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Background: As far as we know, no previous study has determined the relationship between volume and outcomes for shoulder arthroplasty. We hypothesized that surgeons and hospitals with higher caseloads of total shoulder arthroplasties and hemiarthroplasties have better outcomes as measured by decreased mortality rate, shorter length of stay in the hospital, reduced postoperative complications, and routine disposition of patients on discharge.

Methods: Data on patients undergoing shoulder arthroplasty were extracted from the Nationwide Inpatient Sample databases for the years 1988 through 2000. Logistic regression with generalized estimating equations and multiple linear regression models were used to estimate the adjusted association between surgeon and hospital volume and outcomes for total shoulder arthroplasty and hemiarthroplasty after adjusting for comorbidity, age, race, household income, and sex.

Results: The mortality rates for patients who had a total shoulder arthroplasty performed by surgeons who did fewer than two procedures per year (0.36%) or who did between two and fewer than four procedures per year (0.32%) were higher than those for patients who had a total shoulder arthroplasty performed by surgeons who did four procedures or more per year (0.20%). The risk-adjusted rate of postoperative complications after hemiarthroplasty was significantly higher for patients managed by surgeons who performed fewer than two procedures per year (1.68%) than for those managed by surgeons with a volume of five procedures or more per year (0.97%). The possibility of postoperative complications when total shoulder arthroplasty was performed in hospitals with a volume of fewer than five procedures (1.44%) or in those with a volume of five to ten procedures per year (1.45%) was significantly higher than that in hospitals where ten procedures or more were performed every year (0.64%). The mean lengths of stay in the hospital after total shoulder arthroplasty and hemiarthroplasty were significantly longer when the operations were performed by surgeons who did fewer than two procedures per year or when they were done in hospitals with a volume of fewer than five procedures per year or with a volume of five to fewer than ten procedures per year than when they were done in hospitals or by surgeons in the highest volume category ($p < 0.001$).

Conclusions: Patients who have a total shoulder arthroplasty or hemiarthroplasty performed by a high-volume surgeon or in a high-volume hospital are more likely to have a better outcome.

Level of Evidence: Therapeutic study, Level III-2 (retrospective cohort study). See Instructions to Authors for a complete description of levels of evidence.

Shoulder arthroplasty has become the treatment of choice for many patients with a glenohumeral injury or disease. The frequency of shoulder arthroplasties has increased substantially over the past decade from approximately 10,000 in 1990 to 20,000 in 2000[1].

An inverse relationship between hospital and surgeon volume and nonoptimal clinical outcomes after surgery has been demonstrated for total hip arthroplasty and total knee arthroplasty[2-10]. Shoulder arthroplasty is a technically demanding procedure that is not performed routinely, as most sur-

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geons perform only one or two arthroplasties per year[11]. The combination of surgical difficulty and minimal surgeon experience could influence patient outcomes. To the best of our knowledge, no study has investigated the relationship between volume and outcomes for shoulder arthroplasty.

The objective of this study was to examine the relationship between surgeon and hospital volume and outcomes in shoulder arthroplasty with use of the Nationwide Inpatient Sample databases. We hypothesized that surgeons and hospitals with higher caseloads for total and partial shoulder arthroplasty have better outcomes as measured by a decreased mortality rate, shorter length of hospital stay, reduced postoperative complications, and routine disposition of patients on discharge.

Materials and Methods

Design

We performed a secondary analysis of the Nationwide Inpatient Sample (NIS) databases for the years 1988 through 2000.

Database Description

The NIS database for the years 1988 through 2000 was used for this study[12]. The NIS is part of the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Healthcare Research and Quality (AHRQ). Only patients who were admitted to the hospital are included. The NIS is the largest database for all-payer inpatient care that is publicly available in the United States, and it contains approximately five to eight million records of inpatient stays per year from about 1000 hospitals, which represent a 20% stratified sample of community hospitals in the United States[13]. To ensure maximal representation of hospitals in the United States, the following sampling strata based on five important hospital characteristics were used for the creation of the NIS database: geographic region (Northeast, North Central, West, and South), ownership (public, private not-for-profit, and private investor-owned), location (urban and rural), teaching status (teaching hospital and nonteaching hospital), and size (small, medium, and large) in terms of the number of beds. Information on hospital ownership was obtained from the American Hospital Association (AHA) Annual Survey of Hospitals and includes categories for government nonfederal (public), private not-for-profit (voluntary), and private investor-owned (proprietary)[14].

