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# Assessing the hospital volume–outcome relationship in total elbow arthroplasty

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**Background:** Total elbow arthroplasty (TEA) is an effective intervention for multiple elbow disorders including complex fracture in elderly patients, post-traumatic arthropathy, inflammatory arthropathy, and distal humeral nonunion. Given its known therapeutic value and low utilization rate, an investigation into the thresholds for TEA institutional volume–outcome relationships is warranted. The purpose of this study was to identify TEA volume thresholds that serve as predictors of institutional outcomes including complications, readmissions, revisions, cost of care, length of stay (LOS), and non-home discharge. We hypothesized that increased institutional volume would be associated with decreased 90-day adverse outcomes and resource utilization.

**Methods:** The Nationwide Readmission Database was queried from 2010 to 2017 to identify all cases of TEA. Hospital volume was calculated using a unique hospital identifier and divided into quartiles. Outcomes such as complications, readmissions, revisions, cost of care, LOS, and non-home discharge were then analyzed by quartile. The same outcomes were assessed via stratum-specific likelihood ratio (SSLR) analysis to define volume strata among institutions.

**Results:** SSLR analysis defined statistically significant hospital volume categories for each 90-day outcome. The volume category with the lowest complication rate was ≥21 TEAs per year (5.6%). The volume categories with the lowest readmission rates were 1-3 TEAs per year (4.7%) and ≥18 TEAs per year (9.2%). Revision rates were lowest in the volume categories of 1-5 TEAs per year (0.1%) and ≥18 TEAs per year (0.1%). Hospitals with ≥21 TEAs per year had the lowest cost of care and the highest rate of extended LOS (>2 days). SSLR analysis showed that non-home discharges decreased in a stepwise manner as volume increased. The lowest non-home discharge rate was associated with the volume category of ≥22 TEAs per year (20.3%).

**Conclusion:** This study defines TEA volume strata for institutional outcomes. The highest TEA volume strata were associated with the lowest rates of 90-day complications, revisions, and non-home discharges and the lowest cost of care. This trend is likely attributable to the benefits of high-volume institutional experience and standardized patient-care processes.

**Level of evidence:** Level III; Retrospective Cohort Comparison; Prognosis Study



**Keywords:** Total; elbow; arthroplasty; volume; outcomes; complications

Total elbow arthroplasty (TEA) is an effective intervention for multiple elbow disorders including trauma, post-traumatic arthropathy, inflammatory arthropathy, and distal humeral nonunion.[28] This procedure is performed less often relative to knee, shoulder, and hip arthroplasty, and subsequently, there is less literature regarding any TEA

As this research involved deidentified publicly available data, no institutional review board approval was required.

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hospital volume–outcome relationship. However, identification of any potential system-level factors associated with outcomes in TEA is crucial, as high institutional surgical volume has been shown to be associated with improved orthopedic outcomes.[1] Specifically, it has been well documented that high-volume hospitals are associated with decreased cost, length of stay (LOS), and non-home discharge for total shoulder arthroplasty (TSA).[5,7] For TSA, authors tend to agree that low-volume institutions perform <1 TSA per quarter, high-volume institutions perform >1 TSA per month, and medium-volume institutions settle between these 2 rates.[5,13,21] There is a gap in the literature written in the English language defining TEA hospital volume cutoffs, as well as any implications that hospital volume may have on TEA patient outcomes or resource utilization.

Only 1 study found in the literature describes any hospital volume–outcome association for TEA: Krenek et al[10] used the California Discharge Database to show that hospital volume was not associated with risk of adverse outcomes following TEA. However, specific outcomes such as 90-day complication rate, 90-day readmission rate, 90-day revision rate, cost, LOS, and non-home discharge were not evaluated. Gay et al[6] found that single-surgeon inexperience may be associated with a higher revision rate (6.8%) compared with experienced surgeons (2.8%) performing TEAs in New York State. It is interesting to note that 90.5% of the 1155 TEAs included in their study were performed by surgeons with no recorded experience, making an investigation into volume-outcome relationships in TEA even more necessary.

