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Hospital Volume Predicts Outcomes and Complications after Total Shoulder Arthroplasty in the United States

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Abstract

Objective—To assess the association of hospital procedure volume for total shoulder arthroplasty (TSA) with patient outcomes and complications.

Methods—We used the U.S. Nationwide Inpatient Sample (NIS) from 1998–2011 to study the association of hospital annual TSA procedure volume with patient characteristics and TSA outcomes, including discharge disposition (home vs. inpatient facility), length of index hospitalization, post-arthroplasty periprosthetic fracture and revision. Annual hospital TSA volume was categorized as <5, 5–9, 10–14, 15–24 and ≥25 TSA procedures annually.

Results—Patients receiving TSA at higher volume hospitals were more likely to be female ($p<0.0001$) and White ($p<0.0001$). Compared to low volume hospitals (<5, 5–9, 10–14 procedures annually), patients receiving TSA at higher volume hospitals (15–24, ≥25) had significantly lower likelihood of: (1) being discharged to an inpatient medical facility, 16.5%, 13.4%, 13.0%, 12.7% and 11.5% ($p<0.0001$); (2) hospital stay >median, 46.6%, 40.4%, 36.6%, 34.4% and 29.2% ($p<0.0001$); (3) post-arthroplasty fracture, 1.2%, 0.8%, 0.9%, 0.6% and 0.8% ($p=0.0004$); (4) blood transfusion, 8%, 7.1%, 6.7%, 7.1% and 5.5% ($p=0.006$); and (5) TSA revision, 0.5%, 0.3%, 0.2%, 0.3%, 0.3% ($p=0.045$), respectively.

Conclusions—In this study, we found that higher annual hospital TSA volume was associated with better TSA outcomes in the U.S. These findings document the impact of annual hospital TSA volume on TSA outcomes. Patients, surgeons and policy-makers should be aware of these findings and take them into account in decision-making, policy decisions and resource allocation.

Keywords

hospital volume; total shoulder arthroplasty; TSA; utilization; outcomes; mortality; hospital stay; discharge; fracture; blood transfusion; revision

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Introduction

Total shoulder arthroplasty (TSA) is associated with significant improvements in pain, function and quality of life (1, 2). Katz et al. and others have shown that a higher hospital volume is associated with lower complication rates and better outcomes in patients undergoing total hip or total knee arthroplasty (3–7). To our knowledge, one study has explored the association of TSA volume with TSA outcomes (8). A significantly higher rate of overall postoperative complications for TSA performed in the hospitals with a volume <5 procedures (1.44%) or 5–10 procedure/year (1.45%) than in hospitals that performed >10 TSA procedures/year (0.64%) was reported (8). The previous study did not analyze post-arthroplasty periprosthetic fractures or early revision, complications that are of great interest clinically (9, 10). None of the previous studies investigated the association of hospital TSA volume with discharge disposition (home vs. inpatient facility), an important outcome considering the rapidly rising cost of healthcare and the ongoing efforts to reduce and optimize hospital length of stay after elective surgical procedures.

TSA volume has increased dramatically in the recent years, projected to increase further in the next few years, making it a public health burden (9). Recent studies in Medicare populations have revealed significant changes in characteristics of patients undergoing knee or hip arthroplasty (11, 12). These changes can potentially impact arthroplasty outcomes over time. It is not known whether demographic and clinical characteristics of patients undergoing TSA are changing. Therefore, contemporary data are needed to assess whether this previously observed association of hospital volume with TSA outcomes still holds true for this rapidly evolving surgery.

Our objective was to assess differences in patient characteristics and outcomes after TSA by hospital volume. We hypothesized that patients with certain characteristics (female gender, White race/ethnicity) will utilize hospitals with higher annual TSA volume and a higher hospital TSA volume will be independently associated with lower complication rates and better outcomes after TSA.