NIS datasets provide the following information: hospital identifiers (AHRQ-sponsored and AHA identifiers), synthetic surgeon identifiers, unique patient visit identifier, patient demographic data, and procedure and diagnostic codes classified according to the *International Classification of Diseases, Ninth Edition, Clinical Modification* (ICD-9-CM)[15].

The HCUP assigned validation and quality assessment of these datasets to an independent contractor[16]. To perform the validation, the contractor reviewed the univariate statistics for all numeric data elements and the frequency distributions for all categorical and some continuous data elements, checked the range against standard norms, and performed edit checks to identify inconsistencies between related data elements. The NIS database has also been extensively validated against the National Hospital Discharge Survey and was confirmed to perform very well for many estimates[17].

The combined datasets (1988 through 2000) contain information on 12,876 patients who had a total shoulder arthroplasty and 17,999 patients who had a hemiarthroplasty.

Sample Selection

Data were extracted separately for total shoulder arthroplasties and hemiarthroplasties. The records with an ICD-9-CM procedure code for total shoulder replacement (81.80) and for partial shoulder replacement (81.81) were initially included in the analysis (see Appendix). Each record in the datasets represents a single patient visit and has a unique identification number. As our dataset does not contain a unique patient identifier, patients who were readmitted could not be tracked. Patients with a procedure code for revision shoulder arthroplasty (81.83 – Other repairs of shoulder including revision shoulder arthroplasty) were not included in the study.

Patients who had a primary or secondary diagnosis of infection, malignant tumor, or pathological fracture in the bones of the shoulder region were excluded from the analysis. Cases of patients with evidence that the present surgery was performed as a result of complications of previous shoulder arthroplasty were also excluded (see Appendix). Stratifications based on the diagnosis of osteoarthritis and fracture of the humerus, scapula, or glenoid were attempted for both total shoulder arthroplasty and hemiarthroplasty. There were 12,594 records for total shoulder arthroplasty and 17,452 records for hemiarthroplasty included in the final analyses.

Outcome Measures

The outcomes of interest included inhospital mortality rate, length of stay in the hospital, disposition of the patient on discharge, and inhospital postoperative complications. The mortality rate was based on whether the patient died during hospitalization or was discharged alive. Length of stay was calculated in days by subtracting the admission date from the date of discharge.

The disposition of the patient on discharge was coded into routine and nonroutine disposition. Nonroutine disposition included transfer to a short-term hospital, skilled nursing facility, intermediate care facility, another type of facility, or home health care. Routine disposition reflected patients who were discharged home. The variable for postoperative complications was created on the basis of the information from fourteen secondary diagnoses included in the datasets. Patients with a secondary diagnosis of postoperative wound infection, other infections, a nonhealing surgical wound, disruption of the operative wound, pulmonary embolism, thrombophlebitis, and other unspecified complications were considered to have a postoperative complication (see Appendix).

Main Effects

The primary predictor variables included surgeon and hospital volume. The databases contained a synthetic primary surgeon identifier for each surgeon, which was consistent over thirteen years. The synthetic surgeon identifier was a fixed-key (one-to-one) encryption of the primary surgeon number and served as a unique identifier for each surgeon. Surgeon volume was calculated by counting the number of total shoulder arthroplasties of hemiarthroplasties performed for each of the respective subpopulations during a given year with use of this unique identifier. Surgeon volume was then divided into three categories (fewer than two procedures, two to four procedures, or five procedures or more per year) for both total shoulder arthroplasty and hemiarthroplasty. Synthetic primary surgeon identifiers were missing for 41.3% of total shoulder arthroplasties and 45.5% of hemiarthroplasties. In order to test the impact of missing surgeon identifiers on our results, a sensitivity analysis was conducted. Imputation by best subset regression of missing values for surgeon volume was used to conduct the sensitivity analysis. We calculated the value for missing surgeon volume on the basis of other characteristics such as hospital volume, hospital location, teaching status of hospital, hospital identifier, hospital size in terms of the number of beds, and year of the operation. The combined characteristics of these known variables were used to find the most likely estimate of surgeon volume. The calculation was based on patterns of other characteristics observed in patients for whom the information regarding surgeon volume was available. The method then matched these characteristics to patients without surgeon volume and imputed the most likely value. This method is called *imputation*, which represents an established and frequently used statistical tool[18-23]. Additionally, to test the potential impact of missing surgeon identifiers on our findings, patients with surgeon identifiers were compared with patients without surgeon identifiers in terms of outcomes and demographic variables. We found that the two patient subsets were very similar.