TEA has a higher overall complication rate than hip, knee, and shoulder arthroplasty. The rate of perioperative and/or long-term complication following TEA in the literature ranges from 22% to 34%.[3,18] The most common long-term complications are component loosening, dislocation, infection, and revision surgery.[3,4] Perioperative complications are less common but include intraoperative fracture of the distal humerus, delayed wound healing, deficits of the ulnar nerve, pulmonary embolism, and death.[3,12] A systematic review on TEA from 2003-2017 published by Welsink et al[26] found that 60% of patients were pain free at their latest follow-up. The same study found that TEA provided good to excellent functional outcomes (ie, mean flexion angle of 129°, mean extension lag angle of 30°, mean pronation of 71°, and mean supination angle of 66°). Given its known therapeutic value and low utilization rates, an investigation into the thresholds for TEA institutional volume–outcome relationships is warranted. The purpose of this study was to identify specific TEA volume thresholds that serve as predictors of institutional outcomes including complication rate, readmission rate, revision rate, cost of care, LOS, and non-home discharge. We hypothesized that increased institutional volume would be associated with decreased 90-day adverse outcomes and resource utilization.

## Materials and methods

The Nationwide Readmissions Database (NRD) was queried from 2010 to 2017 to identify all cases of primary TEA (*International Classification of Diseases, Ninth Revision* [ICD-9] procedure code 8184 and *International Classification of Diseases, Tenth Revision* [ICD-10] procedure codes 0RRL0JZ and 0RRM0JZ). The NRD, created by the Agency for Healthcare Research and Quality, records data from nearly 17 million hospital visits per year in the United States across 27 states. The NRD contains a deidentified linker variable to show all same-state hospital readmissions for a given patient in a given year for participating hospitals, which allows for analysis of readmission data with up to 1-year follow-up. The database also contains a discharge weighting coefficient to allow for the extrapolation of data to represent the entire national population.

To ensure that all patients received at least 90 days of follow-up, all patients admitted for TEA during the last quarter of the year (October, November, and December) were excluded from analysis. The discharge weighting coefficient was multiplied by 4/3 to reflect this exclusion. This technique has been validated in previous orthopedic studies.[5,11] Patients with a history of total shoulder, elbow, or wrist arthroplasty were excluded using both ICD-9 (V4361, V4362, and V4363) and ICD-10 (Z9661, Z9662, and Z9663) procedure codes.

Hospital volume was calculated using a unique hospital identifier provided in the database that allows for the calculation of the total number of procedures performed at an institution per year. The medical centers were then divided into quartiles based on number of TEAs performed per year, and these quartiles were used for further data analysis.

To provide a baseline for further outcome analysis and to identify potential confounding variables, demographic, comorbidity, and hospital data were analyzed between quartiles. Several comorbidities and patient characteristics were also analyzed, including the following: obesity, smoking status, alcohol abuse, uncomplicated diabetes, complicated diabetes, Charlson-Deyo Comorbidity Index, and primary payer. Comorbidity data were obtained through standardized *International Classification of Diseases* codes via the NRD.

The institutional outcomes in this study were complication rate, readmission rate, revision rate, cost of care, LOS, and non-home discharge. Complications were identified using both ICD-9 and ICD-10 procedure-specific complication codes that have been validated by previous studies.[15,16] All patients who received an additional procedure within the 90-day window, other than revision surgery for TEA, were excluded to ensure that the complication of interest was due to primary TEA. For the all-cause readmission rate, patients readmitted to the hospital for any reason within 90 days were included in the analysis. Revision procedures were identified using ICD-9 and ICD-10 codes for revision or removal of elbow arthroplasty (ICD-9 codes 8002 and 8197 and ICD-10 codes 0RWL0JZ, 0RWM0JZ, 0RPL0JZ, and 0RPM0JZ). Extended LOS was defined as >2 days in the hospital. Non-home discharge was determined using disposition data provided in the database. Total cost was determined using cost data that were inflation adjusted to the 2017 US dollar.