Methods

Data Source

We used the Nationwide Inpatient Sample (NIS) data from 1998 to 2011 for this study. The NIS is the largest all-payer inpatient health care database in the U.S., that provides national estimates of hospital inpatient stays (13). NIS contains all discharge data from >1,000 short-term and non-Federal hospitals each year, obtained from the state inpatient databases; data were received from 46 states in the most recent year. NIS contains a 20% stratified sample of U.S. community hospitals and thus provides a representative U.S. sample. Diagnostic and procedure codes are available for each hospitalization. The NIS contains charge information on all patients regardless of insurance coverage, including individuals who are uninsured. NIS contains unweighted data from approximately 8 million hospital stays each year (13). We used the weights provided in the NIS to get the national estimates of TSA utilization. The Institutional Review Board (IRB) at the University of Alabama at Birmingham approved the study.

Study sample selection

We selected all hospitalizations in the NIS from 1998–2011 with an International Classification of Disease, ninth revision, common modification (ICD-9-CM) code, 81.80 for TSA. ICD-9-CM codes for arthroplasty have been shown to be valid (4, 14).

Covariates, exposure of interest and outcomes of interest

The exposure of interest was the annual hospital TSA volume. This was categorized as <5, 5–9, 10–14, 15–24 and ≥25 TSA procedures annually, similar to the categorization as previously (8).

Covariates including age, gender, race/ethnicity and comorbidity were obtained from the NIS dataset at the index admission preoperatively and categorized as follows. Age was categorized as <50, 50 to <65, 65 to <80 and ≥80 years. Race/ethnicity was categorized as White, Black, Hispanic and other. Medical comorbidity was assessed using the validated Deyo-Charlson index, which consists of 17 comorbidities, based on the presence of ICD-9-CM codes (15). Hospital location and teaching status was categorized as rural, urban-non-teaching and urban teaching. We classified the primary payer for the utilization as Medicare, Medicaid, private insurance, self-pay and other where other included other category and the no charge category from NIS. Hospital bed size variable was classified as small, medium or large. Hospital region was categorized as Northeast, Midwest, South and West.

The outcomes of interest included hospital length of stay (number of days from admission to discharge for the index TSA admission) categorized as above or below the overall median, proportion of patients discharged to home vs. inpatient facility (short term hospital, skilled nursing facility, intermediate care facility or another type of inpatient facility) and mortality, assessed as death related to the index admission either in the hospital, medical facility, home or place unknown. Patients who left the hospital against medical advice were considered missing for discharge disposition.

We also assessed post-TSA complications based on the presence of the following ICD-9 codes during the index hospitalization in non-primary positions, similar to the methodology used previously by Jain et al. to differentiate these complications from the underlying reason for TSA (8): (1) fracture: 79.01, 79.11, 79.21, 79.31, 79.61; (2) revision surgery: 81.83; and (3) transfusion: 99.0x.

Statistical Analyses

We used SAS 9.3 (Cary, N.C.) for all the analysis. Survey analysis procedures that take into account the weights, clusters and strata defined in NIS were implemented. We used the Chi-squared test for the categorical and analysis of variance for the continuous variables of interest. Logistic regression was used for comparisons of outcomes including mortality, length of stay, percent discharged to inpatient facility, fracture, revision or transfusion. We adjusted for important variables in two multivariable models: (1) model 1: gender, age, race, Deyo-Charlson-score; (2) model 2: gender, age, race, Deyo-Charlson-score, hospital location, teaching status, hospital bed size, hospital region and primary diagnosis. Since, the race information was missing for a large number of patients, we repeated the analysis with

missing as a category for race (models 3 and 4; corresponding to models 1 and 2, but accounting for missing race category). A p-value <0.05 was considered statistically significant. Sensitivity analyses were done by re-categorizing the hospital volume by the number of TSA and hemiarthroplasty surgeries combined, instead of TSA surgeries alone, to allow comparison to the only previous study of TSA volume and outcomes (8).

Results

Patient Characteristics

Significant differences in gender distribution, with higher proportion of males in the higher volume hospitals, were noted ($p<0.0001$, Table 1). A greater proportion of patients undergoing TSA at hospitals with lower procedure volume were Black ($p<0.0001$, Table 1). Sensitivity analyses re-analyzing the data by the number of annual TSA and hemiarthroplasty procedures, rather than by annual TSA procedures, confirmed the findings (Appendix 1).

