Original research

Surgeon and Facility Volume are Associated With Postoperative Complications After Total Knee Arthroplasty

Peter G. Brodeur, MA a,*, Kang Woo Kim, BA a, Jacob M. Modest, MD b, Eric M. Cohen, MD b, Joseph A. Gil, MD b, Aristides I. Cruz Jr., MD, MBA b

a Warren Alpert Medical School of Brown University, Providence, RI, USA
b Department of Orthopaedic Surgery, Warren Alpert Medical School of Brown University, Providence, RI, USA

ARTICLE INFO

Article history:
Received 25 July 2021
Received in revised form 24 October 2021
Accepted 25 November 2021
Available online 17 January 2022

Keywords:
Knee arthroplasty
Complications
Revision
Volume

ABSTRACT

Background: Surgeon and hospital volumes may affect outcomes of various orthopedic procedures. The purpose of this study is to characterize the volume dependence of both facilities and surgeons on morbidity and mortality after total knee arthroplasty.

Methods: Adults who underwent total knee arthroplasty for osteoarthritis from 2011 to 2015 were identified using International Classification of Diseases-9 Clinical Modification diagnostic and procedural codes in the New York Statewide Planning and Research Cooperative System database. Readmission, in-hospital mortality, and other adverse events were compared across surgeon and facility volumes using multivariable Cox proportional hazards regression, while controlling for patient demographic and clinical factors. Surgeon and facility volumes were compared between the lowest and highest 20%.

Results: Of 113,784 identified patients, 71,827 were treated at a high- or low-volume facility or by low- or high-volume surgeon. Low-volume facilities had higher 1-month, 3-month, and 12-month rates of readmission, urinary tract infection, cardiorespiratory arrest, surgical site infection, and wound complications; higher 3- and 12-month rates of pneumonia, cellulitis, and in-facility mortality; and higher 12-month rates of acute renal failure and revision. Low-volume surgeons had higher 1-, 3-, and 12-month rates of readmission, urinary tract infection, acute renal failure, pneumonia, surgical site infection, deep vein thrombosis, pulmonary embolism, cellulitis, and wound complications; higher 3- and 12-month rates of cardiorespiratory arrest; and higher 12-month rate of in-facility mortality.

Conclusions: These results suggest volume shifting toward higher volume facilities and/or surgeons could improve patient outcomes and have potential cost savings. Furthermore, these results can inform healthcare policy, for example, designating institutions as centers of excellence.

© 2021 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

The national healthcare expenditure in the United States is projected to increase to $5.4 trillion by 2024, which will account for 19.6% of the gross domestic product [1]. As a result, providers and policymakers are challenged with reducing healthcare costs while maintaining quality of care [2,3]. Total knee arthroplasty (TKA) is a target of healthcare reform given the high annual volume and overall cost burden on the healthcare system. According to projection models based on primary TKAs from 2000 to 2014, the estimated annual TKA volume will be approximately 935,000 procedures by 2030 [4]. Additionally, the rate of revision TKAs have been projected to increase upward of 182% by 2030 [5]. Furthermore, other models estimate an overall 143% growth in volume by 2050, consequently predicting that TKA will be performed for 725 of every 100,000 people [6].

A 2014 review of Medicare beneficiaries receiving primary or revision total joint arthroplasties (TJAs) showed that the average cost ranged greatly: primary TJAs for patients without comorbidities had an average cost of $25,568, and revision TJAs for those with major comorbidities or complications had an average cost of $50,648 [7]. Postdischarge care accounted for 35% of total cost, the biggest contributors being the 49% of patients who were...
transferred to post–acute care facilities (70% of postdischarge costs) and the 10% of patients who were readmitted for complications related to their TJA (11% of postdischarge costs) [7]. Furthermore, a 2017 study [8] of the Nationwide Readmissions Database from the Healthcare Cost and Utilization Project showed that the overall annual total cost for 90-day readmissions after TKA was $629 million with 239,700 days of hospital stays and $417 million covered by Medicare. Considering the significant national economic burden, alongside both the aging United States population and the increased life expectancy [9], it is critical to explore the delivery of TKA and to promote safe pathways to cost-effective care.

Both surgeon and hospital volumes are well-known characteristics that affect the outcomes of various orthopedic procedures. For example, a 2011 analysis of the Pennsylvania Health Care Cost Containment Council database reported that 1-year mortality was significantly higher among patients aged 65 years and older who received elective primary TKA at a lower volume hospital [10]. While numerous studies have explored the relationship between provider and hospital volume and TKA results, they have consistently demonstrated increased risks of postsurgery complications after procedures by low-volume providers or in low-volume hospitals [3,11,12]. The purpose of the current study is to characterize the volume dependence of both facilities and surgeons on post-TKA morbidity and mortality. This study also explores a wider range of complications than similar articles and simultaneously examines the effect of patient demographics such as comorbidities and social deprivation. We hypothesize that patients who receive their treatment from high-volume hospitals and high-volume surgeons will have reduced rates of mortality and complications compared with patients of low-volume hospitals and surgeons.

