



## Original research

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

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## 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.

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## 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

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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  $\geq 40$  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, middle 60% of volume, or highest 20% of volume. The boundaries for the lowest and highest 20% 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 post-operatively 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

**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)	<b>.0141</b>
Sex, n (%)			
Female	14,713 (65.2)	14,719 (63.2)	<b>&lt;.0001</b>
Male	7848 (34.8)	8572 (36.8)	-
Ethnicity, n (%)			
Non-Hispanic	20,094 (89.1)	22,421 (96.3)	<b>&lt;.0001</b>
Hispanic	2467 (10.9)	870 (3.7)	-
Race, n (%)			
White	16,394 (72.7)	18,234 (78.3)	<b>&lt;.0001</b>
Asian	403 (1.8)	372 (1.6)	.1163
African American	3206 (14.2)	1672 (7.2)	<b>&lt;.0001</b>
Other	2558 (11.3)	3013 (12.9)	<b>&lt;.0001</b>
Primary insurance, n (%)			
Private	9152 (40.6)	11,006 (47.3)	<b>&lt;.0001</b>
Federal	11,658 (51.7)	11,293 (48.5)	<b>&lt;.0001</b>
Self-pay	535 (2.4)	112 (0.5)	<b>&lt;.0001</b>
Charlson Comorbidity Index, n (%)			
0	12,218 (54.2)	14,280 (61.3)	<b>&lt;.0001</b>
$\geq 1$	10,343 (45.8)	9011 (38.7)	-
SDI, median (mean, SD)	57 (53.9, 30.4)	38 (44.6, 30.5)	<b>&lt;.0001</b>

SD, standard deviation.

Bolded values are for  $P < .05$ .

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 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)	<b>&lt;.0001</b>
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)	<b>&lt;.0001</b>
Hispanic	2215 (9.5)	1607 (7)	-
Race, n (%)			
White	16,751 (72.1)	19,027 (83.2)	<b>&lt;.0001</b>
Asian	492 (2.1)	303 (1.3)	<b>&lt;.0001</b>
African American	3041 (13.1)	1444 (6.3)	<b>&lt;.0001</b>
Other	2948 (12.7)	2091 (9.1)	<b>&lt;.0001</b>
Primary insurance, n (%)			
Private	9853 (42.4)	10,677 (46.7)	<b>&lt;.0001</b>
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)	<b>&lt;.0001</b>
$\geq 1$	10,167 (43.8)	9333 (40.8)	-
SDI, median (mean, SD)	50 (50.2, 30.7)	34 (42.6, 29.9)	<b>&lt;.0001</b>

SD, standard deviation.

Bolded values are for  $P < .05$ .

**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)	<b>.0001</b>
3 month	1966 (8.7)	1420 (6.1)	1.244 (1.158-1.338)	<b>&lt;.0001</b>
12 month	4277 (19)	3469 (14.9)	1.176 (1.122-1.233)	<b>&lt;.0001</b>
Urinary tract infection				
1 month	780 (3.5)	593 (2.6)	1.196 (1.067-1.34)	<b>.002</b>
3 month	920 (4.1)	659 (2.8)	1.277 (1.148-1.42)	<b>&lt;.0001</b>
12 month	1388 (6.2)	993 (4.3)	1.287 (1.18-1.404)	<b>&lt;.0001</b>
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 (0.984-1.277)	.0871
12 month	858 (3.8)	610 (2.6)	1.191 (1.067-1.329)	<b>.0018</b>
Cardiorespiratory arrest				
1 month	24 (0.1)	7 (0)	2.611 (1.081-6.308)	<b>.033</b>
3 month	37 (0.2)	8 (0)	3.533 (1.59-7.852)	<b>.0019</b>
12 month	57 (0.3)	27 (0.1)	1.791 (1.105-2.905)	<b>.0181</b>
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)	<b>.0285</b>
12 month	495 (2.2)	319 (1.4)	1.357 (1.169-1.575)	<b>&lt;.0001</b>
Acute stroke				
1 month	192 (0.9)	242 (1)	0.789 (0.644-0.965)	<b>.0214</b>
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)	<b>.0146</b>
3 month	495 (2.2)	331 (1.4)	1.232 (1.063-1.428)	<b>.0057</b>
12 month	671 (3)	480 (2.1)	1.173 (1.035-1.329)	<b>.0121</b>
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)	<b>&lt;.0001</b>
3 month	203 (0.9)	325 (1.4)	0.561 (0.466-0.675)	<b>&lt;.0001</b>
12 month	268 (1.2)	356 (1.5)	0.672 (0.568-0.794)	<b>&lt;.0001</b>
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)	<b>.0173</b>
12 month	723 (3.2)	515 (2.2)	1.264 (1.121-1.425)	<b>.0001</b>
Wound complications				
1 month	474 (2.1)	163 (0.7)	2.641 (2.188-3.188)	<b>&lt;.0001</b>
3 month	524 (2.3)	196 (0.8)	2.405 (2.021-2.862)	<b>&lt;.0001</b>
12 month	637 (2.8)	271 (1.2)	2.141 (1.841-2.489)	<b>&lt;.0001</b>
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)	<b>.0175</b>
12 month	109 (0.5)	48 (0.2)	1.851 (1.296-2.642)	<b>.0007</b>
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)	<b>.0003</b>

