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Hospital volume and surgical outcomes after elective hip/knee arthroplasty: A risk adjusted analysis of a large regional database

Jasvinder A. Singh, MBBS, MPH[1], **C. Kent Kwoh, MD**[2], **Robert M. Boudreau, PhD**[2], **Gwo-Chin Lee, MD**[3], and **Said A. Ibrahim, MD, MPH**[2,3]

[1] Medicine Service, VA Medical Center, Birmingham, AL, Division of Rheumatology, University of Alabama at Birmingham, Birmingham, AL and Departments of Health Sciences Research and Orthopedic Surgery, Mayo Clinic, Rochester, MN

[2] VA Pittsburgh Healthcare System and the University of Pittsburgh, Pittsburgh, PA

[3] Philadelphia VA Medical Center and the University of Pennsylvania, Philadelphia, PA

Abstract

Objective—Examine the relationship between hospital procedure volume and surgical outcomes following primary elective total hip or total knee arthroplasty (THA/TKA).

Methods—Using the Pennsylvania Health Care Cost Containment Council database, we identified all patients who underwent primary elective THA/TKA in Pennsylvania. Hospitals were categorized by annual procedure volume of THA/TKA into: ≤25, 26–100, 101–200 and >200. Logistic regression models assessed 30-day complications and 30-day and 1-year mortality, adjusted for age, gender, race, insurance type, hospital region, 3M™ All Patient Refined-Diagnosis Related Group Risk of Mortality score, hospital teaching status and bed count.

Results—THA and TKA cohorts had mean age of 69 years each with 42.8% (n=10,187) and 35% men (n=19,418), respectively. Compared to high-volume hospitals (>200/year), patients who underwent elective primary THA at low-volume hospitals (≤25, 26–100, and 101–200 annually) had higher multivariable-adjusted odds ratios (95% confidence interval) for: venous thromboembolism: 2.0(0.2–16.0), 3.4(1.4–8.0) and 1.1(0.3–3.7), respectively, (p=0.02) (respective events were 3/814, 24/4,163, 7/2,246, 9/2,964); and one-year mortality: 2.1(1.2–3.6) -2.0(1.4–2.9) and 1.0(0.7–1.5) (respective events were 32/814, 147/4,163, 50/2,246, 25/2,964), respectively, (p<0.01). Patients ≥65 who underwent elective primary TKA at low-volume hospitals had significantly higher odds ratios (95% confidence interval) for one-year mortality: 0.6(0.2–2.1), 1.6(1.0–2.4) and 0.9(0.6–1.3), respectively, (p=0.02), compared to high volume hospitals (respective events were 3/309, 58/2,462, 59/3,966, 83/5,750).

Conclusions—A low hospital surgery volume was associated with higher risk of venous thromboembolism and mortality after primary elective THA/TKA. Confounding due to

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Corresponding Author: Jasvinder A. Singh, MBBS, MPH, University of Alabama, Faculty Office Tower 805B, 510 20th Street S, Birmingham, AL 35294.

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unmeasured variables is possible. Modifiable system-based factors/processes should be targeted to reduce complications.

Introduction

Elective total hip (THA) and knee arthroplasty (TKA) are highly successful surgical treatment options for patients with refractory, end-stage knee and hip arthritis. Both procedures are associated with significant improvement in pain, function and health-related quality of life (HRQOL) [1] [2]. Peri- and post-operative medical complications, including cardiac and thromboembolic events, can lead to significant morbidity and mortality after THA/TKA. Furthermore, implant-related complications, including infection, loosening and peri-prosthetic fractures, can lead to early implant failure, necessitating revision surgery [3]. Thus, these complications impact patient morbidity and mortality, which can lead to higher health care utilization and costs [4].