Statistics for analysis of demographic and hospital characteristics were performed using simple $\chi^2$ tests and 1-way analysis of variance. Outcome analyses were performed first by comparing volume quartiles and then by performing stratum-specific

likelihood ratio (SSLR) analysis. SSLR analysis involves generating cutoff points that provide volume categories that are statistically significantly different from their adjacent counterparts. This technique has been used in numerous orthopedic studies to determine significantly different volume categories as they relate to patient outcomes.[5,9,17,19,27] SSLR-generated volume categories were determined first by stratifying the data into categories based on procedures performed per year and then by combining adjacent categories until they no longer had overlapping 95% confidence intervals. This was done until all remaining volume categories were statistically significantly different from each adjacent volume category. All statistics were performed using Microsoft Excel (Microsoft, Redmond, WA, USA) and SPSS Statistics (version 25; IBM, Armonk, NY, USA).

## Results

### Demographic and hospital characteristics

A weighted total of 7256 primary TEAs were included in the analysis. Traditional division of the cohort into volume quartiles resulted in hospital volume categories of ≤2.9 TEAs per year (first quartile), 3.0-5.6 TEAs per year (second quartile), 5.7-12.6 TEAs per year (third quartile), and ≥12.7 TEAs per year (fourth quartile). The majority of patients included in the study were female patients (71%), and there was no significant difference across quartiles regarding average age. Further analysis of demographic characteristics and comorbidities showed that patients who underwent TEA at the highest–quartile volume centers (quartile 4) were significantly more likely than those in any other volume quartile to be male patients (33.9%, $P < .001$), to be obese (16%, $P < .001$), and to have a positive smoking status (21%, $P = .035$). Patients who received surgery in the lowest-volume centers (quartile 1) were significantly more likely than those in any other quartile to have uncomplicated diabetes (18%, $P < .001$). Demographic characteristics and comorbidities by quartile are found in Table I.

### Complication rates

The complication rate was lowest in quartile 4 (10.0%), which was significantly different from quartiles 2 and 3 but not quartile 1 (Fig. 1). SSLR analysis showed that centers performing ≥21 TEAs per year had a significantly lower complication rate (5.6%) than either of the other SSLR groups (12.0% for centers performing 1-3 TEAs per year and 14.7% for those performing 4-20 TEAs per year) (Table II).

### Readmission rates

The readmission rate was lowest in the first quartile (4.7%), whereas the fourth quartile had a significantly lower readmission rate (10.4%) than the third quartile only (13.8%) (Fig. 1). SSLR analysis showed that centers performing 1-3 procedures per year had the lowest readmission rate (4.7%), followed by centers performing ≥18 TEAs per year (9.2%) (Table III).

### Revision rates

Revision rate analysis between quartiles showed no significant differences between quartiles 1 (0.1%), 2 (0.1%), and 4 (0.3%) (Fig. 1). Quartile 3 had a significantly higher revision rate (0.6%) than quartiles 1 and 2 but not quartile 4. SSLR analysis showed that the volume categories of 1-5 TEAs per year (0.1%) and ≥18 TEAs per year (0.1%) had significantly lower revision rates than the volume category of 6-17 TEAs per year (0.8%) (Table II).

### Extended hospital stays

The fourth quartile had a significantly higher frequency of extended hospital stays (49.9%) than all other quartiles (first quartile, 40.5%; second quartile, 42.6%; and third quartile, 39.3%) (Fig. 1). The first, second, and third quartiles did not have significant differences in extended LOS (Table II). SSLR analysis showed that centers performing ≥23 procedures per year had a significantly higher frequency of extended hospital stays (56.8%) relative to centers performing <23 procedures per year (41.0%) (Table III).

### Non-home discharge

The fourth quartile had a significantly lower non-home discharge rate (24.9%) when compared with all other quartiles (first quartile, 33.0%; second quartile, 42.6%; and third quartile, 39.3%). SSLR analysis showed a stepwise decrease in the non-home discharge rate as institutional volume increased (Fig. 1).