Similarly, each hospital had a unique hospital identifier, and this was used to determine the three categories (fewer than five procedures, five to nine procedures, and ten procedures or more per year) for hospital volume of total shoulder arthroplasties and hemiarthroplasties. None of the hospital identifiers were missing.

We chose surgeon and hospital volume categories to obtain approximately similar percentages of procedures in each category and also to have clinically meaningful cut-offs. The terms *high volume* and *low volume* for hospitals and surgeons in this article reflect only surgical volume of either total shoulder arthroplasty and hemiarthroplasty and not total surgical volume. In this article, the term *high volume* is used for surgeons or hospitals in the highest volume category; *medium volume*, for the surgeons or hospitals in the middle volume category; and *low volume*, for surgeons and hospitals in the lowest volume category.

Covariates

Covariates that are available from NIS include age, sex, race, household income, and comorbidity (according to the Charlson index as modified by Deyo et al.) of the patient[24,25]. The Charlson index measures comorbidity by assigning scores of 1, 2, 3, or 6 to each of the comorbid conditions present in a patient. These scores are then added to provide a single index score, which measures the overall comorbidity of the patient. Income is estimated by the median household income in the patient's zip code.

Statistical Analysis

Each of the analyses mentioned below was performed for both total shoulder arthroplasty and hemiarthroplasty. Univariate analyses were performed with use of means and proportions in percentage. Bivariate analyses were performed to measure the association between surgeon and hospital caseload and the remaining covariates. This analysis yielded the proportions in percentage of each surgeon-volume category across hospital-volume categories. Hospital volume was also tabulated across hospital size, total hospital charges, and hospital teaching-status categories. Hospital size categories (small, medium, and large) were based on the number of hospital beds and are specific to the hospital's location and teaching status. The hospital teaching status was obtained from the AHA Annual Survey of Hospitals. A hospital is considered to be a teaching hospital if it has an American Medical Association-approved residency program of any type, is a member of the Council of Teaching Hospitals, or has a ratio of full-time-equivalent interns and residents to beds of 0.25 or higher[12].

Multivariate logistic regression models were used to examine the risk-adjusted association between the surgeon and hospital volume and the outcomes. The surgeon-volume models were controlled for hospital volume (as a continuous variable), but surgeon volume was not used as a confounder for models with hospital volume as the main effect to avoid exclusion of records with missing surgeon volume. Each model was adjusted for age, sex, race, household income, and comorbidity of the patient.

Length of stay in the hospital was examined with use of multivariate linear regression models. Length of stay, which was used as a continuous variable, had a skewed distribution and therefore was modeled with use of a logarithmic transformation. Estimated mean length of stay was obtained by the exponentiation of regression coefficients.

Adjusted odds ratios with 95% confidence intervals were used to express the strength of association between the surgeon and hospital volume and the outcomes. Generalized estimating equations were used to control for clustering of patients within hospitals. Adjusted estimates were calculated for length of stay with use of linear regression. The White test[26] was performed to determine heteroscedasticity in the linear regression models. The estimated parameters were also corrected with use of a smearing factor to adjust for heteroscedasticity (as the White test was significant, $p < 0.001$) and logarithmic transformation[27,28].

