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What Is the Association Between Hospital Volume and Complications After Revision Total Joint Arthroplasty: A Large-database Study

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Abstract

Background Studies of primary total joint arthroplasty (TJA) show a correlation between hospital volume and outcomes; however, the relationship of volume to outcomes in revision TJA is not well studied.

Questions/purposes We therefore asked: (1) Are 90-day readmissions more likely at low-volume hospitals relative to high-volume hospitals after revision THA and TKA? (2) Are in-hospital and 90-day complications more likely at low-volume hospitals relative to high-volume hospitals after revision THA and TKA? (3) Are 30-day mortality rates higher at low-volume hospitals relative to high-volume hospitals after revision THA and TKA?

Methods Using 29,948 inpatient stays undergoing revision TJA from 2008 to 2014 in the Statewide Planning and Research Cooperative System (SPARCS) database for New York State, we examined the relationship of hospital revision volume by quartile and outcomes. The top 5 percentile of hospitals was included as a separate cohort. Advantages of the SPARCS database include comprehensive catchment of all cases regardless of payer, and the ability to track each patient across hospital admissions at different institutions within the state. The outcomes of interest included 90-day all-cause readmission rates and 30- and 90-day reoperation rates, postoperative complication rates, and 30-day mortality rates. The initial cohort that met the MS-DRG and ICD-9 criteria consisted of 30,354 inpatient stays for revision hip or knee replacements. Exclusions included patients with a missing patient identifier (n = 221), missing admission or discharge dates (n = 5), and stays from hospitals that were closed during the study period (n = 180). Our final analytic cohort comprised 29,948 inpatient stays for revision hip and knee replacements from 25,977 patients who had nonmissing data points for the variables of interest. Outcomes were adjusted for underlying hospital, surgeon, and patient confounding variables. The analytic cohort included observations from 25,977 patients, 138 hospitals, 929 surgeons, 14,130 revision THAs, 11,847 revision TKAs, 15,341 female patients (59% of cohort).

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Results Patients had lower all-cause 90-day readmission rates in the highest 5th percentile by volume hospitals relative to all other lower hospital volume categories. Reoperation rates within the first 90 days, however, were not different among volume categories. All-cause 90-day readmissions were higher in the quartile 4 hospitals excluding the top 5th percentile (17%) versus the top 5th percentile by volume hospitals (12%) (odds ratio [OR]: 1.3; 95% confidence interval [CI], 1.0–1.5; p = 0.030). All-cause 90-day readmissions were higher in the quartile 3 hospitals (18%) relative to the top 5 percentile by volume hospitals (12%) (OR: 1.5; 95% CI, 1.2–1.9; p < 0.001). All-cause 90-day readmissions were higher in quartile 2 hospitals (18%) relative to the top 5 percentile by volume hospitals (12%) (OR: 1.4; 95% CI, 1.1–1.8; p = 0.010). All-cause 90-day readmissions were higher in quartile 1 hospitals (21%) versus the top 5 percentile by volume hospitals (12%) (OR: 1.6; 95% CI, 1.1–2.3; p = 0.010). Postoperative complication rates were higher among only the quartile 1 hospitals compared with institutions in each higher-volume category after revision TJA. The odds of 90-day complications compared with quartile 1 hospitals were 0.49 (95% CI, 0.33–0.72; p = 0.010) for quartile 2, 0.60 (95% CI, 0.40–0.88; p = 0.010) for quartile 3, 0.43 (95% CI, 0.28–0.64; p = 0.010) for quartile 4 excluding top 5 percentile, and 0.36 (95% CI, 0.22–0.59; p = 0.010) for the top 5 percentile of hospitals. There does not appear to be an association between 30-day mortality rates and hospital volume in revision TJA. The odds of 30-day mortality compared with quartile 1 hospitals were 0.54 (95% CI, 0.20–1.46; p = 0.220) for quartile 2, 0.75 (95% CI, 0.30–1.91; p = 0.550) for quartile 3, 0.57 (95% CI, 0.22–1.49; p = 0.250) for quartile 4 excluding top 5 percentile, and 0.61 (95% CI, 0.20–1.81; p = 0.370) for the top 5 percentile of hospitals.

Conclusions These findings suggest that regionalizing revision TJA services, or concentrating surgical procedures in higher-volume hospitals, may reduce early complications rates and 90-day readmission rates. Disadvantages of regionalization include reduced access to care, increased patient travel distances, and possible capacity issues at receiving centers. Further studies are needed to evaluate the benefits and negative consequences of regionalizing revision TJA services to higher-volume revision TJA institutions.

Level of Evidence Level III, therapeutic study.