### Total cost

The fourth quartile had a significantly lower total cost of admission ($19,302) relative to all other quartiles (first quartile, $20,210; second quartile, $20,079; and third quartile, $20,481) (Fig. 1). SSLR analysis showed that centers performing ≥21 procedures per year had a significantly lower cost ($17,516) when compared with centers performing <21 procedures per year ($20,486) (Table III).

## Discussion

It is known that both single-surgeon procedure volume and institutional procedure volume affect orthopedic outcomes.[1,23] Indeed, higher single-surgeon volume is

**Table I** Demographic characteristic and hospital characteristic analysis

| | First quartile | Second quartile | Third quartile | Fourth quartile | *P* value |
|---|---|---|---|---|---|
| Procedures per year | ≤2.9 | 3.0-5.6 | 5.7-12.6 | ≥12.7 | — |
| n | 1810 | 1817 | 1821 | 1808 | — |
| Age, mean (SD), yr | 63.3 (16) | 63.2 (16) | 63.3 (17) | 62.5 (16) | .304 |
| Sex, n (%) | | | | | <.001* |
| Female | 1331 (73.5) | 1287 (70.9) | 1373 (75.4) | 1195 (66.1) | |
| Male | 480 (26.5) | 529 (29.1) | 447 (24.6) | 613 (33.9) | |
| Comorbidities, n (%) | | | | | |
| Obesity | 227 (13) | 262 (14) | 215 (12) | 297 (16) | <.001* |
| Smoking | 326 (18) | 360 (20) | 326 (18) | 383 (21) | .035* |
| Alcohol abuse | 45 (2.5) | 31 (1.7) | 37 (2.0) | 37 (2.1) | .435 |
| Uncomplicated diabetes | 330 (18) | 254 (14) | 258 (14) | 238 (13) | <.001* |
| Complicated diabetes | 63 (3.5) | 44 (2.4) | 58 (3.2) | 63 (3.5) | .214 |
| Charlson-Deyo Comorbidity Index, mean (SD) | 0.84 (1.2) | 0.82 (1.3) | 0.80 (1.2) | 0.83 (1.2) | .742 |
| Payer code, n (%) | | | | | <.001* |
| Private | 969 (54) | 935 (52) | 997 (55) | 904 (50) | |
| Medicare | 154 (8.5) | 129 (7.1) | 120 (6.6) | 88 (4.9) | |
| Medicaid | 450 (25) | 554 (31) | 492 (27) | 624 (35) | |
| Other | 237 (13) | 199 (11) | 206 (11) | 185 (10) | |
| Control of hospital, n (%) | | | | | <.001* |
| Government, nonfederal | 278 (15) | 219 (12) | 311 (17) | 403 (22) | |
| Private nonprofit | 1201 (66) | 1353 (75) | 1295 (71) | 1174 (65) | |
| Private investor owned | 331 (18) | 245 (14) | 214 (12) | 231 (13) | |
| Hospital bed size, n (%) | | | | | <.001* |
| Small | 225 (12) | 324 (18) | 234 (13) | 286 (16) | |
| Medium | 531 (29) | 449 (25) | 334 (18) | 190 (11) | |
| Large | 1054 (58) | 1043 (57) | 1252 (69) | 1332 (74) | |
| Teaching status, n (%) | | | | | <.001* |
| Metropolitan non-teaching | 727 (40) | 509 (28) | 384 (21) | 180 (10) | |
| Metropolitan teaching | 1029 (57) | 1096 (60) | 1305 (72) | 1559 (86) | |
| Non-metropolitan | 54 (3.0) | 212 (12) | 132 (7.3) | 68 (3.8) | |

*SD*, standard deviation.
* Statistically significant.

associated with decreased LOS and complication rates in shoulder arthroplasty.[2,5,25] High surgeon volume is also strongly associated with a lower rate of hip dislocation following hip arthroplasty.[22] Regarding TEA, single-surgeon experience has been shown to decrease revision rates.[6] There are currently empirical institutional volume thresholds that predict outcomes in lower-extremity arthroplasty, shoulder arthroplasty, and general surgery.[2,5,9,14,19,20,27] To this point, there is a gap in the literature written in the English language regarding historical thresholds for TEA institutional volume–outcome relationships. Given its known therapeutic value yet low utilization, empirically defined volume strata were warranted to characterize TEA in the United States.