Material and methods

Patients ≥40 years old were identified in the New York Statewide Planning and Research Cooperative System (SPARCS) database from 2011 to 2015. The SPARCS is a comprehensive all-payer database collecting all inpatient and outpatient (emergency department, ambulatory surgery, and hospital-based clinic visits) claims in New York State. This includes International Classification of Diseases (ICD) diagnosis codes and ICD/Current Procedural Terminology (CPT) procedure codes associated with all visits. Inpatient claims were first identified using the ICD-9 Clinical Modification (CM) knee osteoarthritis diagnosis codes (715.16, 715.26, 715.36, and 715.96). Claims were then filtered by ICD-9-CM procedure codes to isolate patients who went on to receive a TKA (ICD-9-CM: 81.54). Only a patient’s first operation was considered eligible for follow-up. Nonresidents of New York were not included in our analysis. Given ICD-9 coding was discontinued after the third quarter of 2015, only the first 3 quarters of 2015 were used as these statistics are still likely to be indicative of the low to high volume comparison.

Unique surgeon and facility identifiers were used to calculate the total number of procedures per surgeon and facility per year. Based on the total volume per year, surgeons and facilities were subject to the lowest 20% of volume, midde 60% of volume, or highest 20% of volume. The boundaries for the lowest and highest 20% were deviated slightly by year but were selected to minimize the difference from the 20% volume mark.

Patients were followed up to a maximum of 1 year postoperatively in the inpatient and outpatient setting. The 1-month, 3-month, and 12-month risks of interest were as follows: readmission, urinary tract infection, acute renal failure, cardiorespiratory arrest, pneumonia, acute stroke, surgical site infection, deep vein thrombosis, acute respiratory failure, pulmonary embolism, cellulitis, wound complications, in-facility mortality, and revision surgery (see Supplemental Table 1 for codes used). SPARCS claim dates are listed as the first day of the month in which the service occurred owing to SPARCS deidentification policy. Therefore, if a complication occurred within the same month as the primary procedure, the time to complication was defined as 0.5 months [13].

Statistical analyses

Patient demographics were compared separately across facility volume and surgeon volume using chi-squared analysis. T-tests were used for comparing sample means, and Mann-Whitney U tests were used when appropriate when continuous data were found to be not normally distributed.

Multivariable Cox proportional hazards regression was used for the analysis of risk likelihood across the volume groups. Each complication was modeled separately while controlling for patient

| Table 1 | Patient demographics and characteristics, by facility volume. |
|--------|---------------------------------------------------------------|
| Demographic | Low volume, n = 22,561 | High volume, n = 23,291 | P-value |
| Age, mean (SD) | 65.9 (10.2) | 66.2 (9.7) | .0141 |
| Sex, n (%) | | | |
| Female | 14,713 (65.2) | 14,719 (63.2) | .0001 |
| Male | 7848 (34.8) | 8572 (36.8) | - |
| Ethnicity, n (%) | | | |
| Non-Hispanic | 20,094 (89.1) | 22,421 (96.3) | .0001 |
| Hispanic | 2467 (10.9) | 870 (3.7) | - |
| Race, n (%) | | | |
| White | 16,394 (72.7) | 18,234 (78.3) | .0001 |
| Asian | 403 (1.8) | 372 (1.6) | .1163 |
| African American | 3206 (14.2) | 1672 (7.2) | .0001 |
| Other | 2558 (11.3) | 3013 (12.9) | .0001 |
| Primary insurance, n (%) | | | |
| Private | 9152 (40.6) | 11,006 (47.3) | .0001 |
| Federal | 11,658 (51.7) | 11,293 (48.5) | .0001 |
| Self-pay | 535 (2.4) | 112 (0.5) | .0001 |
| Charlson Comorbidity Index, n (%) | | | |
| 0 | 12,218 (54.2) | 14,280 (61.3) | .0001 |
| ≥1 | 10,343 (45.8) | 9011 (38.7) | .0001 |
| SDI, median (mean, SD) | 57 (53.9, 30.4) | 38 (44.6, 30.5) | .0001 |