There is growing literature linking surgical outcomes with surgical volume for various subspecialties [5–7]. With respect to hip and knee replacements, studies have reported an association between hospital volume and a decreased risk of some complications, but not others. Katz et al. studied 90-day complication rates in 80,904 Medicare patients who underwent primary TKA and adjusted the analyses for age, gender, Medicaid eligibility, comorbidity and underlying diagnosis [8], and reported that patients who had joint replacements performed in “low volume” hospitals were at a significantly higher risk of developing pneumonia [8]. However, no significant differences were noted in mortality, acute myocardial infarction or pulmonary embolus [8]. Similarly, in another study of 76,627 Medicare patients who underwent primary of revision THA, there was a significant association between higher hospital volume and lower 90-day mortality [9]. On the other hand, a population-based study of 14,352 patients who underwent TKA from 1993–1996 in Canada found no association between low hospital volume and in-hospital major complications, 90-day mortality, or knee infection rates at one or three years [10]. Similarly, Kreder et al. found no association of hospital volume with complications or mortality following hip arthroplasty [11]. Consequently, it is unclear whether these conflicting findings of the relationship between hospital volume and postoperative complications are due to differences in study setting (U.S. versus Canada), cohort characteristics (Medicare patients 65 years and older versus population-based study), or the volume thresholds considered. Furthermore, the estimates reported in previous studies were not adjusted for overall risk of surgical mortality, which can lead to residual confounding.

Therefore, the purpose of this study is to examine the relationship between hospital surgical volume and postoperative complications, including 30 and 90 day mortality in a group of 29,000 patients undergoing elective THA/TKA using a large, regional database adjusted for overall risk of surgical mortality.

Methods

Study Sample and Data Collection

We used the Pennsylvania Health Care Cost Containment Council (PHC4) Database to identify all elective primary THA and TKA surgeries performed during the fiscal year 2002 in the State of Pennsylvania. Cases were identified using the International Classification of Diseases, Ninth Revision (ICD-9) codes of 81.54 (THA) and 81.51 (TKA). Patients with prior hip or knee replacement were excluded from the analysis (**Appendix 1**). The dataset includes information on demographics on all patients who underwent TKA or THA at 170 acute care nongovernmental hospitals in Pennsylvania between 07/01/2001 and 6/30/2002. For THA, patients were excluded if they had a hip fracture (ICD-9 code 820) as the cause of arthroplasty, or they had underwent hemi-arthroplasty (ICD 9 code 81.52), a procedure commonly performed in the management of hip fractures. This study was approved by the Institutional Review Board at the Veterans Affairs Pittsburgh Healthcare system.

Main predictor and covariates/confounders

The primary predictor of interest was hospital volume, defined as the annual number of joint arthroplasties performed in each hospital. The hospital volume categories were: <25 surgeries, 26–100, 101–200 and >200 surgeries per year. The reference group was highest volume hospitals, with >200 surgeries per year. The covariates for the study included: gender, race, age, region, hospital teaching status (teaching or non-teaching), and insurance status (categorized as none or unknown, Medicaid, Medicare/government, or private). For surgical risk adjustment, we used 3M™ All Patient Refined-Diagnosis Related Group Risk of Mortality (APR-ROM) score. This risk-adjustment tool provides a categorical risk assessment based on interactions of age, type of surgical procedure, co-morbidity, and the principal diagnosis and has been previously validated [12–15]. The 3M™ APR-ROM score assigns a risk of death to each surgical procedure as minor, moderate, major, or extreme.

Study Outcomes

The study outcomes of interest were: 1) Overall mortality at 30-days and at one-year and 2) 30-day complications. To assess complications, we used ICD-9 codes to identify five major patient-centered complications. These complications comprise the most common major complications after TJR, including: acute myocardial infarction (MI) (ICD-9 codes: 410.00, 410.01, 410.10, 410.11, 410.20, 410.21, 410.30, 410.31, 410.40, 410.41, 410.50, 410.51, 410.60, 410.61, 410.70, 410.71, 410.80, 410.81, 410.90, 410.91; additional code of 997 with any of the above for post-operative MI), venous thromboembolism (VTE), that is, pulmonary embolism/deep venous thromboses (ICD-9 codes:415.1, 415.11, 415.19, 451.11, 451.19, 451.2, 451.81, 451.9, 453.40, 453.41, 453.42, 453.8, 453.9), catheter-associated urinary tract infection (ICD-9 codes: 996.54 with an additional code of 595.xx or 599.0), prosthetic device malfunction (ICD-9 codes: 996.40, 996.41, 996.42, 996.43, 996.46, 996.47, 996.49) and/or surgical wound infection (ICD-9 codes: 682.5, 682.6, 682.8, 682.9). To assess mortality, the cohort was linked to the National Death Index.