Hospital Volume and Unadjusted TSA outcomes

Compared to hospitals with lower annual volume, proportion of patients discharged to home was significantly higher in hospitals with higher annual TSA volume, 83.5% in low annual TSA volume (<5) to 88.5% in high annual volume of ≥ 25 ($p<0.0001$, Appendix 2). Length of hospital stay above the median was significantly higher at hospitals with lower annual volume compared to those with higher procedure volume, 46.6% with low annual volume <5 compared 29.2% in hospitals with high annual volume ≥ 25 ($p<0.0001$, Table 2 and Appendix 2). Inpatient mortality by hospital volume ranged from 0.1% to 0.2%, with no significant differences by TSA annual volume ($p=0.39$, Table 2 and Appendix 2). Sensitivity analyses that re-analyzed the unadjusted rates by the number of TSA and hemiarthroplasty procedures confirmed the findings (Appendix 3).

Post-arthroplasty fracture rates were significantly higher in hospitals with lower annual procedure volume ($p=0.0004$, Table 2), 1.2% in hospitals with low volume <5 compared to 0.8% in hospitals with high volume ≥ 25 . Revision rate was significantly higher in hospitals with lower annual procedure volume at 0.5% vs. 0.3% in high volume hospitals ($p=0.045$, Table 2). Blood transfusion rates were significantly higher in lower hospital TSA volume compared to higher ($p=0.006$), for example being 8.0% vs. 5.5% in hospitals with volumes <5 compared to volume ≥ 25 (Table 2). Sensitivity analyses re-analyzing the data by the TSA and hemiarthroplasty annual volumes instead of TSA annual volumes confirmed the findings (Appendix 3).

Hospital Volume and Adjusted TSA outcomes

In multivariable-adjusted models, hospital TSA volume was significantly and independently associated with discharge to home and the length of hospital stay ($p<0.0001$ in all models for each outcome), post-arthroplasty fracture and revision ($p<0.05$ in 2 of the 4 models for each outcome) and transfusion (p -value <0.05 in 3 of the 4 models) (Table 2). Sensitivity analyses with missing race confirmed these findings (Table 2). Sensitivity analyses

considering annual TSA and hemishoulder arthroplasty instead of TSA volume revealed similar findings (Appendix 4).

Additional sensitivity analyses dichotomizing annual TSA volume at 5 procedures/year showed that compared to <5 annual TSA procedures, patients undergoing TSA at hospitals with annual TSA volume of 5 or more had significantly higher adjusted odds of discharge to home, and lower adjusted odds of post-arthroplasty fracture, transfusion, revision, longer hospital stay (Appendix 5).

Exploration of association of hospital TSA volume and outcomes by the underlying diagnosis (OA, RA, fracture, avascular necrosis, other) confirmed similar findings in each diagnostic group as in the overall sample, except fracture, where baseline rate of complications were higher and the differences by annual volume less predictable (Appendix 6).

Discussion

One previous study by Jain et al. used the NIS data from 1988 to 2000 and reported a significantly higher rate of overall postoperative complications for TSA performed in the hospitals with a volume <5 procedures (1.44%) or 5–10 procedure/year (1.45%) than in hospitals that performed >10 TSA procedures/year (0.64%) (8). Although the study provided great insights into epidemiology of TSA, two key limitations were the use of a composite complication outcome and the use of TSA and hemiarthroplasty hospital volume rather than TSA volume. Composite complication outcome included postoperative wound infection, other infections, a non-healing surgical wound, disruption of the operative wound, pulmonary embolism, thrombophlebitis, and other unspecified complications. Data on specific complications such as post-arthroplasty fracture and early revision, important to surgeons and patients (10), were not reported. This may be due to the rare occurrence of these specific complications and a sample size <13,000 patients. Our study adds to the current knowledge. We examined contemporary data that indicate current practice in TSA (up to 2011) and assessed key complications after TSA, including post-arthroplasty fracture, transfusion and revision. Several findings deserve further discussion.