| Table 2 | Patient demographics and characteristics, by surgeon volume. |
|--------|---------------------------------------------------------------|
| Demographic | Low volume, n = 23,232 | High volume, n = 22,865 | P-value |
| Age, mean (SD) | 65.5 (10.1) | 66.2 (9.6) | <.0001 |
| Sex, n (%) | | | |
| Female | 14,871 (64) | 14,710 (64.3) | .4692 |
| Male | 8361 (36) | 8155 (35.7) | - |
| Ethnicity, n (%) | | | |
| Non-Hispanic | 21,017 (90.5) | 21,258 (93) | <.0001 |
| Hispanic | 2215 (9.5) | 1607 (7) | - |
| Race, n (%) | | | |
| White | 16,751 (72.1) | 19,027 (83.2) | <.0001 |
| Asian | 492 (2.1) | 303 (1.3) | <.0001 |
| African American | 3041 (13.1) | 1444 (6.3) | <.0001 |
| Other | 2948 (12.7) | 2091 (9.1) | <.0001 |
| Primary insurance, n (%) | | | |
| Private | 9853 (42.4) | 10,677 (46.7) | <.0001 |
| Federal | 11,307 (48.7) | 10,940 (47.9) | .0767 |
| Self-pay | 555 (2.4) | 556 (2.4) | .7649 |
| Charlson Comorbidity Index, n (%) | | | |
| 0 | 13,065 (56.2) | 13,532 (59.2) | <.0001 |
| ≥1 | 10,207 (43.8) | 9333 (40.8) | <.0001 |
| SDI, median (mean, SD) | 50 (50.2, 30.7) | 34 (42.6, 29.9) | <.0001 |

SD, standard deviation. Bolded values are for P < .05.
The CCI was calculated using the method described by Deyo et al [14]. The CCI was dichotomized to a score of 0 vs a score of ≥1. The SDI as described by Butler et al. was linked to each patient based on ZIP code. The SDI provides a robust measure of social determinants of health not traditionally captured by healthcare administrative databases by converting the following categories to an index from 1–100: percent living in poverty, percent with less than 12 years of education, percent single parent household, percent living in rented housing unit, percent living in overcrowded housing unit, percent of households without a car, and percent nonemployed adults younger than 65 years. A higher SDI score equates to increased social deprivation. SDI data in this study were based on 2015 statistics [15,16].

A *P*-value <.05 was considered significant across all statistical analyses. All analyses were performed using SAS, version 9.4 (SAS Inc, Cary, NC).

### Table 3

Risk of complication after knee arthroplasty, by facility volume.

