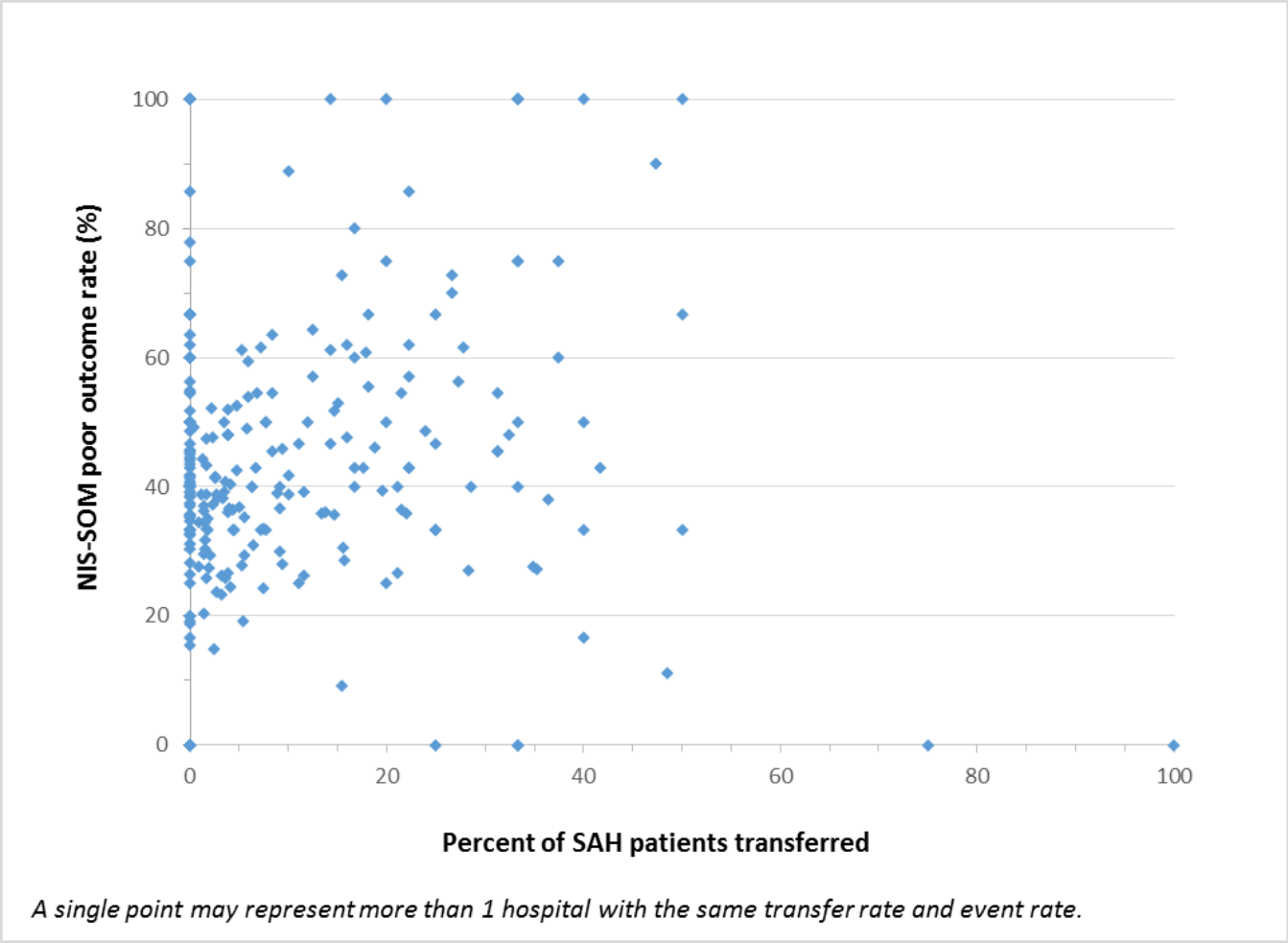


Figure S67. NIS-SOM poor outcome and percent of SAH patients transferred.