Statistical Analyses

For baseline comparisons, we performed chi-square test for categorical variables, and Kruskal-Wallis equality-of-populations rank test for continuous variables. For all analyses, we analyzed hip and knee cases separately. There were 10,187 patients who had hip replacement and 19,418 patients who had knee replacement. We excluded 6 hip patients and 1 knee patient for whom the APR risk classes could not be calculated.

For the analysis for 30-day and 1-year mortality, we used logistic regression models, clustered on hospital, to take into account the fact that patients who were admitted in the same hospital may be correlated in the outcome. The fitted models were adjusted for age, gender, race, APR risk class, insurance type, hospital geographic region within Pennsylvania, hospital teaching status and hospital bed count. We performed logistic regression analyses separately for overall 30-day complication rate, and the rate of each individual complication clustered on hospital. The covariates were the same as those we used in the models for mortality analysis. Lastly, to examine whether volume-outcome associations are specific to older-age patients as reported in two studies of Medicare data [8–9], we conducted additional analyses restricted to patients 65 years of age or older.

Results

Hospital and Study Cohort Characteristics

The distribution of hospitals by region, number of beds and teaching status for both THA and TKA are shown in Tables 1 and 2. There were significant differences in hospital volume by region for THA, with a larger proportion of high volume hospitals in the more urban regions around Philadelphia, Pittsburgh and Northwest PA (i.e., Erie). For TKA, this difference did not reach statistical significance.

The THA cohort had a mean age of 69 years with 43% men. All demographic and clinical characteristics differed significantly by hospital volume. The highest volume hospitals operated on patients who were younger, more likely to be male, less likely to be white, less likely to have government insurance, or had a lower APR risk of mortality (Table 3). The TKA cohort had a mean age of 69 years and 35% were men. Similar to the THA cohort, hospitals performing the highest volume of TKAs annually operated on patients who were younger, more likely to be male, less likely to be white, less likely to have government insurance, or had a lower APR risk of mortality (Table 4). Overall, 61% in primary THA, and 64% in primary TKA group, were 65 years of age and older.

Surgical outcomes in THA sample

The 30-day and 1-year mortality rates following primary THA were 0.52% (53/10,187) and 2.74% (279/10,187). Within 30-days, incident VTE was noted in 0.42% (43/10,187), myocardial infarction in 0.40% (41/10,187) and infection in 0.25% (25/10,187). Thirty-day mortality did not differ by hospital volume in the entire cohort or in those 65 years and older. However, there was a statistically significant association between low hospital volume and higher 1-year mortality (Table 5). This finding was also found when the analyses were restricted to THA patients who were 65 years and older. Low hospital volume was also associated with higher risk of VTE in THA patients (Table 5). However, this association was not found when the analyses were restricted to those 65 years and older. Thirty-day complication rates did not differ by hospital volume.

Surgical outcomes for patients with TKA

In patients who underwent primary TKA, the 30-day and 1-year mortality rates were 0.27% (52/19,418) and 1.27% (246/19,418). The incidence of VTE was 0.98% (190/19,418), myocardial infarction was 0.30% (59/19,418) and infection was 0.33% (64/19,418). Thirty-day mortality did not differ significantly by hospital volume across the entire cohort (Table 6). There was a suggestion that 1-year mortality rates were higher in hospitals performing 26–100 TKA surgeries per year which did not achieve statistical significance after adjusting for multiple comparisons. In patients 65 years and older, however, performance of TKA in hospitals performing 25–100 TKA surgeries per year was associated with significantly higher risk of 1-year mortality than the highest-volume hospitals. There were no significant associations between hospital volume and 30-day complications, 30-day mortality overall, or in those who were 65 years and older.