| Complication                | Low volume, n = 22,561 | High volume, n = 23,291 | Hazard ratio (95% CI) | P-value |
|-----------------------------|------------------------|-------------------------|-----------------------|---------|
| Readmission                 |                        |                         |                       |         |
| 1 month                     | 1280 (5.7)             | 952 (4.1)               | 1.192 (1.091-1.303)   | .0001   |
| 3 month                     | 1966 (8.7)             | 1420 (6.1)              | 1.244 (1.158-1.338)   | <.0001  |
| 12 month                    | 4277 (19)              | 3469 (14.9)             | 1.176 (1.122-1.233)   | <.0001  |
| Urinary tract infection     |                        |                         |                       |         |
| 1 month                     | 780 (3.5)              | 593 (2.6)               | 1.196 (1.067-1.34)    | .002    |
| 3 month                     | 920 (4.1)              | 659 (2.8)               | 1.277 (1.148-1.42)    | <.0001  |
| 12 month                    | 1388 (6.2)             | 993 (4.3)               | 1.287 (1.18-1.404)    | <.0001  |
| Acute renal failure         |                        |                         |                       |         |
| 1 month                     | 536 (2.4)              | 402 (1.7)               | 1.104 (0.962-1.266)   | .1583   |
| 3 month                     | 595 (2.6)              | 442 (1.9)               | 1.121 (1.094-1.385)   | .0019   |
| 12 month                    | 858 (3.8)              | 610 (2.6)               | 1.191 (1.067-1.329)   | .0181   |
| Cardiorespiratory arrest    |                        |                         |                       |         |
| 1 month                     | 24 (0.1)               | 7 (0)                   | 2.611 (1.081-6.308)   | .033    |
| 3 month                     | 37 (0.2)               | 8 (0)                   | 3.533 (1.59-7.852)    |         |
| 12 month                    | 57 (0.3)               | 27 (0.1)                | 1.791 (1.015-2.905)   |         |
| Pneumonia                   |                        |                         |                       |         |
| 1 month                     | 206 (0.9)              | 154 (0.7)               | 1.149 (0.92-1.435)    | .2209   |
| 3 month                     | 259 (1.2)              | 182 (0.8)               | 1.252 (1.024-1.531)   | .0285   |
| 12 month                    | 495 (2.2)              | 319 (1.4)               | 1.357 (1.169-1.575)   | <.0001  |
| Acute stroke                |                        |                         |                       |         |
| 1 month                     | 192 (0.9)              | 242 (1)                 | 0.789 (0.644-0.965)   | .0214   |
| 3 month                     | 230 (1)                | 267 (1.2)               | 0.864 (0.715-1.043)   | .128    |
| 12 month                    | 391 (1.7)              | 382 (1.6)               | 1.007 (0.866-1.17)    | .9323   |
| Surgical site infection     |                        |                         |                       |         |
| 1 month                     | 410 (1.8)              | 276 (1.2)               | 1.224 (1.041-1.44)    | .0146   |
| 3 month                     | 495 (2.2)              | 331 (1.4)               | 1.232 (1.063-1.428)   | .0057   |
| 12 month                    | 671 (3)                | 480 (2.1)               | 1.173 (1.035-1.329)   | .0121   |
| Deep vein thrombosis        |                        |                         |                       |         |
| 1 month                     | 435 (1.9)              | 350 (1.5)               | 1.053 (0.907-1.222)   | .4973   |
| 3 month                     | 519 (2.3)              | 415 (1.8)               | 1.067 (0.93-1.223)    | .3563   |
| 12 month                    | 615 (2.7)              | 519 (2.2)               | 1.034 (0.914-1.171)   | .595    |
| Acute respiratory failure   |                        |                         |                       |         |
| 1 month                     | 78 (0.4)               | 67 (0.3)                | 1.034 (0.73-1.465)    | .8501   |
| 3 month                     | 91 (0.4)               | 74 (0.3)                | 1.137 (0.82-1.577)    | .4412   |
| 12 month                    | 152 (0.7)              | 111 (0.5)               | 1.277 (0.984-1.658)   | .0656   |
| Pulmonary embolism          |                        |                         |                       |         |
| 1 month                     | 171 (0.8)              | 307 (1.3)               | 0.5 (0.411-0.61)      | <.0001  |
| 3 month                     | 203 (0.9)              | 325 (1.4)               | 0.561 (0.406-0.675)   | <.0001  |
| 12 month                    | 268 (1.2)              | 356 (1.5)               | 0.672 (0.568-0.794)   | <.0001  |
| Cellulitis                  |                        |                         |                       |         |
| 1 month                     | 476 (2.1)              | 370 (1.6)               | 1.128 (0.976-1.304)   | .104    |
| 3 month                     | 548 (2.4)              | 409 (1.8)               | 1.18 (1.03-1.353)     | .0173   |
| 12 month                    | 723 (3.2)              | 515 (2.2)               | 1.264 (1.121-1.425)   | .0001   |
| Wound complications         |                        |                         |                       |         |
| 1 month                     | 474 (2.1)              | 163 (0.7)               | 2.641 (2.188-3.188)   | <.0001  |
| 3 month                     | 524 (2.3)              | 196 (0.8)               | 2.405 (2.021-2.862)   | <.0001  |
| 12 month                    | 637 (2.8)              | 271 (1.2)               | 2.141 (1.841-2.489)   | <.0001  |
| In-facility mortality       |                        |                         |                       |         |
| 1 month                     | 35 (0.2)               | 17 (0.1)                | 1.707 (0.924-3.153)   | .0879   |
| 3 month                     | 47 (0.2)               | 21 (0.1)                | 1.936 (1.123-3.339)   | .0175   |
| 12 month                    | 109 (0.5)              | 48 (0.2)                | 1.851 (1.296-2.642)   | .0007   |
| Revision                    |                        |                         |                       |         |
| 1 month                     | 7 (0)                  | 2 (0)                   | 2.44 (0.478-12.452)   | .2835   |
| 3 month                     | 15 (0.1)               | 4 (0)                   | 2.393 (0.759-7.543)   | .1362   |
| 12 month                    | 43 (0.2)               | 9 (0)                   | 3.951 (1.87-8.35)     | .0003   |

CI, confidence interval.
Bolded values are for *P* < .05.
Hazard ratios are adjusted for surgeon volume, age, sex, race, ethnicity, primary insurance type, CCI, and SDI.
Results

Of the 113,784 patients identified, 71,827 patients were treated at a high- or low-volume facility or by a high- or low-volume surgeon. Yearly facility volume ranged from 1 to 3442 (mean: 156, median: 78) procedures. Yearly surgeon volume ranged from 1 to 495 (mean: 34, median: 18) procedures. The number of procedures per year in New York increased slightly from 24,313 in 2011 to 25,536 in 2014 (19,626 through 3 quarters of 2015). The range for the number of procedures used as the upper boundary for the lowest 20% of volume by facility was 128-149 (115 through 3 quarters of 2015), and the range for the lower boundary for the highest 20% was 766-897 (645 through 3 quarters of 2015). Low-volume facilities accounted for 22,561 procedures, and high-volume facilities accounted for 23,291 procedures. The range of the number of procedures used as the upper boundary for the lowest 20% of volume by surgeon was 34-37 (29 through 3 quarters of 2015), and the range for the lower boundary for the highest 20% was 149-161 (126 through 3 quarters of 2015). Low-volume surgeons accounted for 23,232 procedures, and high-volume surgeons accounted for 22,865 procedures (Tables 1 and 2).