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.

age, sex, race, ethnicity, Charlson Comorbidity Index (CCI), primary insurance type, and social deprivation index (SDI). Other race excludes White, Asian, and African American but does include multiracial patients. The regression models assess the risk difference across surgeon and facility groups simultaneously by controlling for both in the same model.

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  $\geq 1$ . 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 4**  
Risk of complication after knee arthroplasty, by surgeon volume.

Complication	Low volume, n = 23,232	High volume, n = 22,865	Hazard ratio (95% CI)	P-value
Readmission				
1 month	1348 (5.8)	898 (3.9)	1.356 (1.24-1.484)	<b>&lt;.0001</b>
3 month	1989 (8.6)	1364 (6)	1.312 (1.219-1.412)	<b>&lt;.0001</b>
12 month	4370 (18.8)	3451 (15.1)	1.192 (1.137-1.25)	<b>&lt;.0001</b>
Urinary tract infection				
1 month	768 (3.3)	558 (2.4)	1.269 (1.13-1.426)	<b>&lt;.0001</b>
3 month	878 (3.8)	634 (2.8)	1.252 (1.122-1.396)	<b>&lt;.0001</b>
12 month	1320 (5.7)	982 (4.3)	1.215 (1.112-1.327)	<b>&lt;.0001</b>
Acute renal failure				
1 month	556 (2.4)	332 (1.5)	1.495 (1.294-1.726)	<b>&lt;.0001</b>
3 month	612 (2.6)	377 (1.7)	1.448 (1.264-1.659)	<b>&lt;.0001</b>
12 month	859 (3.7)	543 (2.4)	1.405 (1.253-1.574)	<b>&lt;.0001</b>
Cardiorespiratory arrest				
1 month	28 (0.1)	11 (0.1)	2.027 (0.965-4.26)	.0621
3 month	41 (0.2)	13 (0.1)	2.236 (1.148-4.354)	<b>.0179</b>
12 month	64 (0.3)	33 (0.1)	1.631 (1.043-2.552)	<b>.0321</b>
Pneumonia				
1 month	211 (0.9)	138 (0.6)	1.378 (1.096-1.732)	<b>.006</b>
3 month	245 (1.1)	163 (0.7)	1.324 (1.073-1.635)	<b>.009</b>
12 month	470 (2)	304 (1.3)	1.353 (1.16-1.577)	<b>.0001</b>
Acute stroke				
1 month	183 (0.8)	213 (0.9)	0.909 (0.737-1.122)	.3749
3 month	209 (0.9)	242 (1.1)	0.885 (0.726-1.078)	.2247
12 month	367 (1.6)	379 (1.7)	0.947 (0.812-1.104)	.4869
Surgical site infection				
1 month	458 (2)	224 (1)	1.788 (1.509-2.119)	<b>&lt;.0001</b>
3 month	561 (2.4)	275 (1.2)	1.794 (1.539-2.091)	<b>&lt;.0001</b>
12 month	744 (3.2)	394 (1.7)	1.675 (1.471-1.907)	<b>&lt;.0001</b>
Deep vein thrombosis				
1 month	491 (2.1)	275 (1.2)	1.67 (1.429-1.952)	<b>&lt;.0001</b>
3 month	569 (2.5)	327 (1.4)	1.61 (1.394-1.86)	<b>&lt;.0001</b>
12 month	683 (2.9)	448 (2)	1.438 (1.267-1.631)	<b>&lt;.0001</b>
Acute respiratory failure				
1 month	77 (0.3)	59 (0.3)	1.222 (0.85-1.755)	.2787
3 month	83 (0.4)	67 (0.3)	1.134 (0.803-1.599)	.4754
12 month	139 (0.6)	107 (0.5)	1.141 (0.872-1.494)	.3369
Pulmonary embolism				
1 month	235 (1)	186 (0.8)	1.429 (1.168-1.749)	<b>.0005</b>
3 month	258 (1.1)	201 (0.9)	1.408 (1.16-1.709)	<b>.0005</b>
12 month	323 (1.4)	240 (1.1)	1.41 (1.183-1.681)	<b>.0001</b>
Cellulitis				
1 month	484 (2.1)	286 (1.3)	1.507 (1.29-1.762)	<b>&lt;.0001</b>
3 month	560 (2.4)	339 (1.5)	1.469 (1.272-1.697)	<b>&lt;.0001</b>
12 month	718 (3.1)	466 (2)	1.363 (1.204-1.544)	<b>&lt;.0001</b>
Wound complications				
1 month	337 (1.5)	162 (0.7)	1.304 (1.067-1.595)	<b>.0097</b>
3 month	393 (1.7)	192 (0.8)	1.347 (1.119-1.621)	<b>.0016</b>
12 month	498 (2.1)	265 (1.2)	1.321 (1.125-1.549)	<b>.0007</b>
In-facility mortality				
1 month	32 (0.1)	19 (0.1)	1.327 (0.722-2.439)	.3616
3 month	44 (0.2)	28 (0.1)	1.211 (0.728-2.016)	.4611
12 month	99 (0.4)	54 (0.2)	1.463 (1.03-2.079)	<b>.0335</b>
Revision				
1 month	8 (0)	2 (0)	2.909 (0.576-14.682)	.1961
3 month	14 (0.1)	3 (0)	3.17 (0.861-11.673)	.0828
12 month	35 (0.2)	15 (0.1)	1.439 (0.753-2.75)	.2707