Introduction

The prevalence of revision total joint arthroplasty (TJA) has been increasing over time due to a greater volume of primary arthroplasties, broadened surgical indications for primary arthroplasties, and increases in certain patient comorbidities such as obesity or diabetes mellitus [5]. Frequently, revision TJA is more complicated than primary TJA due to bone loss, soft tissue deficiencies, presence of infection or fractures, increased intraoperative blood loss, and extended procedural times resulting in higher complication rates for patients [5, 12, 14, 20, 22, 30, 38]. Previous studies have shown an association between surgical volume at both the surgeon- and hospital-levels with complication rates and readmission rates after primary THA and TKA [1, 6, 7, 16, 19, 21, 25, 26, 31, 33, 40, 44]. These studies suggest that efforts to regionalize joint replacement services, or concentrate surgical procedures at higher-volume institutions and away from lower-volume institutions, may reduce early readmissions and postoperative complications after primary THA and TKA. This remains controversial, however, and other complex elective surgical fields like bariatric surgery have not found a benefit to patient outcomes by directing services to only designated centers of excellence [15].

While the relationship between surgical volume and outcomes after primary THA and TKA is more established, this relationship in revision THA and TKA has not been extensively studied [26, 42]. Given the increased complexity of revision THA and TKA compared with primary procedures and the lower volume of revision procedures being performed, regionalization of these services by referring patients to the highest-volume institutions in the region may be more beneficial than in primary THA and TKA to reduce postoperative patient readmissions and complications. Regionalization of these services can have substantial consequences for patients, however, and disadvantages may include reduced access to care, increased patient travel distances, disruption of traditional referral patterns, and capacity issues at receiving centers. Due to the potential negative consequences of regionalizing revision THA and TKA services, further studies are needed to clarify the relationship between hospital volume and postoperative outcomes in this patient population.

We therefore asked: (1) Are 90-day readmissions more likely at low-volume hospitals relative to high-volume hospitals after revision THA and TKA? (2) Are in-hospital and 90-day complications more likely at low-volume hospitals relative to high-volume hospitals after revision THA and TKA? (3) Are 30-day mortality rates higher at low-volume hospitals relative to high-volume hospitals after revision THA and TKA?

Patients and Methods

Data

We used the 2008 to 2014 Statewide Planning and Research Cooperative System (SPARCS) [35] database for

New York to study the variation in the outcomes of these surgeries. SPARCS datasets are all-payer administrative datasets compiled from billing records of inpatient, outpatient, emergency, and ambulatory surgery episodes from healthcare facilities certified under Article 28 of Public Health Law [34]. This statute requires all New York State hospitals, as well as diagnostic and treatment centers (both hospital-owned and freestanding) to periodically submit data to SPARCS. These datasets contain episode-level information about patient demographics, diagnostic and surgical codes, services provided, charges, and hospital and provider identifiers. One study of administratively coded data supported its accuracy and found that comorbidities and complications correlate reasonably well with the clinical record [4]. The benefit of the SPARCS database is the comprehensive catchment of all cases performed in New York State regardless of payer, and most previous studies have focused only on a single-payer population. Additionally, each patient has a unique identifier allowing the patient to be tracked across hospital admissions at different institutions within the state. We linked these files to the Annual American Hospital Association Survey Database to obtain hospital-level characteristics. New York State represents an excellent cross-section of US hospitals ranging from small, rural critical-access hospitals to the highest-volume revision TJA institutions in the country, making it best for the goals of our study compared with other databases. SPARCS is an all-payer database that includes observations from facilities certified through Article 28 of the Public Health Law. The database is managed by the New York State Department of Health which provides elaborate guidelines for the submission of data (https://www.health.ny.gov/statistics/sparcs/training/). The data are periodically audited to ensure compliance with recommended guidelines (https://www.health.ny.gov/statistics/sparcs/audit.htm).

Cohort Definition

We used the Medical-Severity Diagnosis Related Groups (MS-DRG) 466-468 to identify inpatient episodes for revision hip and knee arthroplasty in New York State (n = 31,136). We further used ICD-9-CM diagnosis and procedure codes to exclude stays that may have been primarily admitted for conditions or surgeries other than revision arthroplasty (n = 787). We also excluded stays that were missing patient identifiers (n = 221), as these identifiers were essential to track patients longitudinally, and stays that were from hospitals that closed down or merged from 2008 to 2014 (n = 180). Our final analytic cohort comprised 29,948 inpatient stays in New York hospitals for 25,977 patients who underwent revision arthroplasty from 2008 to 2014. The analytic cohort included observations from 25,977 patients, 138 hospitals, 929 surgeons, 14,130 revision THA, 11,847 revision TKA, 15,341 female patients (59% of cohort).

Variables

Outcomes

For analyzing outcome variations by hospital revision volume, the primary outcomes of interest were (1) readmissions for reoperation after revision arthroplasty (30 and 90 days) after the first revision arthroplasty (hereafter called index revision) and (2) all-cause 90-day hospital readmission. We specified these as binary indicators of whether a hospitalization occurred within the timeframe under consideration. We also constructed a binary indicator for whether at least one hospitalization (any or none) for revision arthroplasty was recorded for a patient from 2008 to 2014.