Several demographic differences were noted to be statistically significant. Low-volume facilities and surgeons had patient age...
distributed toward younger ages relative to high volume and higher social deprivation relative to high volume (Tables 1 and 2). Low-volume facilities had increased incidence of female sex, Hispanic ethnicity, African American race, other race, federal insurance, self-pay, and having \( \geq 1 \) Charlson comorbidity (Table 1). Low-volume surgeons had increased incidence of Hispanic ethnicity, Asian race, African American race, other race, and having \( \geq 1 \) Charlson comorbidity (Table 2).

Compared with high-volume facilities, low-volume facilities had higher 1-month, 3-month, and 12-month rates of readmission, urinary tract infection, cardiorespiratory arrest, surgical site infection, and wound complications; higher 3 and 12-month rates of pneumonia, cellulitis, and in-facility mortality; and higher 12-month rates of acute renal failure and revision. Low-volume facilities had lower 1-, 3-, and 12-month rates of pulmonary embolism and lower 1-month rate of acute stroke (Table 2). Figures 2 and 4 illustrate how the SDI varies across New York ZIP codes, with darker areas representing higher social deprivation. Figure 2 illustrates the rate of 3-month complications among patients by ZIP code stratified by facility and surgeon volume. Higher rates of complications can be appreciated in northern and western New York in Figure 2. These areas are also associated with higher social deprivation in Figure 1. Figure 3 illustrates the density of low- and high-volume facilities by county code. High-volume facilities are scarcer and tend to be concentrated in metropolitan areas. There is also a disproportionate amount of low-volume facilities in areas with the highest SDI scores: western New York, northern New York, and western Long Island. Figure 4 shows the density of patients with 1 or more Charlson comorbidity. Western Long Island has both high SDI scores as well as a high density of patients with a Charlson comorbidity (Figs. 1 and 4).

Discussion

This study supplemented the current literature concerning the relationship between hospital and surgeon volume and postoperative TKA morbidity and mortality by examining a wide range of complications, patient demographic and socioeconomic factors, and varying postoperative time periods. Additionally, this study evaluated the regionalization of complication rates and its relationship to socioeconomic status. The data showed an overall association between facility and surgeon volume with complications after TKA, thus coinciding with findings by other authors. For example, low-volume hospitals had significantly higher rates of, among other complications, readmission, wound complication, pneumonia, and cardiorespiratory failure. Likewise, low-volume surgeons had higher rates of acute renal failure, surgical site infection, deep vein thrombosis, etc. The literature on post-TJA results similarly states increased rates of complications, readmissions, reoperations, and mortality with low-volume centers and providers [17–19]. Additionally, our study found increased risk of revisions after 12 months for low-volume hospitals, a result that not only parallels other publications [12,20] but also reflects projection models that estimate increasing incidence of revision TKAs and consequently encourage institutions to generate revision-specific protocols to promote effective care [5].

The study also found an exception in the association between volume and outcome: low-volume facilities had lower 1-, 3-, and 12-month rates of pulmonary embolism and a lower 1-month rate of acute stroke. As stated previously, such findings have not been similarly shown in other TKA studies, as the literature tends to report increased rates of complications with decreased volume. A study of the American College of Surgeons National Surgical Quality Improvement Program database from 2008 to 2016 reported that overweight and obese patients had an increased risk of pulmonary embolism after primary TJA and the risk was elevated despite aggressive pharmacologic anticoagulation regimens [21]. Additionally, Anis et al. recently found that patients with a body mass index \( >40 \) were more likely to be treated at high-volume centers, thus suggesting a possible reason as to why high-volume facilities have increased risks of pulmonary embolism [22].

The current study also showed that, compared with patients with a CCI of 0, those with a CCI of 1 or greater were more likely to be treated at low-volume facilities. In contrast, a recent study has reported that increased CCI scores are associated with treatment at high-volume centers [22]; however, our findings suggest a counterintuitive association where patients with more comorbidities are treated at low-volume facilities and thus have an increased likelihood of postsurgery morbidity and mortality. Despite our retrospective study controlling for varying demographic features in its analysis of complication rates, there is a chance our results are due to a reversed causal effect and that patients treated at low-volume hospitals have more complications owing to having a higher CCI.