CI, confidence interval.

Bolded values are for  $P < .05$ .

Hazard ratios are adjusted for facility volume, age, sex, race, ethnicity, primary insurance type, CCI, SDI.

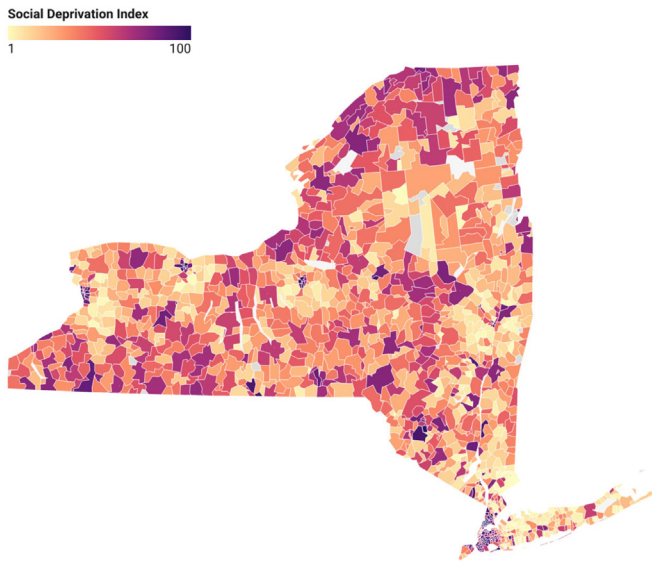
## Results

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





**Figure 1.** SDI by New York ZIP code. Gray ZIP codes had no TKA cases during the study period.

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 3). Compared with high-volume surgeons, 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 (Table 4).