Because of the very low mortality rates in our dataset, which are in agreement with those in other datasets[29] and previous studies[30], the outcome rate of mortality for total shoulder arthroplasty was not sufficient to do a regression analysis

TABLE I Selected Characteristics of Patients Undergoing Shoulder Arthroplasty from 1988 Through 2000 in the United States

Baseline Characteristics	Total Shoulder Arthroplasty (N = 12,594)	Hemiarthroplasty (N = 17,452)
Age* *(yr)*	68.3 ± 11.8	68.4 ± 13.7
Sex *(no. of patients)*		
Male	4885 (38.8%)	5226 (29.9%)
Female	7708 (61.2%)	12,225 (70.1%)
Data missing	1 (0%)	1 (0%)
Race *(no. of patients)*		
White	8427 (66.9%)	11,386 (65.2%)
Black	339 (2.7%)	402 (2.3%)
Hispanic	164 (1.3%)	346 (2.0%)
Other	130 (1.0%)	203 (1.2%)
Data missing	3534 (28.1%)	5115 (29.3)
Charlson Index†	1.5 ± 3.2	1.6 ± 3.6
No. of diagnoses on this discharge†	4.0 ± 2.4	4.6 ± 2.7

*The values are given as the mean and the standard deviation. Data were missing for one patient. †The values are given as the mean and the standard deviation. There were no missing values.

TABLE II Selected Outcomes of Patients Undergoing Shoulder Arthroplasty from 1988 Through 2000 in the United States

Outcome	Total Shoulder Arthroplasty (N = 12,594)	Hemiarthroplasty (N = 17,452)
Length of stay* *(days)*	3.9 ± 3.8	4.9 ± 5.3
No. of patients with missing data	21 (0.2%)	
Mortality *(no. of patients)*		
Survived	12,550 (99.7%)	17,351 (99.4%)
Died	32 (0.3%)	68 (0.4%)
Data missing	12 (0.1%)	33 (0.2%)
Postoperative complications *(no. of patients)*		
Absent	12,442 (98.8%)	17,219 (98.7%)
Present	152 (1.2%)	233 (1.3%)
Disposition of patient at discharge		
Routine	9116 (72.4%)	11,378 (65.2%)
Nonroutine	3466 (27.5%)	6041 (34.6%)
Data missing	12 (0.1%)	33 (0.2%)

*The values are given as the mean and the standard deviation.

for surgeon volume. Hence, surgeon volume was recategorized (fewer than two procedures, two to fewer than four procedures, and four procedures or more) to calculate adjusted odds ratios. A sensitivity analysis with surgeon-volume categories of fewer than two procedures, two to fewer than three procedures, and three procedures or more was also conducted to add robustness and validity to the analysis.

Incremental odds ratios were used to determine whether every increase in hospital or surgeon volume (category) is associated with an increased risk of the outcome. This approach is more stringent and accurate than the Mantel extension trend statistic[31], and it requires that all of the incremental odds ratio estimates be greater than (less than) 1.0 in order to confirm a dose-response relation.

Stratification based on the diagnosis of osteoarthritis or fracture of the humerus, glenoid, or scapula was attempted. Because of the extremely small percentage of patients who died, multivariate logistic regression was conducted only on postoperative complications and nonroutine disposition of the patient on discharge as outcome variables.

Statistical analyses were conducted with use of Intercooled Stata for Windows (version 7.0; Stata, College Station, Texas) and SAS for Windows (version 8.02; SAS Institute, Cary, North Carolina).

Results

Patients included in our analysis were predominantly white (66.9% for total shoulder arthroplasty and 65.2% for hemiarthroplasty) and female (61.2% for total shoulder arthroplasty and 70.1% for hemiarthroplasty), and they had a mean age of approximately sixty-eight years for both procedures. The mean Charlson index was 1.5 ± 3.2 for total shoulder arthroplasty and 1.6 ± 3.6 for hemiarthroplasty, and the mean number of diagnoses on discharge was 4.0 ± 2.4 for total shoulder arthroplasty and 4.6 ± 2.7 for hemiarthroplasty (Table I).

On the average, patients undergoing hemiarthroplasty had a longer stay in the hospital (4.9 ± 5.3 days) than those who had a total shoulder arthroplasty (3.9 ± 3.8 days). Postoperative complications were uncommon, affecting 1.2% of the patients who had a total shoulder arthroplasty and 1.3% of the patients who had a hemiarthroplasty. Nonroutine disposition was recorded for 27.5% of the patients who had a total arthroplasty and 34.6% of patients who had a hemiarthroplasty (Table II).