Our study shows that hospitals with higher TSA volume had significantly lower rates of two key surgical complications, post-arthroplasty fracture and revision. To our knowledge, this is the first study to document this association in a TSA cohort. The findings can not be compared to the finding in Jain et al. due to inclusion of multiple complications such as implant-related, medical complications and all types of wound infections (8). Our findings extend similar findings in knee/hip arthroplasty, namely the association of lower hospital volume with higher rates of early revision surgery after knee arthroplasty (7) and a higher rate of dislocation after hip arthroplasty (4). Our findings are particularly interesting, since patients with higher complexity (i.e. higher Deyo-Charlson index) were more likely to be operated upon in hospitals with higher TSA volume. This indicates that TSA procedures at hospitals with high volume are associated with better outcomes compared to hospitals with lower volume, despite a higher patient complexity.

We also noted that high volume hospitals had lower rates of discharge to inpatient facilities and a shorter index hospitalization stay. These are important findings, given a higher patient complexity in higher volume hospitals, compared to lower volume hospitals. Higher discharge rate to home in higher volume hospitals may be due to streamlined post-arthroplasty inpatient care and a better transition of care and discharge planning. Our study showed that low-volume hospitals are far more likely than high-volume hospital to be in rural areas, where access to rehabilitation services and facilities may be lower, leading to a higher rate of discharge to intermediary in-patient facilities rather than home. It is also possible that patients undergoing TSA at low vs. high volume hospitals differ in social support and insurance status that impacts their discharge disposition. Future studies need to explore the reasons for these differences. While lower volume hospitals differed in hospital characteristics (location, teaching status) and patient profile (age, gender, race, underlying diagnosis) and patient's insurance status in our study, our multivariable-adjusted analyses accounted for these differences and the associations with outcomes noted are independent of these factors.

We found that the transfusion rates were higher in hospitals with lower annual procedure volumes. This may possibly be due to more blood loss during the surgery, although it is possible that the threshold for transfusions may be lower at hospitals with lower vs. higher volume hospitals. This is a new finding and fills a knowledge gap.

In our study, trend towards higher medical comorbidity with Deyo-Charlson index of 2 or more was seen in 9.1% vs. 8.0% in hospitals with >25 vs. <5 annual TSA procedures ($p=0.11$). Not only were TSA patients with higher complexity undergoing TSA at high volume hospitals being discharged half a day sooner, but also more were discharged to home. This might imply a more optimal, appropriate and conservative resource use at higher volume hospitals, compared to low volume hospital. This is particularly interesting from a resource utilization perspective.

Our study has several strengths and limitations. The NIS is a nationally representative sample, but excludes federal facilities such as military hospitals and Veterans Affairs medical centers. The inclusion of hospitals from almost every state supports the applicability of findings to U.S. population. The findings may not be applicable to settings outside of U.S. and some groups within the U.S., such as veterans. NIS counts hospitalizations and not procedures, i.e., bilateral procedures are missed and counted as single procedures. Given that simultaneous bilateral TSA are uncommon, this is unlikely to have impacted our estimates greatly.

Our study strengths include the use of a representative sample and the inclusion of a sample large enough to allow analyses of individual complications. Multiple sensitivity analyses confirmed the robustness of our study findings.

We believe that evidence is accumulating that a higher hospital annual arthroplasty volume was associated with better arthroplasty outcomes. Multiple research groups have shown these findings consistently across time-periods, datasets, practice setting (US/Canada) and types of arthroplasty (knee/hip/shoulder, primary/revision) (3–8). More than a decade of

research supports the fact the patients who undergo arthroplasty at high-volume hospitals have better outcomes than patients who undergo these procedures at low-volume hospitals. While these findings are well known to researchers and clinicians, our clinical experience is that most, if not all, patients referred for arthroplasty are unaware of these findings. On the other hand, there is a practical challenge of referring all patients for TSA to large centers, which will lead to health care access issues and difficulties with follow-up due to transportation.