Secondary outcomes of interest were postoperative complications (both in-hospital complications and 90-day complications postoperatively) and 30-day mortality (specified as a binary indicator). Postoperative complications were identified using ICD-9-CM codes and the accompanying present-on-admission indicators to determine whether a condition developed after admission to the hospital (see Appendix, Supplemental Digital Content 1, http://links.lww.com/CORR/A155) [8]. We examined both inpatient complications occurring during the index hospitalization and complications that occurred within 90 days of index revision. The complications of interest were sepsis/septicemia/shock, pneumonia, mechanical complications, acute myocardial infarction, pulmonary embolism, periprosthetic joint infection, and surgical site bleeding. We created a binary indicator of whether any complication occurred during hospital stay.

Explanatory Variables

The key predictor of interest was a categorical variable that represented the quartile of mean hospital-level annual revision arthroplasty volume from 2008 to 2014. The mean volume was considered to be a reliable indicator of a hospital's expertise in revision arthroplasty surgery given annual fluctuations in the surgical volume. We further classified the top quartile to identify hospitals with the top 5 percentile of revision arthroplasty volume, resulting in a variable with five volume-based categories from lowest to highest volume: quartile 1 (0-25th percentile), quartile 2 (26-50th percentile), quartile 3 (51st-75th percentile), quartile 4 excluding top 5 percentile (76-95th percentile), top 5 percentile (96-100th percentile). The top 5 percentile hospitals were analyzed as a separate volume category because some of the highest-volume TJA hospitals in the United States are located in New York State, and it was possible that these highest-volume hospitals may perform better than other lower-volume institutions within the top quartile of hospitals.

We chose a categorical specification for the key predictor to account for the potential nonlinearity in the association between surgical volume and outcomes, and to enable us to draw inferences about high-volume and low-volume hospitals.

Based on previous studies and underlying hospital characteristics, we controlled for several covariates that are likely to confound the association between hospital revision volume and the outcomes of interest. Confounding variables included available demographic characteristics that may influence postsurgical outcomes (age, sex, race, ethnicity), admission characteristics (DRG, hip versus knee, comorbidities, elective versus nonelective admissions, admission source [home versus emergency room versus skilled nursing facility], payer source), surgeon volume, hospital characteristics (size, location, ownership status, academic versus nonacademic).

Statistical Analysis

We assessed the variation in outcomes across hospitals with varying revision surgical volume by estimating multivariate logistic regression models. We isolated the independent association between the surgical volume and outcomes by controlling for several patient-, surgeon-, and hospital-level variables described in the previous subsection. We used hospital random effects to account for the clustering of observations within hospitals. We report the adjusted odds ratio for the logistic models. P values less than 0.05 were used to indicate statistical significance. All statistical analysis was performed using STATA 14.1 MP for Unix (StataCorp LLC, College Station, TX, USA).

To check for the consistency of our findings, we conducted several sensitivity analyses. These included controlling for the volume of primary arthroplasties that a hospital performs in the multivariate models, removing surgeon volume as a covariate, using only admission source as a covariate, and using the hospital volume in the most recent year (instead of the mean annual volume) to construct the key independent variable. We also examined patients having surgery from only New York State zip codes to control for the possibility of out-of-state patients influencing outcomes.

Demographic Characteristics of Hospitals and Volume of Revision TJA in New York State

From 2008 to 2014, a total of 29,948 revision arthroplasties were performed in New York hospitals. Quartile 1 hospitals performed a median of 16 revisions over the study period (range, 4–26), quartile 2 hospitals performed a

Table 1. Descriptive statistics for hospitals in the cohort stratified by revision total hip and knee replacement volume (2008-2014)

	Quartile 1	Quartile 2	Quartile 3	Quartile 4 (excluding top 5 percentile)	Top 5 percentile	Total	p value*
Hospitals (n)	24	41	38	28	7	138	
Index revision stays	665	1704	4916	9127	9565	25,977	
Median revisions per hospital	16	48	126	304	807	86	
Range of revisions per hospital 2008-2014	4 to 26	17 to 85	56 to 201	155 to 657	682 to 4150	4 to 4150	
Ownership, number (%)							0.160
Government	7 (29)	5 (12)	2 (5)	3 (11)	0 (0)	17 (12)	
Not-for-profit	17 (71)	34 (83)	35 (92)	25 (89)	7 (100)	118 (86)	
For-profit	0 (0)	2 (5)	1 (2)	0 (0)	0 (0)	3 (2)	
Medical school affiliation, number (%)	11 (46)	17 (41)	23 (61)	23 (82)†	7 (100)†	81 (59)	< 0.001
Geographic location, number (%)							0.010
Rural	7 (29)	12 (29)	3 (8)	1 (4)	0 (0)	23 (17)	
Urban	17 (71)	29 (71)	35 (92)	27 (96)	7 (100)	115 (83)	
Bed size, number (%)							< 0.001
Small (< 200 beds)	14 (58)	23 (56)	15 (39)	7 (25)‡	2 (29)	61 (44)	
Medium (≥ 200 and < 400 beds)	10 (42)	13 (32)	17 (45)	7 (25)‡	1 (14)	48 (35)	
Large (≥ 400 beds)	0 (0)	5 (12)	6 (16)	14 (50)‡	4 (57)	29 (21)	