Our study results showed an association between institutional volume strata and specific 90-day outcomes related to primary TEA. SSLR analysis generated 2-4 distinct volume categories for all 6 measured outcomes: complications, readmissions, revisions, cost of care, LOS, and non-home discharge. SSLR analysis involved identifying naturally occurring cutoff points that divided the data set into cohorts significantly different from their adjacent counterparts. This technique has been featured in numerous orthopedic studies to determine empirically defined volume categories as they relate to patient outcomes.[5,9,17,19,27] Our hypothesis stated that increased institutional volume would be associated with decreased 90-day adverse outcomes and resource utilization. Of the 6 measured adverse outcomes in this study, 4 were lowest in the highest SSLR-generated institutional volume category, supporting our hypothesis. The volume category with the lowest profile of 90-day adverse outcomes and lowest resource burden ranged from ≥18 to ≥22 TEAs per year. This finding suggests that high-volume centers may be equipped with the surgeon experience, institutional synergy, and/or interdisciplinary coordination necessary to minimize medical risk to the patient and cost burden. Process standardization may indeed be at the core of high-quality and efficient care at high-volume TEA centers. It has already been shown that maximizing adherence to evidence-based protocols in total joint replacement patients improves clinical outcomes and shortens LOS.[1]

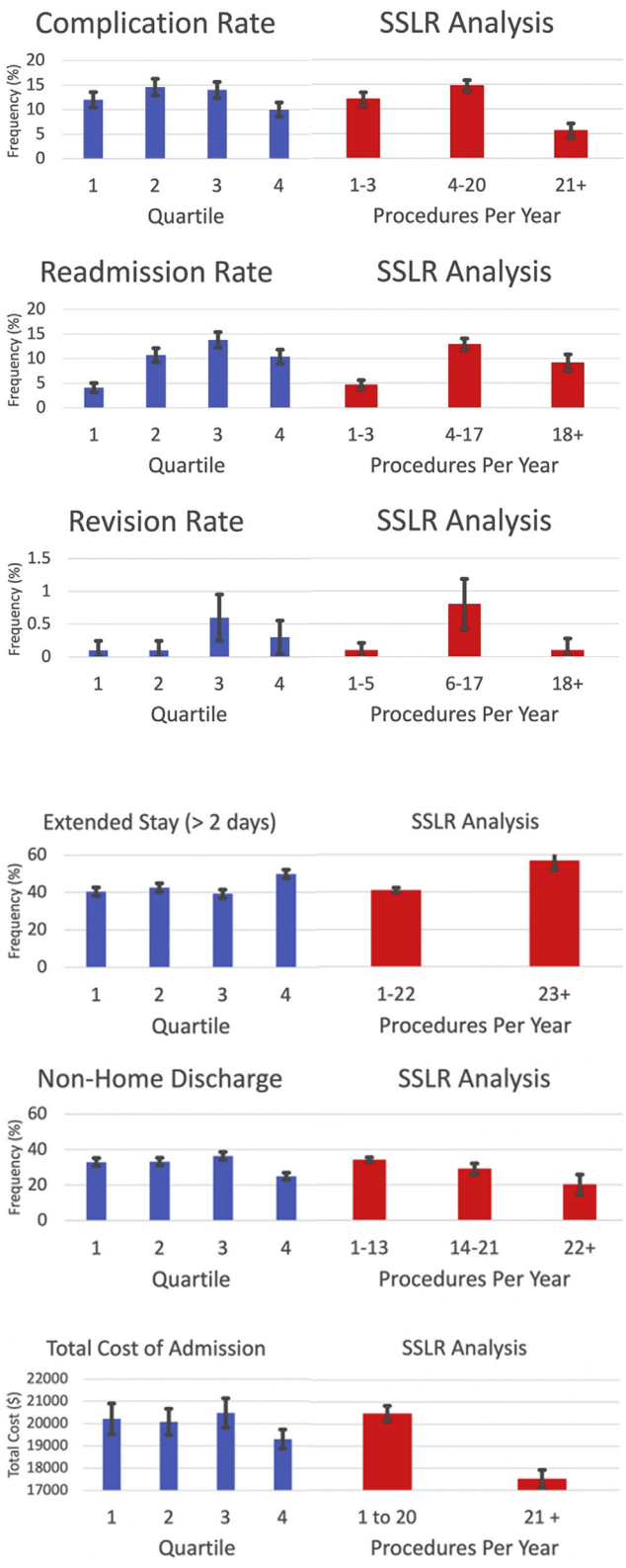


**Figure 1** Quartile and stratum-specific likelihood ratio (*SSLR*) outcome analysis.

Regarding 90-day adverse outcomes, SSLR analysis generated 3 volume categories for complication rate, readmission rate, and revision rate. The highest volume categories (≥21 and ≥18 TEAs per year) were associated with the lowest rates of complications and revisions. The lowest volume categories were actually associated with the second lowest rates of both complications and revisions. It has been shown in the arthroplasty literature that high-volume centers are associated with decreased revision rates. Indeed, Jeschke et al[8] found that the need for total knee arthroplasty revision surgery was lower for patients