The most effective approach might be to consider referral of more complicated cases to high-volume surgical centers. There is also a need to inform the general public about this association to increase their awareness and to consider these findings while implementing public health policy changes related to the performance of TSA procedures at high vs. low volume hospitals. Policy makers may consider building incentives for lower complication rates, which might redirect these procedures to high volume hospitals and encourage adoption of processes that reduce complication rates in low-volume hospitals. It is unclear whether these findings will lead to a policy change, or whether more evidence is needed before a policy change.

Conclusions

In conclusion, our study found a higher rate of post-TSA fractures, transfusion and early revision rates in low volume hospitals compared to high volume hospitals. We also found an independent association of annual hospital TSA volume and TSA outcomes using the U.S. NIS. High TSA volume centers had better patient outcomes including shorter hospitalization stay and higher likelihood of discharge to home, which should catch the attention of policy makers. These findings can inform surgeons, patients and policy-makers. Future studies should explore whether redirecting higher-risk (or all) TSA patients to high-volume centers can improve overall patient outcomes and reduce healthcare costs and resource utilization for TSA and post-TSA care.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Significance and Innovation

1. The risk of post-TSA fractures, transfusion and early revision rates were 1.5–1.6 times higher in hospitals with low annual TSA volume compared to high TSA volume hospitals in the U.S.
2. High TSA volume hospitals had shorter hospitalization stay and higher likelihood of discharge to home after index TSA compared to low TSA volume hospitals.

Table 1

TSA tables by annual Hospital TSA volume across years* (1998 – 2011)

	Annual Hospital TSA volume (total sample n=256,934)					p-value ^d
	<5 (n=31,417)	5 – 9 (n=36,906)	10 – 14 (n=28,405)	15–24 (n=41,720)	25 (n=118,486)	
% female	59.8	56.7	56.8	55.2	54.4	<0.0001
Mean Age	68.9	69.1	68.6	68.8	68.5	<0.0001
Age Group						
<50	5.4	4.2	4.5	3.9	4.8	0.005
50–64	24.5	25.9	27.0	26.9	27.0	0.02
65–79	54.5	55.0	54.6	55.3	54.4	0.78
80	15.7	14.9	13.8	13.9	13.8	0.02
Race						
White	87.5	89.3	90.1	91.0	91.8	<0.0001
Black	4.9	5.3	3.8	3.4	3.6	<0.0001
Hispanic	4.9	3.2	3.3	2.6	2.4	<0.0001
Other	2.8	2.2	2.8	3.1	2.2	0.38
Deyo- Charlson score						
0	64.1	64.0	64.1	64.0	63.7	0.98
1	27.9	27.9	27.3	27.6	27.2	0.81
2	8.0	8.1	8.6	8.5	9.1	0.11
Hospital location and teaching status						
Rural	25.3	15.9	12.3	9.7	4.9	<0.0001
Urban non-teaching	50.5	50.3	48.1	43.2	37.3	<0.0001
Urban teaching	24.1	33.7	39.6	47.2	57.9	<0.0001
Primary payer						
Medicaid	3.5	1.9	2.0	1.7	1.6	<0.0001
Medicare	68.8	67.5	67.6	67.2	64.8	0.0006
Other	3.5	3.1	3.5	3.0	3.9	0.06
Private	23.6	27.1	26.5	27.6	29.4	<0.0001
Self	0.6	0.4	0.4	0.5	0.4	0.17

	Annual Hospital TSA volume (total sample n=256,934)					p-value ^a
	<5 (n=31,417)	5 – 9 (n=36,906)	10 – 14 (n=28,405)	15–24 (n=41,720)	25 (n=118,486)	
Hospital Bed size						
Small	20.1	14.8	13.2	16.4	13.8	0.19
Medium	32.0	28.7	26.1	25.7	16.9	
Large	47.9	56.5	60.6	58.0	69.4	
Hospital region						
Northeast	19.2	14.3	11.8	16.5	12.2	0.055
Midwest	26.7	29.2	26.2	25.7	29.9	0.61
South	34.6	35.5	37.5	34.0	35.5	0.95
West	19.6	21.1	24.4	23.8	22.4	0.79
Underlying diagnosis, n (%)						
Osteoarthritis	76.4	78.3	79.9	81.3	77.3	0.001
Rheumatoid arthritis	2.2	2.5	2.0	1.6	1.8	0.007
Fracture	6.3	3.5	2.9	2.3	2.1	<0.0001
Avascular necrosis	2.7	2.2	1.8	1.8	1.5	<0.0001
Other	12.5	13.6	13.4	13.1	17.3	<0.0001