Discussion

Total hip and knee replacements are successful in relieving pain and improving function in patients with end stage arthrosis of the hip and knee joints [1–2]. Although both these procedures have proven long term clinical successes, complications that either occur in the perioperative period (i.e., AMI, VTE, and or mortality) or postoperative (i.e., infection, loosening, and or fractures) can cause significant morbidity to the patient and increase health care costs. Recently, several studies have shown an association between the surgical volume of a hospital and the risk of certain postoperative complications. Katz et al. reported that lower hospital volume was associated with significant higher risk of pneumonia in patients undergoing elective TKA and a higher 90 day mortality in Medicare patients undergoing elective THA [8–9]. However, the two Canadian population-based studies have failed to prove a correlation between low surgical volume and increased rates of postoperative complications [10–11]. Studies of Medicare population provide estimates only in patients ≥65 years leading to selection bias, since one-third of all knee and hip arthroplasties in U.S. are performed in adults younger than 65 years, as reported in a study from California [16]. Therefore, we examined the relationship between hospital surgical volume and postoperative complications in 29,000 patients undergoing elective THA/TKA using a large, regional database adjusted for overall risk of surgical mortality. Major advances with our study over previous studies from Medicare and other databases were our ability to adjust for overall surgical mortality risk and use of a population-based regional database approach that avoided selection bias and allowed inclusion of patients of all age-groups undergoing arthroplasty, not just patients 65 years and older.

In this large study of primary elective THA and TKA, not limited to Medicare beneficiaries performed in one fiscal year in the state of Pennsylvania, we found that lower hospital volume was associated with higher risk of 30-day VTE and one-year mortality after primary THA. Also, looking at the subset of TKA patients older than 65 years, lower hospital volume was also associated with higher risk of 1-year mortality. This result confirms some, but not all, of the findings previously published on this subject. For instance, we found that low hospital volume is associated with higher risk of VTE following THA. In particular, patients who received THA in low volume hospitals had 2.0–3.4 higher odds of developing VTE, compared to patients receiving hip replacements at the highest-volume hospitals. This is in contrast to the previous study by Katz et al. that found no association between hospital volume and VTE rates in an analysis limited to the Medicare population [9]. Differences in patient population (all comers versus ≥65 years; Pennsylvania versus entire U.S.) and confounders adjusted in analyses may account for the discordant findings. We also were able to adjust for the risk of overall surgical mortality using the APR-score: whereas, the previous study did not. However, the overall incidence of VTE in our cohort (about 1%) is consistent with previously-reported [17–18]. Among patients who underwent TKA, we did not find significantly higher risk of VTE in cases performed at low-volume hospitals. This finding is consistent with three previous studies by Katz [8], Hervey [19] and Kraeder[10], who found no relationship between hospital volume and VTE rates among patients who underwent TKA. There was a suggestion in our study that very low volume hospitals (≤ 25 cases/yr) have higher risk of VTE (OR=2.4, p=0.10). This is consistent with patients reports of patients who underwent TKA in the state of California [20].

VTE is a preventable complication following elective THA and TKA. There is an intense ongoing debate regarding the choice of best medication/devices for VTE prophylaxis in patients undergoing THA and TKA [21] [22]. The risk of VTE is most likely impacted not only by the choice of thromboprophylactic agent/device, but also the time of initiation and cessation of such therapy [23]. Studies are needed to examine whether the type and duration of the thromboprophylactic agent/device being used in the low-volume hospitals are associated with this increased risk of VTE. If differences are found in thromboprophylaxis regimens between high- and low-volume hospitals, interventions targeting thromboprophylaxis regimen may be needed to improve VTE outcomes in patients undergoing THA/TKA at low-volume hospitals.