who underwent primary arthroplasty at a high-volume center, even when controlling for clinical factors and socioeconomic characteristics. It is possible that high-volume centers are equipped with the surgeon experience and interdisciplinary network necessary to minimize complications and the need for revision surgery, even in the most medically complex patients. Meanwhile, low-volume centers may elect to operate only on less medically complex patients with fewer comorbidities. Indeed, our data indicate that both obesity and smoking were more prevalent in TEA patients in the highest volume quartile (16% and 21%, respectively) relative to the lowest quartile (13% and 18%, respectively) (Table I). The readmission rate was lowest in the volume category of 1-3 TEAs per year. This trend could also be related to the possibility that extremely low-volume centers take on relatively straightforward cases with a lower comorbidity burden. Moreover, complication, readmission, and revision data from low-volume centers may not be captured by our data set given the fact that, once these adverse outcomes do arise following surgery at a low-volume center, patients may be referred to a separate, higher-volume center for tertiary care.

Regarding resource utilization, SSLR analysis generated 2 volume categories for cost and extended LOS and 3 volume categories for non-home discharge. The higher volume category (≥21 TEAs per year) was associated with decreased cost of care for TEA. Moreover, a stepwise decline in non-home discharge rate was observed as procedures per year increased by volume category. These trends may be attributable to efficient interdisciplinary networks and process standardization more commonly present in high-volume centers.[1] It is interesting to note that extended LOS (>2 days) was associated with the higher SSLR volume category of ≥23 TEAs per year. This finding may also suggest the influence of interdisciplinary teams involved in the care of TEA patients. There is little to no literature describing the physical and/or occupational therapy course for TEA patients; however, it is possible that physical and/or occupational therapy providers may visit with patients postoperatively in high-volume centers and ultimately recommend milestones prior to discharge. This