Surgeons in the low-volume category performed 33.5% of the total shoulder arthroplasties and 42.0% of the hemiarthroplasties; those in the medium-volume category, 37.6% and 44.0%, respectively; and those in the high-volume category, 28.9% and 14.1%. The percentage of procedures performed consistently decreased for low-volume surgeons across low to high-volume hospitals for total shoulder arthroplasty (21.5% to 4.5%) and hemiarthroplasty (24.5% to 6.0%). In contrast, for surgeons with a higher caseload, the proportion of procedures performed consistently increased across low to high-volume hospitals for total shoulder arthroplasty (0.3% to 20.8%) and hemiarthroplasty (0.4% to 9.4%) (see Appendix). In an attempt to better understand the distribution of surgeon volume across hospital volume, a bar graph was drawn that displays the distribution of surgeon volume as a proportion of individual hospital-volume categories (Fig. 1).

Bivariate analysis of hospital volume and hospital characteristics was performed. These results are displayed in the Appendix.

The multivariate logistic regression modeling demonstrated that patients undergoing total shoulder arthroplasty were 4.4 times (95% confidence interval, 0.6 to 31.2) more likely to die during the hospital stay if the operation was done by a surgeon who performed fewer than two procedures per year and 4.2 times (95% confidence interval, 0.6 to 29.6) more likely to die if the operation was performed by a surgeon who did two to fewer than four procedures per year than were patients managed by surgeons who performed at least four procedures every year (Table III). The trends analysis also yielded incremental odds ratios of 4.2 and 1.04 for decreasing surgeon-volume categories compared with surgeons with volume of at least four procedures (see Appendix). The sensitivity analysis performed with use of hospital-volume categories of fewer than two procedures, two to fewer than three procedures, and three procedures or more per year also yielded similar results. The results obtained for hospital vol-

TABLE III Associations Between Surgeon Volume and Selected Outcomes of Shoulder Arthroplasty from 1988 Through 2000 in the United States Determined with Use of Generalized Equation Models

Outcome	Procedure Volume	Outcome Rate	Adjusted Odds Ratio (95% Confidence Interval)
Total shoulder arthroplasty			
Mortality	<2	0.36%	4.4 (0.6-31.2)
	≥2 to <4	0.32%	4.2 (0.6-29.6)
	≥4	0.20%	1.0
Postoperative complications	<2	1.46%	1.4 (0.6-3.0)
	≥2 to <5	1.34%	1.5 (0.7-3.0)
	≥5	0.80%	1.0
Nonroutine disposition of patient on discharge	<2	30.9%	1.1 (0.8-1.4)
	≥2 to <5	28.7%	0.98 (0.8-1.2)
	≥5	26.8%	1.0
Hemiarthroplasty			
Mortality	<2	0.50%	0.9 (0.3-2.3)
	≥2 to <5	0.36%	0.7 (0.2-1.9)
	≥5	0.38%	1.0
Postoperative complications	<2	1.68%	2.2 (1.1-4.4)
	≥2 to <5	1.29%	1.5 (0.7-3.2)
	≥5	0.97%	1.0
Nonroutine disposition of patient on discharge	<2	37.8%	1.3 (1.1-1.5)
	≥2 to <5	38.1%	1.3 (1.1-1.6)
	≥5	29.8%	1.0

TABLE IV Associations Between Hospital Volume and Selected Outcomes of Shoulder Arthroplasty from 1988 Through 2000 in the United States Determined with Use of Generalized Equation Models

Outcome	Procedure Volume	Outcome Rate	Adjusted Odds Ratio (95% Confidence Interval)
Total shoulder arthroplasty			
Mortality	<5	0.36%	2.1 (0.7-6.6)
	≥5 to <10	0.29%	1.5 (0.4-5.5)
	≥10	0.08%	1.0
Postoperative complications	<5	1.44%	2.5 (1.5-4.2)
	≥5 to <10	1.45%	2.1 (1.2-3.6)
	≥10	0.64%	1.0
Nonroutine disposition of patient on discharge	<5	29.7%	1.2 (1.0-1.4)
	≥5 to <10	25.9%	1.1 (0.9-1.3)
	≥10	26.3%	1.0
Hemiarthroplasty			
Mortality	<5	0.49%	1.2 (0.6-2.5)
	≥5 to <10	0.32%	0.9 (0.4-1.9)
	≥10	0.33%	1.0
Postoperative complications	<5	1.29%	1.1 (0.7-1.8)
	≥5 to <10	1.37%	1.2 (0.8-1.9)
	≥10	1.37%	1.0
Nonroutine disposition of patient on discharge	<5	35.1%	1.1 (0.9-1.3)
	≥5 to <10	35.7%	1.2 (1.02-1.4)
	≥10	32.8%	1.0