*p values for chi-square tests comparing the overall distribution of the variable across the five hospital groups;
†significant p values for pairwise comparisons comparing the distribution quartile 4 and top 5 percentile with quartile 2;
‡significant p values for pairwise comparisons comparing the distribution of quartile 4 with quartiles 1 and 2.

median of 48 revisions (range, 17–85), quartile 3 hospitals performed a median of 126 revisions (range, 56–201), quartile 4 hospitals performed a median of 304 revisions (range, 155–657), and the top 5 percentile hospitals performed a median of 807 revisions (range, 682–4150) (Table 1).

Hospital Demographic Characteristics

Hospitals in lower-volume categories were less likely to be medical school affiliated, more likely to be in a rural location, and less than 400 beds relative to higher-volume hospitals (Table 1).

Patient Demographic Characteristics

Of the 25,977 patients who underwent revisions (index revisions), 3284 (13%) underwent multiple revisions (two or more revisions during the study period). As compared with quartile 1 hospitals, the top 5 percentile hospitals had a higher proportion of whites (82% versus 63%; $p < 0.001$), elective surgeries (91% versus 60%; $p < 0.001$), patients admitted from home/office (96% versus 82%; $p < 0.001$), and patients who were privately insured (41% versus 27%; $p < 0.001$; Table 2). At the provider-level, mean surgeon volume was higher at the top 5 percentile hospitals compared with quartile 1 hospitals (mean 34 cases [SD 22] versus 4 [SD 4], respectively) ($p < 0.001$; Table 2). There was a strong correlation between surgeon volume and hospital volume (Spearman's rho 0.6).

Results

Association Between Hospital Volume and Readmission Rates After Revision TJA

After controlling for patient- and hospital-level confounders, patients had lower all-cause 90-day readmission rates in the top 5 percentile by volume hospitals relative to all other lower hospital volume categories (Tables 3 and 4). Reoperation rates within the first 90 days, however, were not different among volume categories (Table 3 and 4). All-cause 90-day readmissions were higher in quartile 4 hospitals excluding the top 5 percentile (17%) versus top 5 percentile by volume hospitals (12%) (odds ratio (OR): 1.3; 95% confidence interval [CI], 1.0–1.5; $p = 0.030$; Tables 3 and 4). All-cause 90-day readmissions were higher in quartile 3 hospitals (18%) relative to top 5 percentile by volume hospitals (12%) (OR: 1.5; 95% CI, 1.2–1.9; $p < 0.001$; Tables 3 and 4). All-cause 90-day readmissions were higher in quartile 2 hospitals (18%) relative to top 5 percentile by volume hospitals (12%) (OR: 1.4; 95% CI, 1.1–1.8; $p = 0.010$; Tables 3 and 4). All-cause 90-day readmissions were higher in quartile 1 hospitals (21%) versus top 5 percentile by volume hospitals (12%) (OR: 1.6; 95% CI, 1.1–2.3; $p = 0.010$). Ninety-day reoperations were not different in top 5 percentile by volume hospitals (2%) relative to quartile 1 hospitals (2%) (OR 0.77; 95% CI, 0.34–1.74; $p = 0.530$) (Tables 3 and 4). Ninety-day reoperations were not different in quartile 4 hospitals excluding the top 5 percentile (2%) relative to quartile 1 hospitals (2%) (OR 0.99; 95% CI 0.46–2.14; $p = 0.980$) (Tables 3 and 4). Ninety-day reoperations were not different in quartile 3 hospitals (3%) relative to quartile 1 hospitals (2%) (OR 1.30; 95% CI 0.61–2.78; $p = 0.490$) (Tables 3 and 4). Ninety-day reoperations were not different in quartile 2 hospitals (3%) relative quartile 1 hospitals (2%) (OR 1.10; 95% CI 0.51–2.40; $p = 0.810$) (Tables 3 and 4).

