Research Article

Effects of Hospital and Surgeon Volume on Patient Outcomes After Total Joint Arthroplasty: Reported From the American Joint Replacement Registry

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ABSTRACT

Background: The purpose of this study was to evaluate outcomes and complications because it relates to surgeon and hospital volume for patients undergoing primary total hip arthroplasty (THA) and total knee arthroplasty (TKA) using the American Joint Replacement Registry from 2012 to 2017.

Methods: A retrospective study was conducted on Medicare-eligible cases of primary elective THAs and TKAs reported to the American Joint Replacement Registry database and was linked with the available Centers of Medicaid and Medicare Services claims and the National Death Index data from 2012 to 2017. Surgeon and hospital volume were defined separately based on the median annual number of anatomic-specific total arthroplasty procedures performed on patients of any age per surgeon and per hospital. Values were aggregated into separate surgeon and hospital volume tertile groupings and combined to create pairwise comparison surgeon/hospital volume groupings for hip and knee.

Results: Adjusted multivariable logistic regression analysis found low surgeon/low hospital volume to have the greatest association with all-cause revisions after THA (odds ratio [OR], 1.63, 95% confidence interval [CI], 1.41-1.89, $P < 0.0001$) and TKA (OR, 1.72, 95% CI, 1.44-2.06, $P < 0.0001$), early revisions because of periprosthetic joint infection after THA (OR, 2.50, 95% CI, 1.53-3.15, $P < 0.0001$) and TKA (OR, 2.18, 95% CI, 1.64-2.89, $P < 0.0001$), risk of early THA instability and dislocation (OR, 2.47, 95% CI, 1.77-3.46, $P < 0.0001$), and 90-day mortality after THA (OR, 1.72, 95% CI, 1.27-2.35, $P = 0.0005$) and TKA (OR, 1.47, 95% CI, 1.15-1.86, $P = 0.002$).

Conclusion: Our findings demonstrate considerably greater THA and TKA complications when performed at low-volume hospitals by low-volume surgeons. Given the data from previous literature including this study, a continued push through healthcare policies and healthcare systems is warranted to direct THA and TKA procedures to high-volume centers by high-volume surgeons because of the evident decrease in complications and considerable costs associated with all-cause revisions, periprosthetic joint infection, instability, and 90-day mortality.

Level of Evidence: III

Elective total hip arthroplasty (THA) and total knee arthroplasty (TKA) are two of the most commonly done and effective surgical procedures in the United States providing improvements in function and overall quality of life.[1-5] As the demand for total joint arthroplasty (TJA) continues to increase,[4,6-8] recent healthcare reform has targeted arthroplasty for potential cost savings to the healthcare system. Although TJA has been successful in reducing pain severity and restoring joint function, opportunities for improvement remain in further curtailing length of hospital stay and decreasing complications, including postoperative instability, periprosthetic fracture, and infection to further lower the overall episode of care cost and revision rates.[9]

Previous studies have found hospital and surgeon TJA volume as a strong predictor of quality outcomes and lower risk of complications.[10-21] Courtney et al[8] reported hospitals that performed greater than 100 primary TJA per year had lower Medicare costs, fewer all-cause complications, and greater patient-reported outcomes compared with low-volume centers. Using the Medicare Provider Analysis and Review Research Identifiable Files, Calderwood et al[10] found that more than 90% of US lower volume hospitals performing THA had surgical site infection risks that were substantially higher than those in the largest volume centers. Recent systematic reviews and meta-analysis have similarly reported a trend toward better postoperative outcomes with higher volume surgeons and hospitals.[9,21-23]

Therefore, some policy makers have suggested that streamlining TJA procedures at specialty and higher volume regional centers will result in improved patient care at lower cost.[8] Laucis et al[12] used data from the National Inpatient Sample (NIS) from 2002 to 2012 and reported that TJA volume increased by 148% while the US population increased only 11.6%. The authors further reported that there was a national shift of TJA procedures toward higher volume hospitals and that nearly 82% of the US population resided within 50 miles of a high-volume hospital.[12] However, despite the well-established higher surgical volume and improved outcome relationship of hospitals and surgeons, most of the current literature is derived from older Medicare claims and national registry data with smaller sample sizes.[9,21-23] Because providing value-based care continues to evolve as the central goal for healthcare organizations and clinicians,[24] it is important to understand the latest procedural hospital and surgeon volume trends. Therefore, the purpose of this study was to evaluate outcomes and complications because it relates to surgeon and hospital volume for patients undergoing primary THA and TKA using the American Joint Replacement Registry (AJRR) from 2012 to 2017.