ume were similar, as patients managed at low-volume and medium-volume hospitals were 2.1 times (95% confidence interval, 0.7 to 6.6) and 1.5 times (95% confidence interval, 0.4 to 5.5), respectively, more likely to die compared with those managed at high-volume hospitals (Table IV). Incremental odds ratios of 1.5 and 1.4 showed a positive trend effect (see Appendix).

Patients undergoing hemiarthroplasty performed by surgeons who did fewer than two procedures and by those who did between two and four procedures were 2.2 times (95%

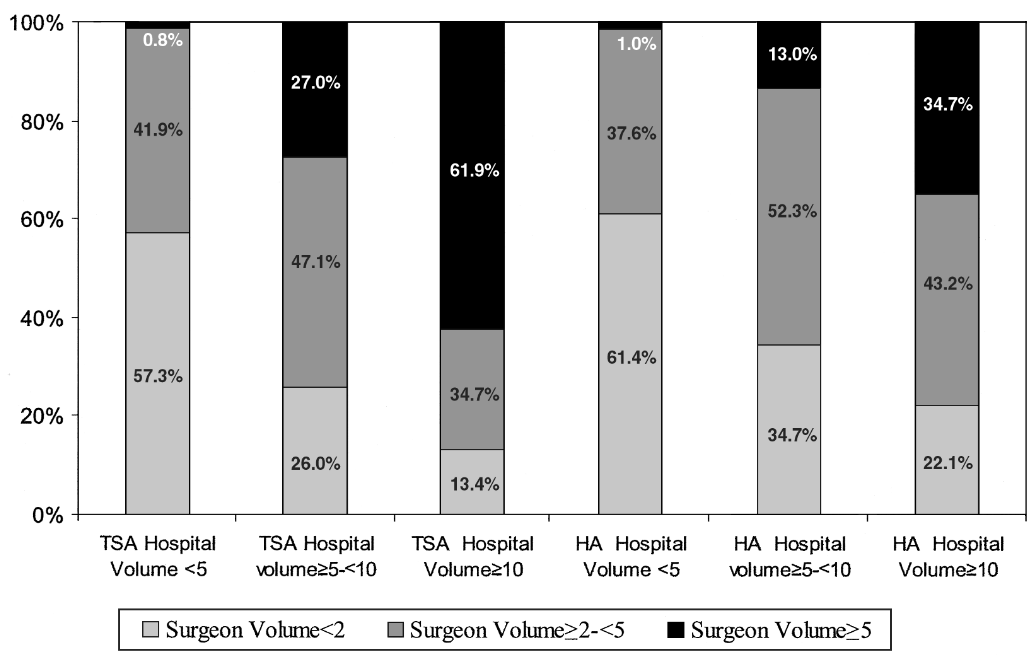

Fig. 1
Distribution of surgeon volume as a proportion of hospital-volume categories from the year 1988 through 2000 in the United States. TSA = total shoulder arthroplasty and HA = hemiarthroplasty.

confidence interval, 1.1 to 4.4) and 1.5 times (95% confidence interval, 0.7 to 3.2), respectively, more likely to have postoperative complications than were those managed by higher-volume surgeons. Trends analysis also showed a dose-response relationship with incremental odds ratios of 1.5 for both categories of decreasing surgeon volume. Significant results were obtained for the relationship between hospital volume for total shoulder arthroplasty and postoperative complications. Odds ratios of 2.5 (95% confidence interval, 1.5 to 4.2) for low-volume hospitals and 2.1 (95% confidence interval, 1.2 to 3.6) for medium-volume hospitals compared with high-volume hospitals with a positive trends analysis (odds ratio, 2.1 and 1.2 for decreasing hospital volume) were obtained.