Our study has additionally found that more vulnerable demographics are suffering increased risk of post-TKA complications: in general, Hispanic, non-White patients, and those without private insurance were significantly more likely to be treated at low-volume hospitals and by low-volume surgeons. Additionally, areas with higher SDI scores tended to have an increased rate of patients with complications. Such disparities in access to health have been shown previously in the New York metropolitan area, as a study of adults undergoing surgery for cancer, cardiovascular disease, and orthopedic conditions showed that African American, Asian, and Hispanic patients were significantly less likely to be operated on by a high-volume surgeon or at a high-volume hospital [23]. Possible explanations for these trends include geographic location of providers, patients, and hospitals, as well as financial incentives where high-volume providers may be able to attract patients with better-paying insurance, a majority of whom may be White [23–25]. Thus, it is critical to consider racial and ethnic disparities in provision...
of care and consequent complications in an increasingly common orthopedic procedure. Furthermore, our study controlled for demographic factors such as race, SDI, and comorbidities in the analysis of risk for complications and still found significant effects of surgeon and facility volume. This highlights that it is critical that both high-volume care become more accessible and the gaps in the treatment between high- and low-volume care be identified and resolved.

The increased risk of postoperative morbidity and mortality at low-volume hospitals and surgeons affects not only the patient but also the healthcare system as a whole. Kurtz et al. showed that post-TKA complications had an annual economic burden of $64 million for infections, $52 million for acute cardiac events, $23 million for acute vascular and thrombotic events, $42 million for localized osteoarthrosis, etc. [8] Naturally, because high-volume hospitals have a greater capacity for care and are not limited to specialty care facilities, specialist medical teams, physiotherapy, and other resources, they may consequently be better equipped to proactively identify and resolve issues before they escalate and adversely influence patient outcomes [26–28]. Thus, high-volume facilities may be more cost-effective not only due to lower mean total hospital specific charges [29,30] but also due to their reduced rates of complications and readmissions [31].

Finally, it is important to consider the fact that although a majority of related literature shares the consensus that lower volume yields worse outcomes in TKA patients, the definitions of “low” and “high” can vary. For example, Singh et al. defined a high-volume hospital as one that performs 101-200 procedures annually, whereas Anis et al. determined >500 as high volume [10,32]. Surgeon volume classifications were equally variable, with high volume ranging from >5 to >50 to even >146 [17,19,33]. This inconsistency is a consequent caveat to generalizing the results of different studies that analyze outcomes as a function of volume. We sought to apply volume percentiles as a way to improve the generalizability of this current study.

This study exhibits several limitations. The use of a large database inherently requires accurate coding. Because this study evaluated outcomes for the same procedure across the database, any
differences in reporting should be global and the large sample size should help minimize substantial changes to the observed outcomes. Moreover, there are several significant demographic differences between the cohort included in this study (Tables 1 and 2), although we did attempt to control for these during our statistical analysis. Our study involved patients within the confined geographic zone of SPARCS database. Therefore, national and global trends cannot be directly considered, possibly limiting appropriate extrapolation to other areas. However, New York is a large state composed of a highly variable population of patients, hospitals, and surgeons with a great degree of demographic variability and therefore may be generalizable to larger populations [34].

Conclusions

The importance of case volume in TKA is relevant for both facilities and providers. Both low-volume facilities and surgeons performing primary TKA have higher rates of readmission, urinary tract infection, acute renal failure, cardiorespiratory arrest, pneumonia, surgical site infection, cellulitis, wound complications, and in-facility mortality. These results suggest volume shifting toward higher volume facilities and/or surgeons could improve patient outcomes and have potential cost savings. Furthermore, these results can inform healthcare policy, for example, designing institutions as centers of excellence.

Conflicts of interest

The authors declare that there are no conflicts of interest. For full disclosure statements refer to https://doi.org/10.1016/j.artd.2021.11.017.

References

[1] Keehan SP, Cuckler GA, Sisko AM, et al. National health expenditure projections, 2014-24: spending growth faster than recent trends. Health Aff (Millwood) 2015;34(8):1407.
[2] Filson CP, Hollingsworth JM, Skolarus TA, Clemens JQ, Hollenbeck BK. Health care reform in 2010: transforming the delivery system to improve quality of care. World J Urol 2011;29(1):85.
[3] Keswani A, Uhler LM, Bozic KJ. What quality metrics is my hospital being evaluated on and what are the consequences? J Arthroplasty 2016;31(6):1139.
[4] Sloan M, Premkumar A, Sheth NF. Projected volume of primary total joint arthroplasty in the U.S., 2014 to 2030. J Bone Joint Surg Am 2018;100(17):1455.
[5] Schwartz AM, Farley KK, Guild GN, Bradbury TL. Projections and epidemiology of revision hip and knee arthroplasty in the United States to 2030. J Arthroplasty 2020;35(6):579.
[6] Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States – an alternative projection model. Osteoarthritis Cartilage 2017;25(11):1797.
[7] Bozic KJ, Ward L, Vail TP, Maze M. Bundled payments in total joint arthroplasty: targeting opportunities for quality improvement and cost reduction knee. Clin Orthop Relat Res 2014;472:188.
[8] Kurtz SM, Lau EC, Ong KL, et al. Which clinical and patient factors influence the national economic burden of hospital readmissions after total joint arthroplasty? Clin Orthop Relat Res 2017;475:2926.
[9] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89(4):780.
Singh JA, Kwoh CK, Boudreau RM, Lee GC, Ibrahim SA. Hospital volume and surgical outcomes after elective hip/knee arthroplasty: a risk-adjusted analysis of a large regional database. Arthritis Rheum 2011;63(8):2531.