Association Between Hospital Volume and Complication Rates After Revision TJA

After controlling for patient- and hospital-level confounders, patients had lower in-hospital complication rates among quartiles 3, 4, and top 5 percentile hospitals by volume relative to quartile 1 hospitals. Patients had lower 90-day complication rates among quartiles 2, 3, 4, and the top 5 percentile hospitals by volume relative to quartile 1 hospitals. In-hospital complication rates were 2% in top 5 percentile hospitals by volume versus 7% in quartile 1 hospitals (OR, 0.47; 95% CI, 0.25–0.91; $p = 0.020$) (Tables 3 and 4). In-hospital complication rates were 3% in quartile 4 hospitals excluding the top 5 percentile by volume versus 7% in quartile 1 hospitals (OR, 0.45; 95% CI, 0.25–0.81; $p = 0.010$) (Tables 3 and 4). In-hospital complication rates were 3% in quartile 3 hospitals versus 7% in quartile 1 hospitals (OR, 0.50; 95% CI, 0.28–0.90; $p = 0.020$) (Tables 3 and 4). Ninety-day complication rates were 7% in top 5 percentile hospitals by volume versus 17% in quartile 1 hospitals (OR, 0.36; 95% CI, 0.22–0.59; $p < 0.001$) (Tables 3 and 4). Ninety-day complication rates were 9% in quartile 4 hospitals excluding the top 5 percentile by volume versus 17% in quartile 1 hospitals (OR, 0.43; 95% CI, 0.28–0.64; $p < 0.001$) (Tables 3 and 4). Ninety-day complication rates were 11% in quartile 3 hospitals versus 17% in quartile 1 hospitals (OR, 0.60; 95% CI, 0.40–0.88; $p = 0.010$) (Tables 3 and 4). Ninety-day complication rates were 10% in quartile 2 hospitals versus 17% in the quartile 1 hospitals (OR, 0.49; 95% CI, 0.33–0.72; $p < 0.001$) (Tables 3 and 4). There was no difference in 90-day complication rates among other hospital volume categories.

Table 2. Descriptive statistics for patients in the cohort stratified by revision total hip and knee replacement volume

Patient characteristic	Quartile 1	Quartile 2	Quartile 3	Quartile 4 (excludes top 5 percentile)	Top 5 percentile	Total	p value*
Index revision stays (n)	374	1995	4916	9127	9565	25,977	
Age, mean (SD)	68 (13)	67 (13)	67 (13)	67 (13)	66 (12)[†]	66 (13)	< 0.001
Female, n (%)	244 (65)	1171 (59)	2958 (60)	5407 (59)	5561 (58)	15,341 (59)	0.020
Race, n (%)							< 0.001[‡]
White	236 (63)	1540 (77)	3850 (78)	7195 (79)	7889 (82)	20,710 (80)	
Black	85 (23)	231 (12)	454 (9)	1148 (13)	813 (9)	2731 (11)	
Other	53 (14)	224 (11)	612 (12)	784 (9)	863 (9)	2536 (10)	
Hispanic ethnicity, n (%)	33 (9)	122 (6)	454 (9)	484 (5)	355 (4)	1448 (6)	< 0.001[§]
Admission type, n (%)							< 0.001[‖]
Emergency	115 (31)	352 (18)	827 (17)	1278 (14)	555 (6)	3127 (12)	
Urgent	34 (9)	118 (6)	161 (3)	420 (5)	312 (3)	1045 (4)	
Elective	225 (60)	1523 (76)	3924 (80)	7417 (81)	8698 (91)	21,787 (84)	
Outpatient admission, n (%)	306 (82)	1798 (90)	4480 (91)	8167 (90)	9223 (96)	23,974 (92)	< 0.001[‡]
Weekend admission, n (%)	30 (8)	104 (5)	225 (5)	370 (4)	277 (3)	1006 (4)	< 0.001[‡]
Primary payer, n (%)							< 0.001
Government	244 (65)	1130 (57)[¶]	2810 (57)	4931 (54)[¶]	5100 (53)[¶]	14,215 (55)	
Private	100 (27)	656 (33)	1696 (35)	3615 (40)	3958 (41)	10,025 (39)	
Diagnosis categories, n (%)							< 0.001[#]
Mechanical loosening	69 (19)	485 (24)	1341 (27)	2593 (28)	3440 (36)	7928 (31)	
Other mechanical loosening	121 (32)	774 (39)	1871 (38)	3561 (39)	3633 (38)	9960 (38)	
Dislocation	65 (17)	247 (12)	576 (12)	1052 (12)	1238 (13)	3178 (12)	
Infection	51 (14)	232 (12)	523 (11)	795 (9)	534 (6)	2135 (8)	
Periprosthetic fracture	27 (7)	110 (6)	264 (5)	450 (5)	335 (4)	1186 (5)	
Stiffness	1 (0.0)	8 (0.0)	26 (1)	36 (0.0)	16 (0.0)	87 (0.0)	
Comorbidities, mean (SD)	2.4 (1.6)	2.4 (1.8)	2.4 (1.7)	2.3 (1.7)	2.2 (1.7)[**]	2.3 (1.7)	< 0.001
Surgeon annual revision volume, mean (SD)	4 (5)	9 (10)	13 (11)	25 (16)	34 (22)	25 (20)	< 0.001[††]