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Methods

A retrospective study was conducted on Medicare-eligible cases of primary elective THAs and TKAs reported to the AJRR database and were supplemented with available Centers of Medicaid and Medicare Services claims and the National Death Index data from 2012 to 2017, where appropriate. Using AJRR data, surgeon and hospital volume were defined separately based on the median annual number of anatomic-specific total arthroplasty procedures done on patients of any age per surgeon and per hospital. Values were aggregated into separate surgeon and hospital volume tertile groupings and combined to create pairwise comparison surgeon/hospital volume groupings for hip and knee. Descriptive statistics assessed demographic and baseline characteristics. Early (≤90 days) revision and mortality rates were calculated per surgery type, when appropriate. A multivariable logistic regression model was used to assess an association between surgeon/hospital volume and early revision for all-cause, periprosthetic joint infection (PJI), hip dislocation/instability, or 90-day mortality adjusting for patient age, sex, Charlson Comorbidity Index, smoking status, and hospital teaching affiliation.

Teaching status was defined by the American Hospital Association (AHA) Data Survey Fiscal Year 2015 and linked to AJRR data. AHA categorizes hospital teaching status by (1) major teaching hospitals: hospitals with Council of Teaching Hospitals designation; (2) minor teaching hospitals: hospitals approved to participate in residency and/or internship training by the Accreditation Council for Graduate Medical Education or American Osteopathic Association or those with the medical school affiliation reported to the AHA; or (3) nonteaching hospitals: hospitals without Council of Teaching Hospitals designation, Accreditation Council for Graduate Medical Education, American Osteopathic Association, or Medical School affiliations.

A lack of consensus exists around the definition of annual procedural volume and what constitutes low, medium, or high.[25] For our study, surgeon volume was defined as low = 1 to 48, medium = 49 to 106, and high >106 for THA and low = 1 to 60, medium = 61 to 129, and high >129 for TKA. Hospital volume was defined by low = 1 to 226, medium 227 to 423, and high >423 for THA and low = 1 to 332, medium 333 to 683, and high >683 for TKA. The threshold cutoffs were determined by dividing the medial annual THA and TKA procedural volume into tertile groupings to create three even groups for respective surgeon and hospital volume variables. SAS version 9.4 (SAS Institute) was used for all statistical analyses.

Results

Demographics and Baseline Characteristics

The final analysis included 201,299 THA patients and 391,272 TKA patients with a mean age of 73.46 ± 6.42 years and 72.96 ± 5.92 years, respectively. Most patients were female (60% undergoing THA and 62% undergoing TKA) with minimal medical comorbidities (Charlson Comorbidity Index 0 to 1: 88% of THA and 87% of TKA). Overall, nearly half the patients underwent TJA at minor academic institutions (54% of THA and 56% of TKA). A complete list of patient demographics and baseline characteristics are summarized in Table 1.

Surgeon and Hospital Volume

High surgeon volume and hospital volume comprised the largest THA and TKA cohort (n = 39,400, 19.6% and n = 75,247, 19.2%, respectively), followed by low surgeon volume and low hospital volume combination (n = 37,307, 18.5% and n = 66,175, 16.9%, respectively). A complete list of surgeon and hospital volume within each subcategory is summarized in Table 2.

All-Cause Revision

Adjusted multivariable logistic regression analysis found low surgeon/low hospital volume to have the greatest association with all-cause revisions after THA (odds ratio [OR], 1.63, 95% confidence interval [CI], 1.41-1.89, $P < 0.0001$) and TKA (OR, 1.72, 95% CI, 1.44-2.06, $P < 0.0001$), followed by medium surgeon/low hospital volume (THA: OR, 1.33, 95% CI, 1.03-1.47, $P = 0.022$; TKA: OR, 1.45, 95% CI, 1.19-1.77, $P = 0.0003$) and low surgeon/medium hospital volume for THA (OR, 1.38, 95% CI, 1.15-1.66, $P = 0.0005$) and low surgeon/high hospital volume for TKA (OR, 1.45, 95% CI, 1.13-1.86, $P = 0.003$). A complete list of all-cause revision and association with surgeon and hospital volume for THA is summarized in Table 3 and for TKA in Table 4.