Soo Hoo NF, Zingmond DS, Lieberman JR, Ko CY. Primary total knee arthroplasty in California 1991 to 2001: does hospital volume affect outcomes? J Arthroplasty 2006;21(2):199.

Jeschke E, Citak M, Günster C, et al. Are TKAs performed in high-volume hospitals less likely to undergo revision than TKAs performed in low-volume hospitals? Clin Orthop Relat Res 2017;475(11):2669.

Testa EJ, Brodeur P, Kahan LG, et al. The effect of hospital and surgeon volume on complication rates following fixation of peritrochanteric hip fractures. J Orthop Trauma 2022;36(1):23–9.

Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol 1992;45(6):613.

Butler DC, Petterson S, Phillips RL, Bazemore AW. Measures of social deprivation that predict health care access and need within a rational area of primary care service delivery. Health Serv Res 2013;48(2 Pt 1):539.

Brodeur PG, Patel DD, Licht AH, et al. Demographic disparities amongst patients receiving carpal tunnel release: a retrospective review of 52,951 patients. Plast Reconstr Surg Glob Open 2021;9(11):e3959.

Lau RL, Perruccio AV, Gandhi R, Mahomed NN. The role of surgeon volume on patient outcome in total knee arthroplasty: a systematic review of the literature. BMC Musculoskelet Disord 2012;13:250.

Bozic KJ, Maselli J, Pekow PS, et al. The influence of procedure volumes and standardization of care on quality and efficiency in total joint replacement surgery. J Bone Joint Surg Am 2010;92(16):2643.

Wilson S, Marc RG, Pan TJ, Lyman S. Meaningful thresholds for the volume-outcome relationship in total knee arthroplasty. J Bone Joint Surg Am 2016;98(20):1683.

Palmer AM, Gehricke T, Günster C, et al. Low hospital volume increases Reversion rate following aseptic revision total knee arthroplasty: an analysis of 23,644 cases. J Arthroplasty 2020;35(4):1054.

Sloan M, Sheth N, Lee GC. Is obesity associated with increased risk of deep vein thrombosis or pulmonary embolism after hip and knee arthroplasty? A large database study. Clin Orthop Relat Res 2019;477(3):523.

Anis HK, Arnold NR, Ramanathan D, et al. Are we treating similar patients? Hospital volume and the difference in patient populations for total knee arthroplasty. J Arthroplasty 2020;35(6):587.

Epstein AJ, Gray BH, Schlesinger M. Racial and ethnic differences in the use of high-volume hospitals and surgeons. Arch Surg 2010;145(2):179.

Kronenbusch K, Gray BH, Schlesinger M. Explaining racial/ethnic disparities in use of high-volume hospitals: decision-making complexity and local hospital environments. Inquiry 2014;51(1):1.

Zhang W, Lyman S, Boutin-Foster C, et al. Racial and ethnic disparities in utilization rate, hospital volume, and perioperative outcomes after total knee arthroplasty. J Bone Joint Surg Am 2016;98(15):1243.

Butler DC, Petterson S, Phillips RL, Bazemore AW. Measures of social deprivation that predict health care access and need within a rational area of primary care service delivery. Health Serv Res 2013;48(2 Pt 1):539.

Brodeur PG, Patel DD, Licht AH, et al. Demographic disparities amongst patients receiving carpal tunnel release: a retrospective review of 52,951 patients. Plast Reconstr Surg Glob Open 2021;9(11):e3959.

Lau RL, Perruccio AV, Gandhi R, Mahomed NN. The role of surgeon volume on patient outcome in total knee arthroplasty: a systematic review of the literature. BMC Musculoskelet Disord 2012;13:250.

Bozic KJ, Maselli J, Pekow PS, et al. The influence of procedure volumes and standardization of care on quality and efficiency in total joint replacement surgery. J Bone Joint Surg Am 2010;92(16):2643.

Wilson S, Marc RG, Pan TJ, Lyman S. Meaningful thresholds for the volume-outcome relationship in total knee arthroplasty. J Bone Joint Surg Am 2016;98(20):1683.