*p values for chi-square tests comparing the overall distribution of the variable across the five hospital groups;
†significant p values for pairwise comparison tests comparing top 5 percentile and quartiles 3 and 4;
‡significant p values for all pairwise comparison tests except for those comparing quartiles 3 and 4 with quartile 2;
§significant p values for all pairwise comparison tests except for those comparing quartiles 3 and top 5 percentile with quartile 1;
‖significant p values for all pairwise comparison tests except for those comparing quartiles 3 and 2;
¶significant p values for pairwise comparison tests comparing quartiles 2, 4, and top 5 percentile with quartile 1;
#significant p values for all pairwise comparison tests except for those comparing quartile 3 with quartile 2, and quartile 4 with quartile 3;
**significant p values for pairwise comparison tests comparing top 5 percentile with quartiles 2 to 4;
††significant p values for all pairwise comparison tests.

Association Between Hospital Volume and 30-day Mortality Rates After Revision TJA

After controlling for patient- and hospital-level confounders, there was no difference between 30-day mortality rates across hospital volume categories. Thirty-day mortality rates were not different in the top 5 percentile by volume hospitals (0.5%) relative quartile 1 hospitals (2%) (OR, 0.61; 95% CI, 0.20–1.81; p = 0.370) (Tables 3 and 4). Thirty-day mortality rates were not different in quartile 4 hospitals excluding the top 5 percentile (0.8%) relative quartile 1 hospitals (2%) (OR, 0.57; 95% CI, 0.22–1.49; p = 0.250) (Tables 3 and 4). Thirty-day mortality rates were not different in quartile 3 hospitals (1%) relative quartile 1 hospitals (2%) (OR, 0.75; 95% CI, 0.30–1.91; p = 0.550) (Tables 3 and 4). Thirty-day mortality rates were not different in quartile 2 hospitals (1%) relative quartile 1 hospitals (2%) (OR, 0.54; 95% CI, 0.20–1.46; p = 0.220) (Tables 3 and 4).

Table 3. Descriptive outcomes across hospital categories

Patient outcome	Quartile 1	Quartile 2	Quartile 3	Quartile 4 (excludes top 5 percentile)	Top 5 percentile	Total
Index revision stays (n)	665	1704	4916	9127	9565	25,977
90-day all-cause readmission, n (%)	80 (21)	365 (18)	893 (18)	1532 (17)	1132 (12)	4002 (15)
Reoperations (reoperation following index revision), n (%)						
One or more reoperations	41 (11)	250 (13)	637 (13)	1230 (14)	1151 (12)	3309 (13)
90-day reoperations	8 (2)	51 (3)	134 (3)	215 (2)	171 (2)	579 (2)
One or more in-hospital complications, n (%)	25 (7)	085 (4)	161 (3)	292 (3)	234 (2)	797 (3)
Sepsis/septicemia/shock	6 (1.6)	17 (0.9)	50 (1)	106 (1.2)	43 (0.5)	222 (0.9)
Pneumonia	9 (2.4)	28 (1.4)	52 (1.1)	79 (0.9)	49 (0.5)	217 (0.8)
Mechanical complications	7 (2)	19 (1)	35 (0.7)	63 (0.7)	62 (0.7)	186 (0.7)
AMI	2 (0.5)	12 (0.6)	19 (0.4)	43 (0.5)	43 (0.5)	119 (0.5)
Pulmonary embolism	1 (0.3)	6 (0.3)	14 (0.3)	32 (0.4)	44 (0.5)	97 (0.4)
Periprosthetic joint infection	1 (0.27)	5 (0.25)	8 (0.16)	17 (0.19)	12 (0.13)	43 (0.17)
Surgical site bleeding	2 (0.5)	2 (0.1)	6 (0.1)	8 (0.1)	7 (0.1)	25 (0.1)
90-day complications, n (%)	65 (17)	207 (10)	525 (11)	838 (9)	662 (7)	2297 (9)
30-day mortality, n (%)	8 (2)	21 (1)	63 (1)	76 (0.8)	43 (0.5)	211 (0.8)

All values listed as number of cases (percentage of total).

Discussion

The relationship between higher surgical volume and improved outcomes after primary TKA and THA at both the provider- and hospital-level is well established [1, 7, 16, 19, 21, 24, 25, 28, 31, 32, 33]; however, the effect of these variables on revision surgery is less clear. Given the increased complexity and lower incidence of revision TJA compared with primary procedures, hospitals with higher revision TJA volume may have reduced early readmission and complication rates relative to lower-volume institutions. Our results suggest that all-cause 90-day readmission rates were lower in the highest 5 percentile by volume hospitals relative to lower-volume hospitals. Reoperation rates within the first 90 days, however, were not different among volume categories. Postoperative complication rates were higher among only the quartile 1 volume institutions compared with higher-volume institutions after revision TJA. There was no association between 30-day mortality rates and hospital volume in revision TJA.