Periprosthetic Joint Infection

Multivariable logistic regression analysis found low surgeon/low hospital volume to have the greatest link with early revisions because of PJI after THA (OR, 2.50, 95% CI, 1.53-3.15, $P < 0.0001$) and TKA (OR, 2.18, 95% CI, 1.64-2.89, $P < 0.0001$), followed by low surgeon/medium hospital volume (THA: OR, 2.45 95%

Table 1. Demographics and Baseline Characteristics

Factors	THA (N = 201,299)	TKA (N = 391,272)
Age, mean ± SD	73.46 ± 6.42	72.96 ± 5.92
Age category, n (%)		
<65-69	68,095 (33.83)	135,779 (34.70)
70-79	95,263 (47.32)	195,538 (49.97)
80-89	35,316 (17.54)	57,549 (14.71)
≥90	2,625 (1.3)	2,406 (0.61)
Sex, n (%)		
Female	120,830 (60.03)	242,508 (61.98)
Male	80,425 (39.95)	148,642 (37.99)
Unknown	44 (0.02)	122 (0.03)
Charlson Comorbidity Index, n (%)		
0	147,321 (73.19)	276,849 (70.76)
1	30,477 (15.14)	64,721 (16.54)
≥2	23,501 (11.67)	49,702 (12.70)
Teaching status, n (%)		
Major	45,883 (22.79)	75,093 (19.19)
Nonteaching	46,560 (23.13)	96,756 (24.73)
Minor	108,531 (53.92)	218,814 (55.92)
Unknown	325 (0.16)	609 (0.16)
Smoking status, n (%)		
Never smoke	163,656 (81.30)	325,971 (83.31)
Current smoker	3,268 (1.62)	4,348 (1.11)
Former smoker	34,375 (17.08)	60,953 (15.58)

THA = total hip arthroplasty, TKA = total knee arthroplasty

CI, 1.64-3.67, $P < 0.0001$; TKA: OR, 1.82, 95% CI, 1.30-2.57, $P = 0.0005$) and low surgeon/high hospital volume for THA (OR, 2.17, 95% CI, 1.35-3.50, $P = 0.0014$) and medium surgeon/high hospital volume for TKA (OR, 1.87, 95% CI, 1.34-2.59, $P = 0.0002$). A complete list of early revisions secondary to PJI and association with surgeon and hospital volume for THA is summarized in Table 5 and for TKA in Table 6.

Table 2. Surgeon and Hospital Volume Characteristics

Surgeon and Hospital Volume	THA (N = 201,299), n (%)	TKA (N = 391,272), n (%)
Low surgeon/low hospital volume	37,307 (18.53)	66,175 (16.91)
Low surgeon/medium hospital volume	17,537 (8.71)	35,383 (9.04)
Low surgeon/high hospital volume	10,868 (5.40)	22,677 (5.80)
Medium surgeon/low hospital volume	22,146 (11.00)	47,055 (12.03)
Medium surgeon/med hospital volume	25,418 (12.63)	42,217 (10.79)
Medium surgeon/high hospital volume	17,305 (8.60)	38,396 (9.81)
High surgeon/low hospital volume	7,626 (3.79)	16,122 (4.12)
High surgeon/medium hospital volume	23,692 (11.77)	48,000 (12.27)
High surgeon/high hospital volume	39,400 (19.57)	75,247 (19.23)

THA = total hip arthroplasty, TKA = total knee arthroplasty

Table 3. **Adjusted Multivariable Logistic Regression Assessing Relationship Between Early All-Cause Linked Revisions (≤90 Days) and Surgeon/Hospital Volume for THA**