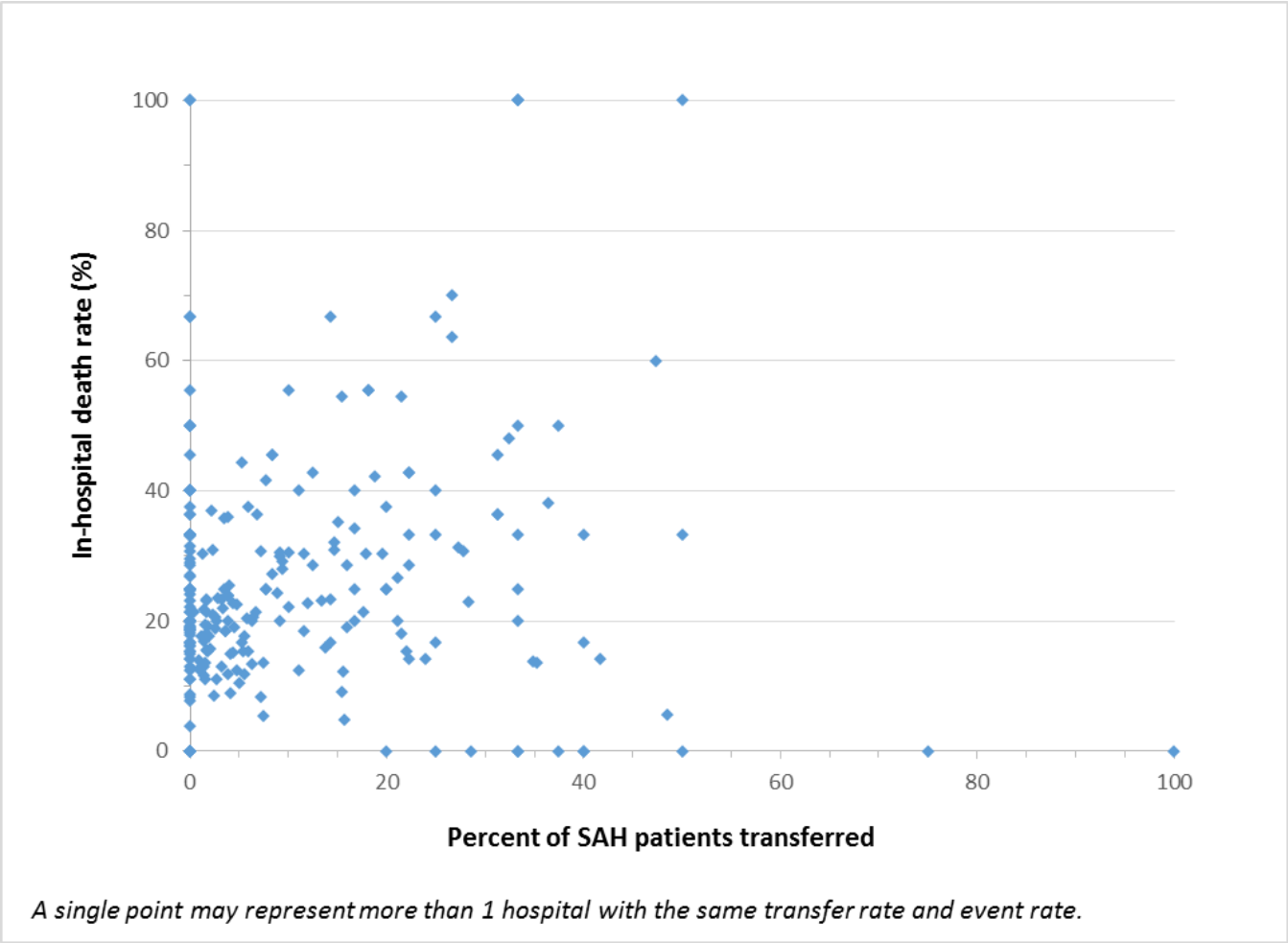


Figure S68. In-hospital mortality rate and percent of SAH patients transferred.