We acknowledge several limitations of this study. Administrative data relies on accurate coding of complications and incorrect reporting by institutions could have uncertain effects on our data. The accuracy of the SPARCS data is supported by previous studies showing administratively coded comorbidities and complications correlate reasonably well with the clinical record [4]. Case complexity is not captured by administrative data, which limits our ability to assess these variables in relation to hospital volume. The SPARCS does not provide outcomes for patients who sought subsequent care outside of New York State. We conducted a sensitivity analysis to only look at patients who resided in New York State zip codes throughout their care period to reduce possibly confounding effects of patients seeking follow up revision care from outside regions in New York State, and this did not alter our results. The SPARCS only contains patients seeking care within New York State. New York State represents an excellent cross-section of US hospitals ranging from small, rural critical-access hospitals to the highest-volume revision TJA institutions in the country, making it appropriate for the goals of our study compared with other databases; however, the results in other states with a different population and hospital distribution may be different. Further studies in other states or with national databases would be warranted. Readmission after revision TJA can be a subjective decision and may reflect less social support or outpatient resources for care that may not be reflected in our analysis. Reasons for readmission across different hospital categories cannot be assessed through administrative data and would need to be investigated in the further in the future. Mortality rates may be underpowered to detect differences given the uncommon nature of the outcomes.

In our study, all-cause 90-day readmission rates were lower in the highest 5 percentile by volume hospitals relative to lower-volume hospitals. Preventing early readmissions in revision TJA is critical for hospitals and

Table 4. Multivariate estimates examining the association between hospital volume of revision surgeries and outcomes of care

	90-day all-cause readmissions		90-day reoperations		In-hospital complications		90-day complications		30-day mortality	
Hospital volume quartile	**Odds ratio with 95%CI**	**p value**	**Odds ratio with 95% CI**	**p value**	**Odds ratio with 95% CI**	**p value**	**Odds ratio with 95% CI**	**p value**	**Odds ratio with 95% CI**	**p value**
Quartile 1	Reference		Reference		Reference		Reference		Reference	
Quartile 2	0.86 (0.63-1.17)	0.33	1.10 (0.51-2.40)	0.81	0.56 (0.31-1.03)	0.06	0.49‡ (0.33-0.72)	< 0.001	0.54 (0.20-1.46)	0.220
Quartile 3	0.91 (0.67-1.24)	0.56	1.30 (0.61-2.78)	0.49	0.50* (0.28-0.90)	0.02	0.60† (0.40-0.88)	0.01	0.75 (0.30-1.91)	0.550
Quartile 4 excluding top 5 percentile	0.77 (0.56-1.05)	0.10	0.99 (0.46-2.14)	0.98	0.45† (0.25-0.81)	0.01	0.43‡ (0.28-0.64)	< 0.001	0.57 (0.22-1.49)	0.250
Top 5 percentile	0.61†, § (0.43-0.88)	0.01	0.77 (0.34-1.74)	0.53	0.47* (0.25-0.91)	0.02	0.36‡ (0.22-0.59)	< 0.001	0.61 (0.20-1.81)	0.370

*$p < 0.05$;
†$p < 0.01$;
‡$p < 0.001$; these p values are for tests comparing quartile 2 to top 5 percentile hospitals with quartile 1;
§significant p values for pairwise comparisons comparing top 5 percentile with quartiles 2 to 4 – 90-day all-cause readmission for quartile 4 hospitals excluding the top 5 percentile versus the top 5 percentile by volume hospitals (odds ratio [OR], 1.3; 95% confidence interval [CI], 1.0–1.5; p = 0.03); quartile 3 hospitals relative to the top 5 percentile by volume hospitals (OR, 1.5; 95% CI, 1.2–1.9; p < 0.001); quartile 2 hospitals relative to the top 5 percentile by volume hospitals (OR, 1.4; 95% CI, 1.1–1.8; p = 0.01); quartile 1 hospitals versus the top 5 percentile by volume hospitals (OR, 1.6; 95% CI, 1.1–2.3; p = 0.01).

surgeons because these serve as important measures of quality and correlate with total episode-of-care costs [9, 10, 11, 13]. Our results suggest that 90-day readmission rates may be lower in the highest-volume institutions; however, 90-day reoperation rates were not different. These results are consistent with previous studies examining these relationships in primary TJA and limited studies performed looking at revision TJA [7, 26, 28]. After revision THA in the Medicare population, higher hospital THA revision volumes (> 50 per year) had lower dislocation rates compared with very low volume (< 5) hospitals [26]. In contrast, mortality, deep infection, and pulmonary embolism were not different across volume categories for revision THA [26]. One study using the Perspective database between 2003 to 2005 showed a correlation between both higher surgical volume at the individual provider-level and institutional-level and decreased readmission rates and home discharge destination after primary THA or TKA [7]. Importantly, previous studies in primary arthroplasty have shown that risk of revision continues to increase over time when performed in low volume institutions. For example, after primary cemented THA, hospitals performing less than 50 THAs per year had increased risk of reoperation for revision THA up to 15 years after the index procedure [19]. One important consideration is that hospital volume may not be the best standard to measure quality of care. Adherence to standardized process of care measures can lead to improved quality and efficiency of care, independent of hospital or surgeon volume [7]. This may explain why the relationship between hospital volume and readmissions in our study was different between only the highest-volume institutions compared with lower-volume categories.