Factor	THA (n = 200,930)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**1.628 (1.405-1.886)**	<**0.0001**
Low surgeon/medium hospital volume[a]	**1.38 (1.15-1.655)**	**0.0005**
Medium surgeon/low hospital volume[a]	**1.33 (1.03-1.467)**	**0.0219**
Medium surgeon/high hospital volume[a]	**1.322 (1.098-1.592)**	**0.0032**
High surgeon/low hospital volume[a]	**1.301 (1.008-1.679)**	**0.0432**
Medium surgeon/medium hospital volume[a]	**1.29 (1.093-1.523)**	**0.0026**
Low surgeon/high hospital volume[a]	1.235 (0.989-1.541)	0.0624
High surgeon/medium hospital volume[a]	1.032 (0.86-1.237)	0.7365
Age	1.017 (1.011-1.024)	<0.0001
Sex: female vs male	1.38 (1.256-1.516)	<0.0001
Charlson Comorbidity Index	1.102 (1.061-1.144)	<0.0001
Smoking status: current smoker vs never smoker	1.21 (0.875-1.675)	0.2493
Smoking status: former smoker vs never smoker	1.181 (1.055-1.323)	0.0039
Teaching status: minor vs major	0.945 (0.846-1.024)	0.3219
Teaching status: nonteaching vs major	0.894 (0.781-1.024)	0.1047

THA = total hip arthroplasty
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that $p<0.05$ is statistically significant.

Table 4. **Adjusted Multivariable Logistic Regression Assessing Relationship Between Early All-Cause Linked Revisions (≤90 Days) and Surgeon/Hospital Volume for TKA**

Factor	TKA (n = 390,541)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**1.72 (1.44-2.056)**	<**0.0001**
Low surgeon/high hospital volume[a]	**1.451 (1.131-1.862)**	**0.0034**
Medium surgeon/low hospital volume[a]	**1.449 (1.186-1.77)**	**0.0003**
Medium surgeon/medium hospital volume[a]	**1.305 (1.056-1.612)**	**0.0139**
Low surgeon/medium hospital volume[a]	**1.306 (1.045-1.633)**	**0.0191**
Medium surgeon/high hospital volume[a]	**1.265 (1.016-1.575)**	**0.0354**
High surgeon/low hospital volume[a]	1.147 (0.841-1.565)	0.3856
High surgeon/medium hospital volume[a]	0.989 (0.793-1.233)	0.9214
Age	1.004 (0.996-1.013)	0.3278
Sex: female vs male	0.758 (0.681-0.844)	<0.0001
Charlson Comorbidity Index	1.122 (1.076-1.171)	<0.0001
Smoking status: current smoker vs never smoker	1.146 (0.718-1.83)	0.5683
Smoking status: former smoker vs never smoker	1.354 (1.185-1.546)	<0.0001
Teaching status: minor vs major	1.029 (0.892-1.187)	0.6969
Teaching status: nonteaching vs major	1.02 (0.866-1.201)	0.8154

TKA = total knee arthroplasty
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that $p<0.05$ is statistically significant.

Table 5. Adjusted Multivariable Logistic Regression Assessing Relationship Between Early Linked Revisions (≤90 Days) Because of PJI and Surgeon/Hospital Volume for THA

Factor	THA (N = 200,930)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**2.497 (1.531-31.153)**	<**0.0001**
Low surgeon/medium hospital volume[a]	**2.451 (1.635-3.673)**	<**0.0001**
Low surgeon/high hospital volume[a]	**2.174 (1.35-3.502)**	**0.0014**
Medium surgeon/medium hospital volume[a]	**2.062 (1.404-3.027)**	**0.0002**
Medium surgeon/high hospital volume[a]	**1.955 (1.272-3.005)**	**0.0022**
Medium surgeon/low hospital volume[a]	1.52 (0.986-2.344)	0.0582
High surgeon/medium hospital volume[a]	1.222 (0.78-1.914)	0.3821
High surgeon/low hospital volume[a]	1.191 (0.599-2.369)	0.6188
Age	0.995 (0.98-1.011)	0.5235
Sex: female vs male	0.825 (0.676-1.007)	0.0591
Charlson Comorbidity Index	1.164 (1.079-1.254)	<0.0001
Smoking status: current smoker vs never smoker	0.442 (0.141-1.38)	0.1598
Smoking status: former smoker vs never smoker	1.319 (1.037-1.68)	0.0243
Teaching status: minor vs major	0.954 (0.744-1.224)	0.7132
Teaching status: nonteaching vs major	0.894 (0.66-1.212)	0.4714

THA = total hip arthroplasty, PJI = periprosthetic joint infection
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that $p<0.05$ is statistically significant.