Figure 1 illustrates 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

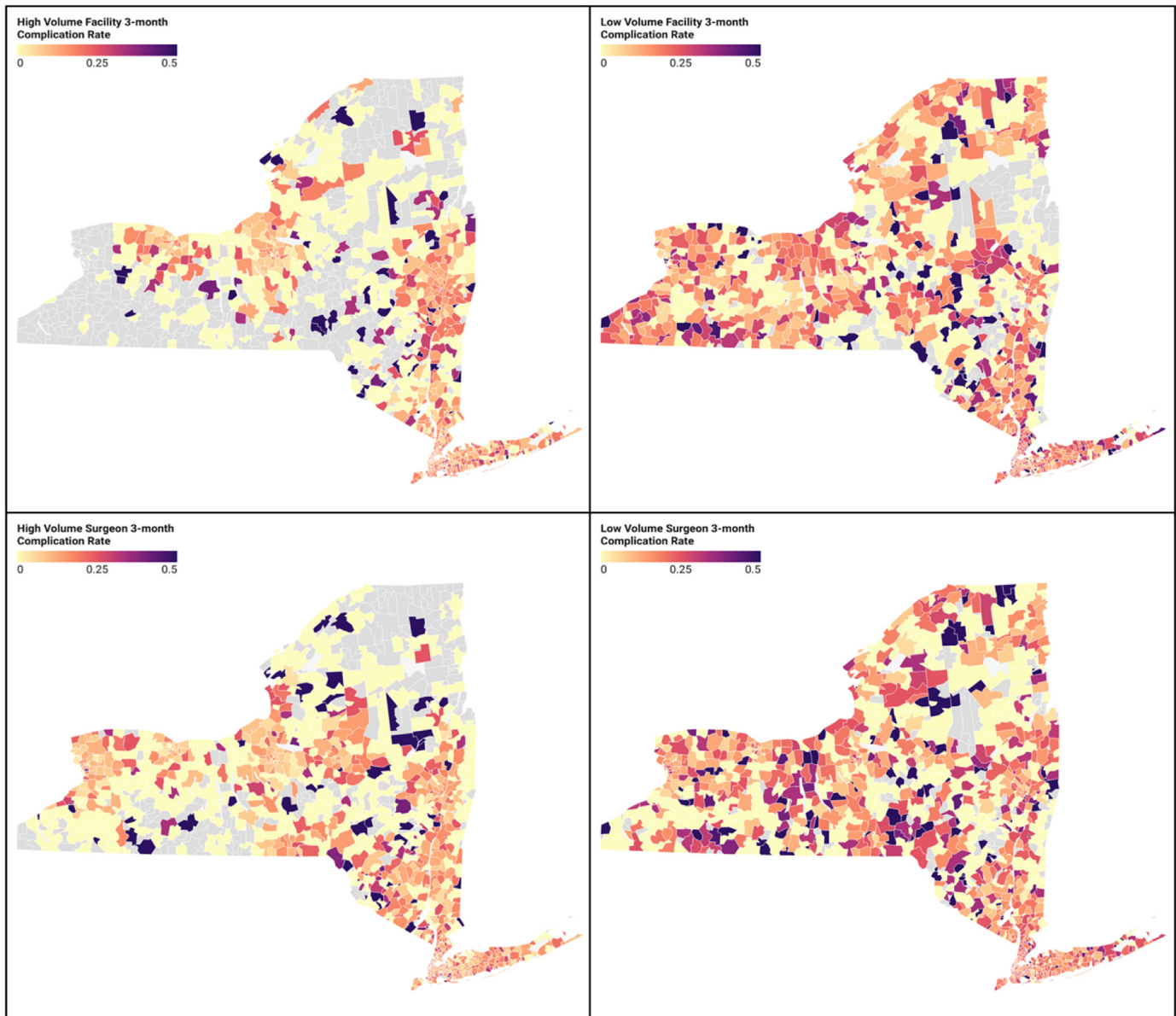
This study supplemented the current literature concerning the relationship between hospital and surgeon volume and

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



**Figure 2.** Three-month complication rates by facility and surgeon volume by ZIP codes. Gray ZIP codes had either no complications or no TKA cases during the study period.

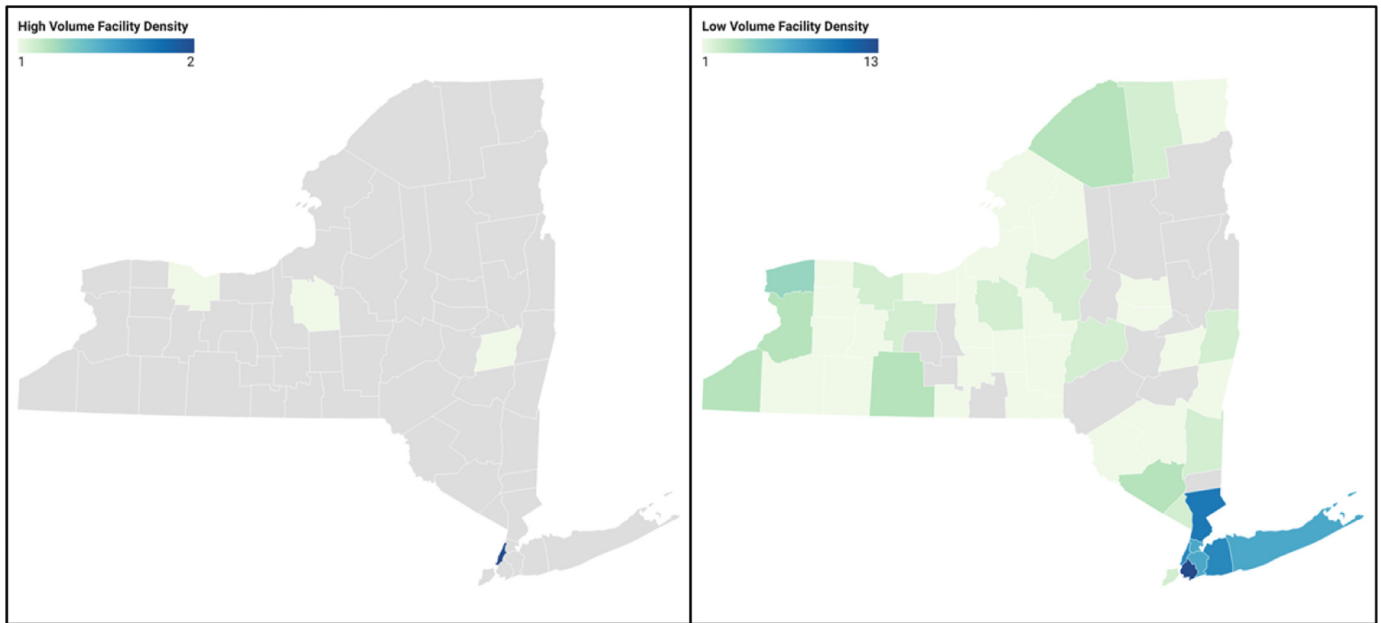
of care and consequent complications in an increasingly common orthopedic procedure. Furthermore, our study controlled for demographic factors such as race, SDI, and comorbidities in the analysis of risk for complications and still found significant effects of surgeon and facility volume. This highlights 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 osteoarthritis, 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