Our results show that low surgical volume is associated with higher one year mortality rate in patients undergoing elective THA. These results confirm the findings by Katz et al., who reported a similar correlation between hospital volume and 90-day mortality following THA in the Medicare population [9]. However, we found no association between hospital volume and 30-day mortality after THA. Previous studies have reported that lower hospital volume was associated with higher in-patient mortality following TKA (primary and revision knee arthroplasty combined) in U.S. National Inpatient Sample [19] and higher 90-day mortality in those who underwent elective primary TKA in California [20]. Our results also show a higher one-year mortality rate in TKA patients 65 years or older undergoing surgery at low-volume hospitals. The causes for this discrepancy remain unclear, but further studies are needed to understand the causes of post-operative mortality and to determine what proportion of mortality following these THA/TKA is related to the procedure versus management of pre-existing medical comorbidities.

Our results should be interpreted with the following important limitations in mind. We used a large administrative database, which has potential inconsistencies in documentation and no information on key variables, such as body mass index and patient-reported outcomes, including pre-operative and post-operative pain, functional status, quality of life and satisfaction. Therefore, we are limited in assessing these outcomes. Leading health care quality organizations, such as the Agency for Healthcare Research and Quality**,** support the use of administrative databases, such as the PHC4 dataset to evaluate patient outcomes and address important questions [24] [25] [17] [26]. Since our sample consisted only of patients who underwent surgery in the State of Pennsylvania, we could have complications at hospitals outside Pennsylvania for some patients. Due to regional variation in rates of joint arthroplasty across the U.S. [27], these findings may not be generalizable to other regions. Our database lacked information regarding the utilization of specific type/brand-name of joint prostheses, limiting us from comparing different types of prostheses. Our study used data from 2002, since this was available to us for analyses and we wanted to have data to assess 4.5/5 year revision rates. Although it is possible that volume-complication relationship may have varied over time, it is unlikely given that there have been no major technological advances in total knee or total hip arthroplasty expected to impact volume-outcomes relatioship. Studies examining these associations longitudinally are required to investigate period effect on volume-complication association after THA/TKA. Residual confounding due to unmeasured variables is possible, due to lack of availability of all potential confounding factors. Despite the large number of patients studied, the number of events was low for several outcomes making our results liable to type II error, i.e, missing significant outcomes when they actually existed, due to small number of events.

In conclusion, in this large group of elective primary THA and TKA performed in the state of Pennsylvania during one fiscal year, we found that procedures performed at low volume hospitals (<200 arthroplasties/year) were associated with significantly higher adjusted risk of pulmonary embolism within 30-days and 1-year mortality in patients who underwent primary THA, and higher risk of pulmonary embolism and one-year mortality in patients who underwent TKA. Future studies should focus on investigating whether the underlying reasons for suboptimal outcomes at low-volume hospitals are modifiable (i.e., system factors, peri-operative and post-operative care algorithms). Interventions targeted at modifiable predictors of poor outcomes are likely to improve post-arthroplasty outcomes in low-volume hospitals.

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Table 1

Characteristics of 170 Hospitals in Pennsylvania stratified by hospital procedure volume for Total Hip Arthroplasty (THA)

Characteristic	Hospital Volume* (n (%) of hospitals)					
	Overall	**Very Low (≤25 cases/yr)**	**Low (26–100 cases/yr)**	**High (101–200 cases/yr)**	**Very High (>200 cases/yr)**	**P- Value**
Total number	169 (100%)	69 (100%)	75 (100%)	17 (100%)	8 (100%)	
Region						**0.0082****
Pittsburgh and surrounding area	33 (19.5)	9 (13.0)	17 (22.7)	5 (29.4)	2 (25.0)	
Northwest Pennsylvania	24 (14.2)	13 (18.8)	8 (10.7)	3 (17.7)	0 (0)	
Southern Laurel Highlands	11 (6.5)	6 (8.7)	5 (6.7)	0 (0)	0 (0)	
North Central Pennsylvania	12 (7.1)	8 (11.6)	1 (1.3)	3 (17.7)	0 (0)	
South Central Pennsylvania	16 (9.5)	3 (4.4)	9 (12.0)	2 (11.8)	2 (25.0)	
Northeast Pennsylvania	14 (8.3)	5 (7.3)	8 (10.7)	1 (5.9)	0 (0)	
East Pennsylvania	13 (7.7)	5 (7.3)	5 (6.7)	1 (5.9)	2 (25.0)	
Surrounding Philadelphia	25 (14.8)	8 (11.6)	15 (20)	2 (11.8)	0 (0)	
Philadelphia	21 (21.4)	12 (17.4)	7 (9.3)	0 (0)	2 (25.0)	
No. of hospital beds –median (IQR)	204 (111–314)	104 (74–171)	239 (171–314)	366 (319–504)	550 (475–689)	**<0.01**
Teaching hospital	24 (14.2)	3 (4.4)	9 (12.0)	9 (52.9)	3 (37.5)	**<0.01**