Table 6. Adjusted Multivariable Logistic Regression Assessing Relationship Between Early Linked Revisions (≤90 Days) Because of PJI and Surgeon/Hospital Volume for TKA

Factor	TKA (N = 390,541)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**2.177 (1.638-2.894)**	<**0.0001**
Medium surgeon/high hospital volume[a]	**1.865 (1.342-2.591)**	**0.0002**
Low surgeon/medium hospital volume[a]	**1.82 (1.296-2.556)**	**0.0005**
Medium surgeon/medium hospital volume[a]	**1.718 (1.236-2.388)**	**0.0013**
Medium surgeon/low hospital volume[a]	1.674 (1.213-2.31)	0.0017
Low surgeon/high hospital volume[a]	**1.555 (1.035-2.337)**	**0.0337**
High surgeon/medium hospital volume[a]	**1.526 (1.101-2.117)**	**0.0113**
High surgeon/low hospital volume[a]	1.155 (0.688-1.938)	0.5853
Age	0.987 (0.974-1.001)	0.0725
Sex: female vs male	0.541 (0.461-0.635)	<0.0001
Charlson Comorbidity Index	1.19 (1.124-1.259)	<0.0001
Smoking status: current smoker vs never smoker	1.599 (0.899-2.846)	0.1102
Smoking status: former smoker vs never smoker	1.488 (1.23-1.801)	<0.0001
Teaching status: minor vs major	0.983 (0.795-1.214)	0.8711
Teaching status: nonteaching vs major	1.028 (0.806-1.31)	0.8238

TKA = total knee arthroplasty, PJI = periprosthetic joint infection
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that $p<0.05$ is statistically significant.

Instability

Multivariable logistic regression analysis found low surgeon/low hospital volume to have the highest association with THA revisions because of dislocation and instability (OR, 2.47, 95% CI, 1.77-3.46, $P < 0.0001$), followed by low surgeon/medium hospital volume (OR, 1.81, 95% CI, 1.20-2.72, $P = 0.005$). A complete list of early THA revisions secondary to instability and dislocation with surgeon and hospital volume association is summarized in Table 7.

90-Day Mortality

Multiple logistic regression found low surgeon/low hospital volume to have the greatest associate with 90-day mortality after THA (OR, 1.72, 95% CI, 1.27-2.35, $P = 0.0005$) and TKA (OR, 1.47, 95% CI, 1.15-1.86, $P = 0.002$), followed by low surgeon/medium hospital volume (THA: OR, 1.54, 95% CI, 1.06-2.24, $P = 0.023$; TKA: OR, 1.41, 95% CI, 1.06-1.88, $P = 0.017$) and high surgeon/low hospital volume (THA: OR, 1.47 95% CI, 1.02-2.71, $P = 0.041$; TKA: OR, 1.46, 95% CI, 1.01-2.10, $P = 0.042$). A complete list illustrating the relationship between 90-day mortality and surgeon/hospital volume for THA is summarized in Table 8 and for TKA in Table 9.

Discussion

As the demand for THA and TKA continues to increase,[4] recent healthcare reform policies have focused on cost-saving strategies because total expenditure for managing patients with osteoarthritis surpassed $350 billion in 2005.[8] There has been emerging studies suggesting that streamlining care by doing TJA procedures at high-volume specialty centers can improve patient outcomes while mitigating complications and cost of care and improving procedural value.[8] In this nationwide sample of 592,571 TJA between 2012 and 2017 using the AJRR, our results demonstrated hospital and surgeon volume to have a direct correlation with complications because the low hospital/surgeon volume cohort had the greatest odds ratio of all-cause revisions, PJI, instability, and 90-day mortality. This is the first study, to the best of our knowledge, to use the AJRR and assess the relationship of procedural volume to outcomes during a recent 5-year period.