**Table II** Statistical analysis of quartile and SSLR analysis

| | OR (95% CI) | *P* value |
|---|---|---|
| 180-d complication rate | | |
| Q1 vs. Q4 | 1.05 (0.85-1.30) | |
| Q2 vs. Q4 | 1.27 (1.05-1.54)* | |
| Q3 vs. Q4 | 1.55 (1.28-1.87)* | |
| Q1 vs. Q3 | 0.84 (0.69-1.02) | |
| Q2 vs. Q3 | 1.05 (0.86-1.27) | |
| Q1 vs. Q2 | 0.80 (0.66-0.98)* | |
| SSLR | | |
| 1-3 vs. ≥21 | 2.27 (1.68-3.08)* | |
| 4-20 vs. ≥21 | 2.93 (2.19-3.91)* | |
| 1-3 vs. 4-20 | 0.78 (0.66-0.91)* | |
| Extended hospital stay (>2 d) | | |
| Q1 vs. Q4 | 0.68 (0.60-0.78)* | |
| Q2 vs. Q4 | 0.75 (0.65-0.85)* | |
| Q3 vs. Q4 | 0.65 (0.57-0.74)* | |
| Q1 vs. Q3 | 1.05 (0.92-1.20) | |
| Q2 vs. Q3 | 1.14 (1.01-1.31) | |
| Q1 vs. Q2 | 0.916 (0.80-1.05) | |
| SSLR: 1-22 vs. ≥23 | 0.53 (0.46-0.61)* | |
| 180-d readmission rate | | |
| Q1 vs. Q4 | 0.36 (0.28-0.48)* | |
| Q2 vs. Q4 | 1.04 (0.84-1.82) | |
| Q3 vs. Q4 | 1.39 (1.13-1.70)* | |
| Q1 vs. Q3 | 0.26 (0.20-0.34)* | |
| Q2 vs. Q3 | 0.75 (0.61-0.91)* | |
| Q1 vs. Q2 | 0.35 (0.27-0.46)* | |
| SSLR | | |
| 1-3 vs. ≥18 | 0.48 (0.37-0.63)* | |
| 4-17 vs. ≥18 | 1.46 (1.18-1.80)* | |
| 1-3 vs. 4-17 | 0.33 (0.27-0.41)* | |
| Non-home discharge rate | | |
| Q1 vs. Q4 | 1.49 (1.29-1.71)* | |
| Q2 vs. Q4 | 1.50 (1.30-1.73)* | |
| Q3 vs. Q4 | 1.73 (1.50-1.99)* | |
| Q1 vs. Q3 | 0.86 (0.75-0.99)* | |
| Q2 vs. Q3 | 0.87 (0.76-0.99)* | |
| Q1 vs. Q2 | 0.993 (0.86-1.14) | |
| SSLR | | |
| 1-13 vs. ≥22 | 2.05 (1.74-2.42)* | |
| 14-21 vs. ≥22 | 1.56 (1.25-1.96)* | |
| 1-13 vs. 14-21 | 1.31 (1.11-1.60)* | |
| 180-d revision rate | | |
| Q1 vs. Q4 | 0.33 (0.07-1.65) | |
| Q2 vs. Q4 | 0.33 (0.07-1.64) | |
| Q3 vs. Q4 | 1.83 (0.67-4.95) | |
| Q1 vs. Q3 | 0.18 (0.04-0.82)* | |
| Q2 vs. Q3 | 0.18 (0.04-0.82)* | |
| Q1 vs. Q2 | 1.00 (0.14-7.13) | |
| SSLR | | |
| 1-5 vs. ≥18 | 1.00 (0.99-1.01) | |
| 6-17 vs. ≥18 | 1.007 (1.004-1.011)* | |
| 1-5 vs. 6-17 | 0.15 (0.05-0.45)* | |
| Total cost of admission | | |
| Q1 vs. Q4 | | .025* |
| Q2 vs. Q4 | | .013* |
| Q3 vs. Q4 | | .003* |
| Q1 vs. Q3 | | .577 |
| Q2 vs. Q3 | | .373 |
| Q1 vs. Q2 | | .777 |
| SSLR: 1-20 vs. ≥21 | | <.001 |

(*continued on next column*)

**Table II** Statistical analysis of quartile and SSLR analysis (*continued*)

*SSLR*, stratum-specific likelihood ratio; *OR*, odds ratio; *CI*, confidence interval; *Q1*, quartile 1; *Q4*, quartile 4; *Q2*, quartile 2; *Q3*, quartile 3.
* Statistically significant.

would explain extended inpatient stays at high-volume surgery centers. Moreover, complex medical co-management of patients in higher-volume, tertiary care centers may necessitate a longer postoperative inpatient course. Finally, complex patients with polytraumatic injuries undergoing TEA and additional surgery at high-volume, tertiary care centers may require a longer LOS than patients undergoing surgery at low-volume centers. Other than extended LOS, cost and non-home discharges were significantly decreased in higher-volume centers, suggesting that these centers have the institutional infrastructure necessary for resource-efficient TEA.