The risk-adjusted odds ratios of nonroutine discharge after hemiarthroplasty were 1.3 (95% confidence interval, 1.1 to 1.5) and 1.3 (95% confidence interval, 1.1 to 1.6) for patients managed with surgeons who performed fewer than two procedures per year and for those managed by surgeons who performed two to less than five procedures per year, respectively, compared with those managed by surgeons with a caseload of at least five procedures per year. These results were significant ($p = 0.01$) (Table III). Similar results were obtained for hospitals that had a low or medium volume of total shoulder arthroplasties and hemiarthroplasties compared with those that had a high volume (Table IV).

Surgeons who performed five total shoulder arthroplasties or more per year discharged their patients an average of seventeen hours earlier than did surgeons who performed fewer than two procedures per year ($p < 0.001$). Similarly, patients who had the operation in hospitals with a volume of ten procedures or more per year were discharged an average of twelve hours earlier than those who had the operation in hospitals with caseloads of between five and nine procedures per year and 1.1 days earlier than those who had the operation in hospitals with fewer than five procedures per year ($p < 0.001$). The mean length of stay for patients managed by surgeons who performed fewer than two hemiarthroplasties per year (5.4 ± 1.3 days) was significantly higher than that for those managed by surgeons who performed five or more procedures (4.1 ± 1.1 days) ($p < 0.001$). On the average, patients managed in hospitals where ten hemiarthroplasties or more were performed every year were discharged twelve hours before patients managed in hospitals with a volume between five and nine procedures per year and 1.1 days before patients managed in hospitals with a caseload of fewer than five procedures per year; the difference was significant ($p < 0.001$) (Table V).

The sensitivity analysis performed with use of imputation by best-subset regression for missing surgeon volume revealed a variation of up to 13.6% in the odds ratios for all outcomes with a positive trends analysis, except mortality rate for patients managed with total shoulder arthroplasty, which still had odds ratios of >1.0 for both medium and low-volume surgeons and a positive trends analysis. Hence, we concluded that our analysis is robust and valid.

Stratification was performed on the data for patients with a diagnosis of osteoarthritis and those with fractures of bones in the shoulder region. Similar to the observations made on analysis of the results of total shoulder arthroplasty and hemiarthroplasty, associations between better outcomes and higher surgeon and hospital volume were observed for some of the variables (see Appendix).

TABLE V Adjustment Estimates of Length of Stay According to Surgeon and Hospital Volume for Patients Undergoing Shoulder Arthroplasty from 1988 Through 2000 in the United States After Accounting for Smearing

Procedure Volume	Length of Stay* (*days*)
Surgeon	
Total shoulder arthroplasty	
<2	4.0 ± 0.7†
≥2 to <5	3.6 ± 0.7
≥5	3.3 ± 0.7
Hemiarthroplasty	
<2	5.4 ± 1.3†
≥2 to <5	4.6 ± 1.2
≥5	4.1 ± 1.1
Hospital	
Total shoulder arthroplasty	
<5	4.1 ± 0.7†
≥5 to <10	3.7 ± 0.7†
≥10	3.3 ± 0.6
Hemiarthroplasty	
<5	5.3 ± 1.3†
≥5 to <10	4.7 ± 1.1†
≥10	4.2 ± 1.0

*The values are given as the mean and the standard deviation. †Compared with the highest volume category, the difference was significant, according to the linear regression model ($p = 0.001$).

Discussion

To the best of our knowledge, this study is the first attempt to investigate the relationship between volume and outcomes for shoulder arthroplasty. We used thirteen years of data from a 20% stratified probability sample of community hospitals in United States to examine whether surgeon and hospital volume were related to patient outcomes such as mortality, postoperative complications, disposition of patient on discharge, and length of stay. The multivariate logistic regression modeling demonstrated that the likelihood of mortality during hospitalization associated with both total shoulder arthroplasty and hemiarthroplasty increases as the volume of such procedures performed by the surgeons decreases and that the likelihood of postoperative complications associated with hemiarthroplasty is higher in patients managed by low-volume surgeons. An incremental pattern in the possibility of postoperative complications and nonroutine disposition of the patient on discharge after total shoulder arthroplasty was also observed in association with declining hospital volume. The mean length of stay was significantly lower for patients of high-volume surgeons and those treated in high-volume hospitals compared with those managed by low-volume surgeons and those treated in low and medium-volume hospitals.