Our findings of low surgeon and low hospital volume having the greatest OR of all-cause revisions are in line with the current literature.[8,9,19,26,27] Okoro et al[28] analyzed 169,713 TKA patients between 2002 and

Table 7. **Adjusted Multivariable Logistic Regression Assessing Relationship Between Early Linked Revisions (≤90 Days) Because of Dislocation/Instability and Surgeon/Hospital Volume**

Factor	THA (N = 200,930)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**2.472 (1.768-3.456)**	**<0.0001**
Low surgeon/medium hospital volume[a]	**1.806 (1.199-2.718)**	**0.0046**
Medium surgeon/high hospital volume[a]	1.343 (0.858-2.102)	0.1977
Medium surgeon/low hospital volume[a]	1.278 (0.833-1.963)	0.2614
High surgeon/low hospital volume[a]	1.268 (0.674-2.387)	0.4611
Low surgeon/high hospital volume[a]	1.101 (0.628-1.931)	0.7376
Medium surgeon/medium hospital volume[a]	1.08 (0.708-1.648)	0.7217
High surgeon/medium hospital volume[a]	0.798 (0.494-1.288)	0.3558
Age	1.025 (1.009-1.04)	0.0016
Sex: female vs male	1.32 (1.061-1.641)	0.0127
Charlson Comorbidity Index	1.078 (0.986-1.179)	0.1008
Smoking status: current smoker vs never smoker	1.889 (1.03-3.465)	0.04
Smoking status: former smoker vs never smoker	1.066 (0.811-1.402)	0.6474
Teaching status: minor vs major	1.002 (0.771-1.302)	0.9877
Teaching status: nonteaching vs major	0.75 (0.542-1.037)	0.0817

THA = total hip arthroplasty
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that p<0.05 is statistically significant.

Table 8. **Adjusted Multivariable Logistic Regression Assessing Relationship Between 90-day Mortality and Surgeon/Hospital Volume for THA**

Factor	THA (N = 200,930)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**1.724 (1.267-2.346)**	**0.0005**
Medium surgeon/low hospital volume[a]	1.637 (1.156-2.319)	0.0055
Low surgeon/medium hospital volume[a]	**1.541 (1.062-2.236)**	**0.023**
High surgeon/low hospital volume[a]	**1.465 (1.022-2.714)**	**0.0406**
Low surgeon/high hospital volume[a]	1.353 (0.862-2.124)	0.1881
Medium surgeon/medium hospital volume[a]	1.335 (0.941-1.894)	0.1057
Medium surgeon/high hospital volume[a]	1.047 (0.69-1.589)	0.8289
High surgeon/medium hospital volume[a]	0.968 (0.65-1.441)	0.8728
Age	1.109 (1.095-1.122)	<0.0001
Sex: female vs male	0.708 (0.59-0.849)	0.0002
Charlson Comorbidity Index	1.391 (1.327-1.457)	<0.0001
Smoking status: current smoker vs never smoker	1.662 (0.928-2.976)	0.0873
Smoking status: former smoker vs never smoker	0.961 (0.763-1.21)	0.7366
Teaching status: minor vs major	1.271 (1.001-1.615)	0.049
Teaching status: nonteaching vs major	1.036 (0.775-1.385)	0.8102

THA = total hip arthroplasty
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that p<0.05 is statistically significant.

2016 and found that as surgeon volume increased, the risks of all-cause complications and revision concomitantly decreased. The authors reported an inflection point of 70 TKA per year with surgeons performing fewer cases having a relative risk for all-cause revisions increasing by 31% and the relative risk of PJI increasing by 18%.[28] Using data from the National Joint Registry of England, Wales, Northern Ireland, and Isle of Man, Sayers et al[29] evaluated 579,858 primary THA patients and found a near-linear 43% (95% CI, 29.1%-57.4%) reduction of all-cause revision, compared with surgeons with lower annual volume (<200 procedures). Furthermore, Jeschke et al[19] reported patients having TKA at a high-volume hospital to be associated with a decreased risk of having revision TKA within 2 years of the index surgery, even after controlling for clinical factors and socioeconomic variables. Glassou et al[17] reviewed 417,687 THA patients from the Nordic Arthroplasty Registry Association database and found that hospital procedural volume was associated with long-term risk of revision with hospitals performing less than 50 THA per year with an increased risk of revision after 2, 5, 10, and 15 years follow-up. The notable reduction in all-cause revision and complications seen for higher volume surgeons and hospitals may be associated with several factors including more streamlined care pathway and increased hospital staff and surgeon proficiency in supportive care of patients.[12] However, other authors have suggested that increased orthopaedic specializations of hospitals, rather than procedural volume alone, are actual contributors of improved patient outcomes.[30]