*hospitals are divided into 4 groups depending on the annual number of cases of total hip arthroplasty (THA) per year.

**p-value is from the chi-square test and there are many cells which contain 0's. Fischer exact test cannot be performed because of the memory.

Percentages may not round up to 100 percent due to rounding error.

Table 2

Characteristics of 170 Hospitals in Pennsylvania stratified by hospital procedure volume for Total Knee Arthroplasty (TKA)

Characteristic	Hospital Volume* (n (%) of hospitals)					
	Overall	**Very Low (≤25 cases/yr)**	**Low (26–100 cases/yr)**	**High (101–200 cases/yr)**	**Very High (>200 cases/yr)**	**P-Value**
Total number	169 (100%)	69 (100%)	75 (100%)	17 (100%)	8 (100%)	
Region						0.187**
Pittsburgh and surrounding area	33 (19.5)	5 (13.5)	11 (17.2)	8 (19.1)	9 (34.6)	
Northwest Pennsylvania	24 (14.2)	8 (21.6)	10 (15.6)	4 (9.5)	2 (7.7)	
Southern Laurel Highlands	10 (5.9)	4 (10.8)	2 (3.1)	4 (9.5)	0 (0)	
North Central Pennsylvania	12 (7.1)	3 (8.1)	5 (7.8)	1 (2.4)	3 (11.5)	
South Central Pennsylvania	17 (10.1)	1 (2.7)	6 (9.4)	6 (14.3)	4 (15.4)	
Northeast Pennsylvania	14 (8.3)	3 (8.1)	5 (7.8)	6 (14.3)	0 (0)	
East Pennsylvania	13 (7.7)	3 (8.1)	4 (6.3)	2 (4.8)	4 (15.4)	
Surrounding Philadelphia	25 (14.8)	3 (8.1)	12 (18.8)	8 (19.1)	2 (7.7)	
Philadelphia	21 (21.4)	7 (18.9)	9 (14.1)	3 (7.1)	2 (7.7)	
No. of hospital beds –median (IQR)	204 (111–314)	98 (66–163)	163 (107–239)	256 (222–362)	450 (283–536)	**<0.01**
Teaching hospital	24 (14.2)	3 (8.1)	6 (9.4)	4 (9.5)	11 (42.3)	**<0.01**

* hospitals are divided into 4 groups depending on the annual number of cases of total hip arthroplasty (THA) per year.

** p-value is from the chi-square test and there are many cells which contain 0's. Fischer exact test cannot be performed because of the memory.

Percentages may not round up to 100 percent due to rounding error.

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Table 3

Demographic and clinical characteristics of patients who underwent Total Hip Arthroplasty (n= 10,187).