* Hospital volume defined by TSA Hospitalizations only

Frequency and % are given for each category of variables included. All % are for the non-missing values only

^a p-values comparing across hospital TSA volume categories using logistic regression

Table 2

Differences in odds of TSA outcomes by annual hospital TSA volume in unadjusted and adjusted logistic regression analyses (reference category, TSA annual volume <5)

	Unadjusted	Multivariable-adjusted			
		Model 1 ^b OR (95% CI)	Model 2 ^c OR (95% CI)	Model 3 ^d OR (95% CI)	Model 4 ^e OR (95% CI)
Mortality	P=0.39	P=0.55	P=0.54	P=0.37	P=0.41
TSA Volume 5 – 9/year	0.47 (0.17, 1.27)	0.54 (0.18, 1.67)	0.54 (0.18, 1.61)	0.46 (0.17, 1.25)	0.48 (0.18, 1.26)
TSA Volume 10 – 14/year	0.41 (0.13, 1.28)	0.43 (0.11, 1.64)	0.47 (0.13, 1.72)	0.40 (0.13, 1.27)	0.44 (0.14, 1.36)
TSA Volume 15 – 24/year	0.53 (0.22, 1.32)	0.42 (0.14, 1.28)	0.40 (0.12, 1.38)	0.52 (0.21, 1.29)	0.52 (0.20, 1.38)
TSA Volume 25/year	0.56 (0.27, 1.13)	0.66 (0.29, 1.47)	0.71 (0.31, 1.64)	0.54 (0.27, 1.10)	0.57 (0.27, 1.21)
Discharge to inpatient facility	P<0.0001	P<0.0001	P=0.0001	P<0.0001	P=0.0011
TSA Volume 5 – 9/year	0.79 (0.71, 0.88)	0.74 (0.65, 0.85)	0.79 (0.68, 0.91)	0.79 (0.70, 0.89)	0.84 (0.75, 0.95)
TSA Volume 10 – 14/year	0.76 (0.67, 0.86)	0.76 (0.65, 0.89)	0.84 (0.72, 0.98)	0.77 (0.67, 0.88)	0.86 (0.74, 0.99)
TSA Volume 15 – 24/year	0.74 (0.65, 0.85)	0.74 (0.63, 0.87)	0.81 (0.68, 0.96)	0.77 (0.66, 0.88)	0.84 (0.73, 0.98)
TSA Volume 25/year	0.66 (0.58, 0.75)	0.62 (0.54, 0.71)	0.70 (0.60, 0.81)	0.68 (0.60, 0.76)	0.75 (0.66, 0.86)
Post arthroplasty fracture ^f	P=0.0004	P=0.0008	P=0.06	P=0.0013	P=0.197
TSA Volume 5 – 9/year	0.66 (0.46, 0.94)	0.60 (0.40, 0.89)	0.74 (0.48, 1.12)	0.69 (0.48, 0.98)	0.84 (0.58, 1.21)
TSA Volume 10 – 14/year	0.71 (0.50, 1.03)	0.73 (0.49, 1.09)	0.98 (0.64, 1.49)	0.74 (0.52, 1.07)	0.96 (0.65, 1.41)
TSA Volume 15 – 24/year	0.44 (0.31, 0.64)	0.39 (0.25, 0.61)	0.57 (0.36, 0.89)	0.46 (0.32, 0.66)	0.64 (0.43, 0.94)
TSA Volume 25/year	0.62 (0.44, 0.87)	0.69 (0.48, 1.00)	1.00 (0.69, 1.46)	0.66 (0.47, 0.92)	0.88 (0.61, 1.26)
Revision ^g	P=0.045	P=0.13	P=0.09	P=0.04	P=0.02
TSA Volume 5 – 9/year	0.61 (0.35, 1.06)	0.61 (0.33, 1.13)	0.61 (0.32, 1.15)	0.61 (0.35, 1.05)	0.61 (0.32, 1.16)
TSA Volume 10 – 14/year	0.43 (0.23, 0.81)	0.49 (0.25, 0.96)	0.48 (0.24, 0.96)	0.43 (0.23, 0.80)	0.48 (0.24, 0.96)
TSA Volume 15 – 24/year	0.54 (0.32, 0.93)	0.51 (0.28, 0.9)	0.49 (0.27, 0.91)	0.53 (0.31, 0.90)	0.49 (0.27, 0.90)
TSA Volume 25/year	0.57 (0.34, 0.93)	0.57 (0.32, 1.00)	0.50 (0.29, 0.87)	0.55 (0.34, 0.90)	0.50 (0.29, 0.87)
Transfusion ^h	P=0.006	P=0.004	P=0.008	P=0.03	P=0.17
TSA Volume 5 – 9/year	0.88 (0.76, 1.01)	0.90 (0.77, 1.05)	0.96 (0.81, 1.13)	0.91 (0.78, 1.05)	0.98 (0.84, 1.15)
TSA Volume 10 – 14/year	0.82 (0.68, 0.99)	0.87 (0.71, 1.07)	0.92 (0.74, 1.15)	0.86 (0.71, 1.04)	0.93 (0.76, 1.15)