Similar to current published studies,[28] our findings also reported increased PJI risk in lower volume surgeons and lower volume hospitals after primary THA and TKA. However, after reviewing 12,541 primary TKA procedures and accounting for potential confounders, Anis et al[31] reported no notable association with revision TKA for PJI when comparing high-volume and low-volume hospitals (OR, 1.62, 95% CI, 0.761-3.427; *P* = 0.212) and when comparing high-volume and medium-volume hospitals (OR, 1.46; 95% CI, 0.853-2.512; *P* = 0.166). Nonetheless, most of the current literature reports surgeon and hospital volumes to have implications on postoperative infection. Wei et al[32] found higher PJI rate among low-volume surgeons/hospitals versus higher volume surgeons/hospitals (0.99% vs 0.54%, respectively, adjusted OR 2.31, 95% CI, 1.379-3.876). The authors also suggested that surgeon's patient volume had a more substantial effect than a hospital's patient volume on clinical outcomes.[32] Greater PJI and surgical site infections have been associated with longer hospital lengths of stay and longer surgical duration, both of which have been previously reported with low-volume surgeons and hospitals.[9,23,33,34]

There are inconclusive data regarding surgeon/hospital volume and its effect on mortality.[9,21,27,35] In a systematic review and meta-analysis, Lau et al[21] analyzed 286,875 primary TKA patients in 11 studies and found no statistically significant relationship between surgeon volume and mortality rates. However, all 11 observational studies were considered low quality with high risk of biases to draw meaningful conclusions.[21] Conversely, Murphy et al[35] reported 409,844 primary THA procedures from the Centers of Medicaid and Medicare Services Limited Data Set between 2013 and 2016 and found when compared with the highest surgeon volume cohort, each lower volume group had increased readmission rates and mortality rates in a stepwise fashion when controlling for patient-specific variables including Elixhauser Comorbidity Index, demographics, region, and background trend. In another systematic review and meta-analysis, Mufarrih et al[9] studied 58,688 TJA patients from 4 studies and found a significantly higher 90-day mortality rate in low-volume hospitals compared with high-volume hospitals with no heterogeneity among the included studies (relative risk = 1.26, 95% CI, 1.05-1.51, I^2 = 0%, P = 0.01). Similarly, Koltsov et al[27] used the Statewide Planning and Research Cooperative System inpatient database (n = 187,557) and found both hospital volume and surgeon volume to be associated with 90-day complications and mortality. In particular, hospital volume was the most strongly linked with 90-day mortality with the odds of mortality increasing by threefold and sixfold for lower volume centers relative to the highest volume hospitals (≥527 THA per year). Our results found similar findings with the low surgeon/hospital cohort having the greatest odds of 90-day mortality, followed by cohorts that included low surgeon volume or low hospital volumes.

This study is not without limitations. First, no standardized criteria guidelines exist defining the number of cases that constitute low, medium, and high volume for both surgeons and institutions. Previous studies have used percentile-based groupings while others use number thresholds.[12] However, this is the first study, to the best of our knowledge, that determined threshold cutoffs by dividing the medial annual THA and TKA procedural volume into tertile groupings to create three even groups for respective surgeon and hospital volume variables. Lack of standardization of threshold cutoffs may have influenced the findings of our study. Second, there may be a

Table 9. **Adjusted Multivariable Logistic Regression Assessing Relationship Between 90-day Mortality and Surgeon/Hospital Volume for TKA**