Characteristic	Hospital Volume* (n (%) of hospitals)					
	Overall	**Very Low (≤25 cases/yr)**	**Low (26–100 cases/yr)**	**High (101–200 cases/yr)**	**Very High (>200 cases/yr)**	**P- Value**
Total number	**10,187 (100)**	**814 (100)**	**4163 (100)**	**2246 (100)**	**2964 (100)**	
Demographic characteristics						
Mean Age, yr (IQR)	69 (58–76)	72 (62–78)	70 (60–78)	69 (58–76)	65 (54–74)	**<0.01**
Male sex	4,363 (42.8)	304 (37.4)	1,680 (40.4)	995 (44.3)	1,384 (46.7)	**<0.01**
65 years and older	6,256 (61.4)	566 (69.5)	2,757 (66.2)	1,397 (62.2)	153 (51.8)	**<0.01**
Race						**<0.01**
White	8,436 (82.8)	716 (88)	3,698 (88.8)	2,107 (93.8)	1,915 (64.6)	
Black	483 (4.7)	79 (9.7)	194 (4.7)	68 (3)	142 (4.8)	
Other or unknown	1,268 (12.5)	19 (2.3)	271 (6.5)	71 (3.2)	907 (30.6)[a]	
Insurance status						**<0.01**
Government	6,076 (59.6)	564 (69.3)	2,686 (64.5)	1,353 (60.2)	1,473 (49.7)	
Medicaid	289 (2.8)	44 (5.4)	141 (3.4)	38 (1.7)	66 (2.2)	
Private	3,778 (37.1)	195 (24)	1,322 (31.8)	841 (37.4)	1,420 (47.9)	
None or unknown	44 (0.4)	11 (1.4)	14 (0.3)	14 (0.6)	5 (0.2)	
APR risk of mortality*						**<0.01**
Minor likelihood of dying	7,897 (77.5)	579 (71.1)	3,131 (75.2)	1,741 (77.5)	2,446 (82.5)	
Moderate likelihood of dying	1,718 (16.9)	166 (20.4)	776 (18.6)	368 (16.4)	408 (13.8)	
Major likelihood of dying	488 (4.8)	59 (7.3)	219 (5.3)	115 (5.1)	95 (3.2)	
Extreme likelihood of dying	78 (0.8)	9 (1.1)	35 (0.8)	19 (0.9)	15 (0.5)	

*6 patients were excluded for whom we could not calculate APR risk score for mortality IQR, Interquartile range

Table 4

Demographic and clinical characteristics of patients who underwent Total Knee Arthroplasty (n= 19,418).

Characteristic	Hospital Volume* (n (%) of hospitals)					
	Overall	**Very Low (≤25 cases/yr)**	**Low (26–100 cases/yr)**	**High (101–200 cases/yr)**	**Very High (>200 cases/yr)**	**P-Value**
Total number	**19,418 (100)**	**475 (100)**	**3,681 (100)**	**6,096 (100)**	**9,166 (100)**	
Demographic characteristics						
Mean Age, yr (IQR)	69 (60–75)	69 (60–76)	69 (61–76)	69 (61–76)	68 (60–75)	**<0.01**
Male sex	6,797 (35)	165 (34.7)	1,245 (33.8)	2,067 (33.9)	3,320 (36.2)	**<0.01**
65 years and older	12,487 (64.3)	309 (65.1)	2,462 (66.9)	3,966 (65.1)	5,750 (62.7)	**<0.01**
Race						**<0.01**
White	16,529 (85.1)	414 (87.2)	3,242 (88.1)	5,494 (90.1)	7,379 (80.5)	
Black	964 (5)	51 (10.7)	271 (7.4)	271 (4.5)	271 (4.1)	
Other or unknown	1,925 (9.9)	10 (2.1)	168 (4.6)	331 (5.4)	1,416 (15.5)[a]	
Insurance status						**<0.01**
Government	12,013 (61.9)	328 (69.1)	2,353 (63.9)	3,854 (63.2)	5,478 (59.8)	
Medicaid	503 (2.6)	27 (5.7)	120 (3.3)	158 (2.6)	198 (2.2)	
Private	6,840 (35.2)	118 (24.8)	1,192 (32.4)	2,061 (33.8)	3,469 (37.9)	
None or unknown	62 (0.3)	2 (0.4)	16 (0.4)	23 (0.4)	21 (0.2)	
APR risk of mortality*						**<0.01**
Minor likelihood of dying	15,530 (80.0)	368 (77.5)	2,896 (78.7)	4,959 (81.4)	7307 (79.7)	
Moderate likelihood of dying	3,100 (16.0)	90 (19.0)	639 (17.4)	915 (15.0)	1,456 (15.9)	
Major likelihood of dying	666 (3.4)	14 (3.0)	124 (3.4)	184 (3.0)	344 (3.8)	
Extreme likelihood of dying	121 (0.6)	3 (0.6)	22 (0.6)	38 (0.6)	58 (0.6)	

* One patient was excluded for whom we could not calculate APR risk score for mortality; IQR, Interquartile range

Table 5

Adjusted odds ratios (95% confidence interval) of the relationship between hospital procedure volume with surgical outcomes for patients who underwent Total Hip Arthroplasty.