	Unadjusted	Multivariable-adjusted			
		Model 1 ^b OR (95% CI)	Model 2 ^c OR (95% CI)	Model 3 ^d OR (95% CI)	Model 4 ^e OR (95% CI)
TSA Volume 15 – 24/year	0.88 (0.72, 1.06)	0.98 (0.79, 1.21)	1.08 (0.87, 1.34)	0.92 (0.76, 1.12)	1.01 (0.82, 1.24)
TSA Volume 25/year	0.67 (0.54, 0.83)	0.64 (0.50, 0.81)	0.68 (0.53, 0.87)	0.70 (0.56, 0.88)	0.77 (0.61, 0.97)
Length of hospital stay >median	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001
TSA Volume 5 – 9/year	0.78 (0.71, 0.85)	0.76 (0.68, 0.84)	0.76 (0.68, 0.86)	0.78 (0.72, 0.86)	0.79 (0.72, 0.87)
TSA Volume 10 – 14/year	0.66 (0.59, 0.74)	0.67 (0.58, 0.76)	0.67 (0.58, 0.77)	0.67 (0.59, 0.75)	0.67 (0.59, 0.76)
TSA Volume 15 – 24/year	0.60 (0.53, 0.68)	0.60 (0.52, 0.69)	0.60 (0.52, 0.70)	0.61 (0.54, 0.69)	0.60 (0.53, 0.69)
TSA Volume 25/year	0.47 (0.41, 0.54)	0.47 (0.39, 0.55)	0.45 (0.38, 0.55)	0.47 (0.41, 0.55)	0.45 (0.38, 0.53)

^aWe used logistic regression to get the unadjusted p-values for the outcomes

^b, ^c Multivariable-adjusted models: 1) adjusted for gender, age, race and Deyo-Charlson score^b; 2) adjusted for gender, age, race, Deyo-Charlson score, hospital location and teaching status, hospital bed size, hospital region and primary diagnosis^c

^d, ^e Multivariable-adjusted models when missing race is considered as a category; 1) adjusted for gender, age, race and Deyo-Charlson score^d; 2) adjusted for gender, age, race, Deyo-Charlson score, hospital location and teaching status, hospital bed size, hospital region and primary diagnosis^e

^f Post-arthroplasty fracture: using ICD-9 procedure codes 79.01, 79.11, 79.2, 79.31, 79.61

^g Revision: using ICD-9 procedure codes, 81.83

^h Transfusion: Using ICD-9 procedure code, 99.0X

All % are for the non-missing values only