Factor	TKA (N = 390,541)	
	Odds Ratio (Lower Limit-Upper Limit)	*P* Value
Low surgeon/low hospital volume[a]	**1.466 (1.153-1.863)**	**0.0018**
High surgeon/low hospital volume[a]	**1.456 (1.012-2.096)**	**0.0429**
Low surgeon/med hospital volume[a]	**1.413 (1.064-1.876)**	**0.017**
Medium surgeon/low hospital volume[a]	1.159 (0.879-1.528)	0.2972
Low surgeon/high hospital volume[a]	1.128 (0.793-1.606)	0.5019
Medium surgeon/high hospital volume[a]	1.075 (0.798-1.449)	0.6321
Medium surgeon/med hospital volume[a]	1.056 (0.79-1.412)	0.7134
High surgeon/medium hospital volume[a]	1.02 (0.767-1.357)	0.8899
Age	1.104 (1.092-1.116)	<0.0001
Sex: female vs male	0.608 (0.526-0.702)	<0.0001
Charlson Comorbidity Index	1.356 (1.302-1.412)	<0.0001
Smoking status: current smoker vs never smoker	1.943 (1.177-3.207)	0.0094
Smoking status: former smoker vs never smoker	1.026 (0.853-1.233)	0.7888
Teaching status: minor vs major	1.218 (0.998-1.486)	0.0526
Teaching status: nonteaching vs major	1.082 (0.858-1.363)	0.5062

TKA = total knee arthroplasty
[a]Reference for surgeon/hospital volume = high surgeon/high hospital volume. Bold values highlight that $p<0.05$ is statistically significant.

discrepancy with the number of THA and TKA procedures collected for each surgeon. High-volume TJA may disproportionality do THA versus TKA procedures and surgeons may be misclassified depending on the categorization threshold used. Third, by using a large administrative database, there is not an ability to control for when low-volume surgeons cross over to high-volume surgeons. Fourth, risk adjustment is challenging because of the current variable collected in the registry because hospital and surgeon case complexity could not be controlled for. It is plausible that high-volume centers and high-volume surgeons may do procedures with greater orthopaedic complexity and deformity compared with lower volume centers and surgeons who do simpler cases. Finally, data obtained from the AJRR may also disproportionately reflect practice patterns seen in academic centers because of the voluntary nature of reporting. However, despite the data source, our findings of lower volume hospital and surgeons having greater risk of revisions and complications are in line with the findings of the current literature. Furthermore, a recent study found distributions across hospital volume, age, and geography to be proportionally similar between the AJRR and NIS databases further supporting the generalizability of AJRR data to the overall US population.[36]

Previous studies have demonstrated a shift of TJA toward higher volume hospitals with lower rates of complications.[12] Using the NIS database, Laucis et al[12] reported that the number of TJA from 2000 to 2012 increased overall with the greatest proportion of procedural volume increasing at high-volume centers. Although the proportion of procedures done annually in low-volume hospitals (<100 TJA) decreased substantially from 17.9% (95% CI, 15.9%-19.9%) of TJA performed in 2000 to 5.4% (95% CI, 5.0%-5.7%) in 2012, low-volume centers still represented 38.9% of all hospitals that did an elective TJA in 2012.[12] Our results were similar with high surgeon and hospital volume centers comprising the largest THA and TKA cohort (19.6%, 19.2%, respectively), followed by low-volume surgeon and low-volume hospitals doing THA and TKA (18.5%, 16.9%, respectively). Although most TJA procedures have shifted toward high-volume hospitals and surgeons, low-volume hospitals and surgeons continue to be responsible for a considerable portion of TJA done annually.

Conclusion

Our findings demonstrate considerably greater THA and TKA complications when performed at low-volume hospitals by low-volume surgeons. Given the data from previous literature including this study, a continued push through healthcare policies and healthcare systems is warranted to direct THA and TKA procedures to high-volume centers by high-volume surgeons because of the evident decrease in complications and considerable costs associated with all-cause revisions, PJI, instability, and 90-day mortality.

References

Levels of evidence are described in the table of contents. In this article, reference 25 is level II study. References 1-24 and 26-39 are level III studies. Reference 24 is level V study.

References printed in **bold type** are those published within the past 5 years.

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