Palmer AM, Gehricke T, Günster C, et al. Low hospital volume increases Reversion rate following aseptic revision total knee arthroplasty: an analysis of 23,644 cases. J Arthroplasty 2020;35(4):1054.

Sloan M, Sheth N, Lee GC. Is obesity associated with increased risk of deep vein thrombosis or pulmonary embolism after hip and knee arthroplasty? A large database study. Clin Orthop Relat Res 2019;477(3):523.
**Supplemental Table 1**
Diagnosis and procedure codes for knee arthroplasty complications.

| Complication                  | ICD 9 CM | ICD 10 CM/PCS             | CPT         | Code Count |
|-------------------------------|----------|---------------------------|-------------|------------|
| **Revision**                  | 81.55    | 0SWC0JC, 0SWC0JZ, 0SWC3JC, 0SWC4JC, 0SWC4JZ, 0SWCXJC, 0SWCXJZ, 0SWT0JZ, 0SWT3JZ, 0SWT4JZ, 0SWTXJZ, 0SWV0JZ, 0SWV3JZ, 0SWV4JZ, 0SWV4JC, 0SWD0JZ, 0SWD3JZ, 0SWD4JZ, 0SWD4JC, 0SWDXJZ, 0SWDXJC, 0SWU0JZ, 0SWU3JZ, 0SWU4JZ, 0SWUXJZ, 0SWU4JZ, 0SWW0JZ, 0SWW3JZ, 0SWW4JZ, 0SWWXJZ | 27486, 27487 |
| **Pulmonary embolism**        | 415.0, 415.12, 415.19, 415.11 | I26.09, I26.90, I26.92, I26.99, I26.90, I26.99, T80.0XXA, T81.718A, T81.72XA, T82.817A, T82.818A | -           |            |
| **Cardiorespiratory arrest**  | 427.5, 996.0 | I46.9                     | -           |            |
| **Deep vein thrombosis**      | 451.0, 451.11, 451.19, 451.81, 451.82, 451.83, 451.84, 451.89, 451.9, 453.40, 453.41, 453.42 | I80.0, I80.1, I80.20, I80.3, I80.21, I80.8, I80.9, I82.409, I82.429, I82.449, I82.499, I82.4Z9 | -           |            |
| **Pneumonia**                 | 481, 482.0, 482.1, 482.2, 482.30, 482.31, 482.32, 482.39, 482.40, 482.41, 482.42, 482.48, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 997.32 | J13, J15.0, J15.1, J14, J15.4, J15.3, J15.20, J15.211, J15.212, J15.29, J15.8, J15.5, J15.6, A48.1, J15.9, J18.9, J95.89 | -           |            |
| **Acute renal failure**        | 584.5, 584.6, 584.7, 584.8, 584.9 | N17.0, N17.1, N17.2, N17.8, N17.9 | -           |            |
| **Urinary tract infection**   | 996.64, 599.0 | T83.51XA, N39.0 | -           |            |
| **Acute stroke**              | 431, 433.00, 433.01, 433.10, 433.20, 433.30, 433.31, 433.80, 433.81, 433.90, 433.91, 434.01, 434.11, 434.90, 434.91, 433.11, 433.21, 434.00, 434.10 | I61.9, I65.1, I63.22, I65.29, I65.09, I65.8, I63.59, I65.8, I63.59, I65.9, I63.20, I65.30, I65.40, I66.9, I63.50, I63.139, I63.239, I63.019, I63.119, I63.219, I66.09, I66.19, I66.29, I66.09, I66.19, I66.29, I66.9 | -           |            |
| **Acute respiratory failure** | 518.2, 518.82, 518.84, 518.51, 518.52, 518.53 | J98.3, J80, J96.20, J95.821, J96.00, J95.2, J95.3, J95.822, J96.20 | -           |            |
| **Cellulitis**                | 682.6    | L03.119, L03.129, L03.113, L03.114, L03.115, L03.116 | -           |            |
| **Surgical site infection**   | 998.51, 998.59, 996.67 | T81.40XA, K68.11, T84.60XA, T84.7XXA, T84.50XA, T84.59XA, T84.54XA, T84.53XA | -           |            |
| **Wound complications**       | 998.13, 998.32, 998.83, 998.11, 998.12 | T88.8XXX, T81.31XA, T81.89XX, D78.02, D78.22, E36.02, G97.32, G97.52, H59.121, H59.122, H59.123, H59.129, H59.321, H59.322, H59.323, H59.329, H59.22, H59.42, H97.42, H97.62, J95.62, J95.831, K91.62, K91.841, L76.02, L76.22, M96.810, M96.811, M96.830, M96.831, N99.62, N99.821 | -           |            |