In the risk-adjusted analysis, the likelihood of inhospital mortality after total shoulder arthroplasty was found to be low for high-volume surgeons and for high-volume hospitals with a confirmatory trends analysis; however; these findings need to be interpreted with caution. Wide confidence intervals as a result of the small percentage of patients who died necessitate further investigation of this outcome. Similar observations were made in the study by Kreder et al., who attempted to determine the relationship between surgeon and hospital volume and mortality for total hip arthroplasty during initial elective hospitalization[5].

Infection after shoulder arthroplasty has been well documented in previous studies[32-34], and, although pulmonary embolism is not frequently associated with shoulder arthroplasty, it has been reported[35,36]. Katz et al.[7] examined the association between surgeon and hospital volume of total hip arthroplasties and pulmonary embolus and found no significant association; however, in agreement with our findings, they concluded that lower rates of deep infection following total hip arthroplasty were associated with greater hospital volumes. With use of data from the Washington State Department of Health, Kreder et al. found that patients managed by low-volume surgeons had more infections after total hip arthroplasty than did patients managed by high-volume surgeons[5].

The effect of length of stay on patient outcome is an important area of research[37-41]. Our results are in conformity with those of Kreder et al., who found an association between patients managed with a total hip arthroplasty by high-volume surgeons and a shorter length of hospital stay[6]. Lavernia and Guzman, in a study of arthroplasty procedures, noted a similar association between a prolonged length of stay and low-volume surgeons[2]. Length of stay is an important determinant of cost[42,43]. Hence, this finding is very relevant to health care today in light of the pressure placed on hospitals to reduce costs. Additionally, surgeons and hospitals with higher caseloads are more likely to discharge their patients routinely. These results imply that high-volume surgeons and hospitals not only discharge patients earlier but also discharge them with a reduced chance of postoperative complications that would necessitate transfer of the patient to another facility.

It is evident from the results that patients treated by high-volume surgeons or in high-volume hospitals have better outcomes than do patients treated by low-volume surgeons or in low-volume hospitals. Halm et al., in a recently published systematic review of studies on the relationship between volume and outcome, noted that 71% of the studies on hospital volume and 69% of the studies on physician or surgeon volume reported associations between higher volume and better health outcomes[44]. Other studies of the volume and outcome relationship with respect to musculoskeletal disorders[2,3,6,7], coronary artery bypass[8,45], coronary angioplasty[46,47], cardiac transplantation[48,49], cancer surgery[50,51], gastrointestinal surgery[52,53], liver transplantation[54,55], and postoperative wound infection[56] have described similar findings.

Despite the improvements seen in the findings in the present study compared with those in previous volume-outcome studies, our analysis has limitations. First, primary synthetic surgeon identifiers were missing for 41.3% of the total shoulder arthroplasties and for 45.5% of the hemiarthroplasties. However, sensitivity analyses and a comparison of the cases of patients with and without surgeon identifiers indicated that this missing information did not impact our findings. Several investigations have compared the results obtained from actual data and from imputation, and they concluded that imputation is an appropriate method for dealing with missing data[18-23]. Second, the NIS does not provide information with regard to the severity grading for patients requiring shoulder arthroplasty, which prevents additional risk-adjusting of outcomes. Third, complications (e.g., postoperative wound infections and dislocations) occurring after hospital discharge cannot be ascertained, even if patients were readmitted to the hospital. Fourth, clinical outcome indicators on function, strength, range of motion, and patient satisfaction are not available. Last, there is no evidence that the coding of diagnoses in the NIS has been validated against clinical data. However, it is unlikely that miscoding would occur systematically in a certain volume group of hospitals or surgeons, and thus bias can be assumed to be minimal.

Our study showed that better outcomes can be achieved for shoulder arthroplasty when patients are referred to high-volume surgeons and hospitals. This additional evidence may help in the formulation of health policies to encourage better outcomes.

Appendix

eA Inclusion and exclusion criteria categorized by ICD-9-CM codes, the algorithm used for case inclusion or exclusion, and tables showing the bivariate analysis of hospital volume and hospital characteristics, the trend analysis of surgeon and hospital volume, and stratification of data by diagnosis (osteoarthritis or fracture) are available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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