Our study is not without limitations. We were unable to use institutional volume to estimate TEA functional outcomes, long-term (>90 day) adverse outcomes such as complication rate and need for revision surgery, and prosthetic survivorship. This limitation has been observed in similar studies assessing the volume-outcome relationship in shoulder arthroplasty.[5,24] Another database-related limitation includes not being able to include TEAs performed in the last quarter of the year for analysis. Ninety-day outcomes would have been impossible to identify in this cohort. Next, only 27 states are represented by the NRD. Despite the discharge weighting coefficient, these data may not be representative of TEA utilization across the nation as a whole. In addition, although patients may have undergone surgery at a high-volume center, there was no way to determine the experience of the operating surgeon within the institution by use of the NRD. Finally, only same-state readmissions are captured in the NRD, meaning that patients who are readmitted within 90 days to medical centers in a different state than their original presentation are not included in the database. These limitations are common to any study that relies on NRD data analysis.[5] Finally,

**Table III** Quartile and stratum-specific outcome rates

| | Rate, % | Cost, $ |
|---|---|---|
| 180-d complication rate | | |
| Overall | 12.7 | |
| Q1 | 12.0 | |
| Q2 | 14.6 | |
| Q3 | 14.0 | |
| Q4 | 10.0 | |
| SSLR 1 | 12.0 | |
| SSLR 2 | 14.7 | |
| SSLR 3 | 5.6 | |
| Extended hospital stay (>2 d) | | |
| Overall | 43.1 | |
| Q1 | 40.5 | |
| Q2 | 42.6 | |
| Q3 | 39.3 | |
| Q4 | 49.9 | |
| SSLR 1 | 41.0 | |
| SSLR 2 | 56.8 | |
| 180-d readmission rate | | |
| Overall | 9.7 | |
| Q1 | 4.7 | |
| Q2 | 10.7 | |
| Q3 | 13.8 | |
| Q4 | 10.4 | |
| SSLR 1 | 4.7 | |
| SSLR 2 | 12.9 | |
| SSLR 3 | 9.2 | |
| Non-home discharge rate | | |
| Overall | 31.9 | |
| Q1 | 33.0 | |
| Q2 | 33.2 | |
| Q3 | 36.4 | |
| Q4 | 24.9 | |
| SSLR 1 | 34.3 | |
| SSLR 2 | 29.1 | |
| SSLR 3 | 20.3 | |
| 180-d revision rate | | |
| Overall | 0.3 | |
| Q1 | 0.1 | |
| Q2 | 0.1 | |
| Q3 | 0.6 | |
| Q4 | 0.3 | |
| SSLR 1 | 0.1 | |
| SSLR 2 | 0.8 | |
| SSLR 3 | 0.1 | |
| Total cost of admission | | |
| Overall | | 20,001 |
| Q1 | | 20,210 |
| Q2 | | 20,079 |
| Q3 | | 20,481 |
| Q4 | | 19,302 |
| SSLR 1 | | 20,486 |
| SSLR 2 | | 17,516 |

*Q1*, quartile 1; *Q2*, quartile 2; *Q3*, quartile 3; *Q4*, quartile 4; *SSLR*, stratum-specific likelihood ratio.

because TEA is relatively rare, the statistical power of this study was low vs. other studies assessing volume-outcome relationships in more commonly used operations.

## Conclusion

This study suggests that high-volume surgical centers are associated with decreased 90-day complication and revision rates, non-home discharge, and cost of care in TEA. These findings are likely related to surgeon experience, interdisciplinary team synergy, and process standardization within high-volume institutions. It is also clear from our data that the lowest-volume centers see the next lowest rate of adverse outcomes, possibly related to the fact that lower-volume centers generally perform TEA on less medically complex patients. This finding highlights the necessity for moderate-volume centers, which generally had the worst outcomes in this study, to accurately identify indications that they are suited to manage while judiciously referring higher-complexity cases to high-volume centers. This practice may mitigate 90-day adverse outcomes and excess resource utilization alike. The SSLR analysis–generated volume categories for each outcome in this study may serve as guidelines to optimize TEA therapy.

## Disclaimer

Xinning Li is a consultant for FH Ortho, which is unrelated to this body of work. All the authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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