In our study, complications after revision TJA were higher in quartile 1 hospitals compared with higher-volume institutions. This suggests that a threshold effect may exist regarding the relationship between volume and complication rates after revision TJA in New York State particularly at the lowest hospital volumes. This is consistent with studies in primary TJA where volume at the surgeon- and hospital-level correlates most strongly with complication and revision rates at low absolute numbers of cases [1, 7, 19, 23, 24, 25, 36, 40, 44]. In the Norwegian Arthroplasty Register, the risk of subsequent revision was decreased after primary TKA in higher-volume hospitals (>100 cases annually) compared with the lowest-volume (1-24 cases) institutions [1]. In a national insurance database in Germany, the risk of revision TKA in the first 2 years after the index procedure was increased in hospitals performing less than 145 cases per year [24]. In the United States, one single institution study examining primary and revision TJA procedures performed in a safety net hospital versus a university center by the same surgeon had increased total complication rates, although this study did not adjust for underlying patient characteristics, and process-of-care protocols were different between the institutions [23]. California's Office of Statewide Health Planning and Development (OSHPD) database from 1991-2001, readmissions for infection and pulmonary embolism were higher among lower-volume institutions within 90-days of primary TKA [41]. At the surgeon-level, the lowest-volume surgeons also appear to have higher complication and revision rates compared with higher-volume surgeons. Surgeons who performed fewer than 60 surgeries per year–as defined by a stratum-specific likelihood ratio analysis of a receiver operator curve to examine 90-day complications and 2-year revision risk after TKA–had higher rates of 2-year revision risk and complication rates than higher-volume surgeons [44].

In our study, there was no increased rates of 30-day mortality across different hospital volume categories. One study found that mortality rates after revision THA in higher-volume institutions were not different from very low-volume institutions in the Medicare population, however, lower-volume surgeons performing three or fewer revision THA per year may have higher rates of mortality relative to surgeons performing greater than 10 per year [26, 27]. Taken together, our data does not provide strong support for the regionalization of revision TJA services to only the highest-volume institutions because hospitals in the mid-range of volume provided similar short-term readmissions, complications, and mortality rates as the highest-volume institutions. Complications were highest only in quartile 1 hospitals, suggesting that directing surgical services away from these institutions may provide the most improvement in short-term outcomes after revision TJA. It is important to note; however, these hospitals are more likely to be safety net institutions that are taking care of underserved, higher-risk patient populations. For instance, a larger percentage of revision TJA at the quartile 1 hospitals were for a periprosthetic infection diagnosis, emergency room admissions, and Medicaid insurance compared with higher-volume institutions, which had more cases of mechanical loosening, elective admissions, and private insurance. This makes the concept of regionalizing services away from the lowest-volume institutions more complicated and further investigation is necessary to understand the implications of this type of public policy. For example, regionalizing TJA services to the highest-volume institutions would increase the case volumes of hospitals already in the highest tier of procedure volume, which tend to be clustered in major metropolitan areas. At the same time, the lowest-volume institutions, which are more likely to be in rural areas or serve vulnerable patient populations, would see a reduction in surgical cases, possibly increasing the travel burden for these vulnerable populations [2, 3, 29, 39, 43]. Additionally, patients who are unable or unwilling to travel may have increased comorbidities, be older in age, and reside in underserved rural locations [16, 17, 37]. Although 98% of the US population lives within a 50-mile radius of hospitals performing more than 100 THA or TKA cases per year, only 44% of the US population is within 50 miles of a hospital performing more than 1000 cases per year [18, 20]. Overall, the benefit of regionalizing revision TJA services may only exist by directing patients from the quartile 1 hospitals to other hospitals in higher-volume quartiles. Unfortunately, many of these hospitals serve a vulnerable patient population and may create access to care concerns while not substantially affecting patient outcomes. Further studies on the effects of regionalizing revision TJA services are needed.

Taken together, our results suggest that all-cause 90-day readmission rates were lower in the highest 5 percentile by volume hospitals relative to lower-volume hospitals, while reoperation rates within the first 90 days were not different among volume categories. Postoperative complication rates were higher among only the quartile 1 volume institutions after revision TJA. These findings suggest that regionalizing revision TJA services away from the lowest quartile hospitals may reduce early complication rates and 90-day readmission rates; however, possible disadvantages of this type of policy need to be considered, including patient access-to-care issues and overcapacity issues at receiving hospitals. Further studies should address the potential patient care and health policy implications of centralizing revision TJA services away from the lowest-volume institutions.

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