**Figure 3.** Density of high- and low-volume centers in New York by county. Gray county codes had either no facilities or middle-volume facilities only.

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, designating institutions as centers of excellence.

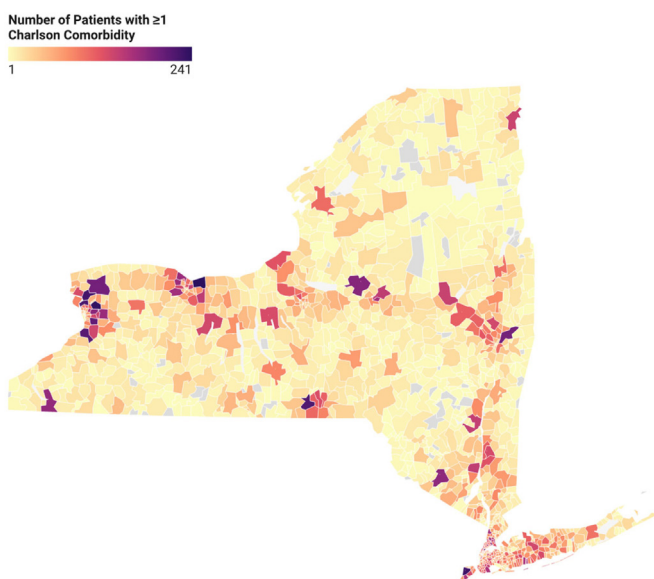
## Conflicts of interest

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>.

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**Figure 4.** Density of patients with 1 or more Charlson comorbidities in New York by ZIP code. Gray ZIP codes had either no TKA cases or no patients with a Charlson comorbidity.

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**Supplemental Table 1**  
Diagnosis and procedure codes for knee arthroplasty complications.

Complication	ICD 9 CM	ICD 10 CM/PCS	CPT
Revision	81.55	0SWC0JC, 0SWC0JZ, 0SWC3JC, 0SWC3JZ, 0SWC4JC, 0SWC4JZ, 0SWCXJC, 0SWCXJZ, 0SWT0JZ, 0SWT3JZ, 0SWT4JZ, 0SWTXJZ, 0SWV0JZ, 0SWV3JZ, 0SWV4JZ, 0SWVXJZ, 0SWD0JC, 0SWD0JZ, 0SWD3JC, 0SWD3JZ, 0SWD4JC, 0SWD4JZ, 0SWDXJC, 0SWDXJZ, 0SWU0JZ, 0SWU3JZ, 0SWU4JZ, 0SWUXJZ, 0SWW0JZ, 0SWW3JZ, 0SWW4JZ, 0SWWXJZ	27486, 27487
Pulmonary embolism	415.0, 415.12, 415.13, 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, 451.2, 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, I82.439, I82.4Y9, 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, 482.49, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 486, 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, I63.30, I63.40, 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	T81.4XXA, 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	T88.8XXA, T81.31XA, T81.89XA, 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, H95.22, H95.42, I97.42, I97.62, J95.62, J95.831, K91.62, K91.841, L76.02, L76.22, M96.810, M96.811, M96.830, M96.831, N99.62, N99.821	-