	Hospital Volume* (n (%) of hospitals)								
	n/N	**Very Low (≤25 cases/yr)**	**n/N**	**Low (26–100 cases/yr)**	**n/N**	**High (101–200 cases/yr)**	**n/N**	**Very High (>200 cases/yr)**	**P- Value**
All patients									
Hip 30-day mortality	6/814	0.9 (0.2–4.2)	29/4,163	1.6 (0.6–4.1)	9/2,246	1.3 (0.4–4.5)	9/2,964	Ref	0.53
Hip 1-year mortality	32/814	2.1 (1.2–3.6)	147/4,163	2.0 (1.4–2.9)	50/2,246	1.0 (0.7–1.5)	25/2,964	Ref	**<0.01**
Hip Overall complications	25/814	1.3 (0.6–2.5)	129/4,163	1.5 (0.9–2.4)	57/2,246	1.3 (0.7–2.3)	67/2,964	Ref	0.40
Venous thromboembolism	3/814	2.0 (0.2–16.0)	24/4,163	3.4 (1.4–8.0)	7/2,246	1.1 (0.3–3.7)	9/2,964	Ref	**0.02**
Myocardial Infarction	3/814	0.3 (0.1–1.5)	16/4,163	0.7 (0.2–1.9)	10/2,246	1.2 (0.3–4.4)	12/2,964	Ref	0.37
Infection	2/814	0.6 (0.1–3.3)	12/4,163	1.1 (0.4–3.4)	4/2,246	0.3 (0.1–1.7)	7/2,964	Ref	0.44
Analyses restricted to patients≥65 years									
Hip 30-day mortality	5/566	1.0 (0.2–4.6)	27/2,757	1.9 (0.7–4.9)	8/1,397	1.1 (0.3–4.5)	7/1,536	Ref	0.32
Hip 1-year mortality	26/566	2.2 (1.2–4.3)	127/2,757	2.2 (1.4–3.4)	45/1,397	1.0 (0.6–1.5)	42/1,536	Ref	**<0.01**
Hip Overall complications	16/566	1.0 (0.4–2.3)	94/2,757	1.4 (0.8–2.6)	39/1,397	1.1 (0.6–2.1)	47/1,536	Ref	0.45
Venous thromboembolism	3/566	2.0 (0.2–18.9)	17/2,757	2.2 (0.7–6.8)	2/1,397	0.3 (0.1–1.2)	8/1,536	Ref	0.06
Myocardial Infarction	3/566	0.2 (0.04–1.2)	14/2,757	0.5 (0.2–1.4)	10/1,397	1.2 (0.3–4.6)	11/1,536	Ref	0.16
Infection	2/566	0.9 (0.1–6.9)	8/2,757	1.6 (0.2–12.0)	1/1,397	0.2 (0.02–1.8)	4/1,536	Ref	0.29

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Table 6

Adjusted odds ratios (95% confidence interval) of the relationship between hospital procedure volume with surgical outcomes for patients who underwent Total Knee Arthroplasty.

	Hospital Volume* (n (%) of hospitals)								
	n/N	**Very Low (≤25 cases/yr)**	**n/N**	**Low (26–100 cases/yr)**	**n/N**	**High (101–200 cases/yr)**	**n/N**	**Very High (>200 cases/yr)**	**P- Value**
All patients									
Knee 30-day mortality	0/475	Not estimable	10/3,681	0.7 (0.3–1.5)	13/6,096	0.5 (0.3–1.0)	29/9,166	Ref	0.18
Knee 1-year mortality	5/475	1.0 (0.4–2.6)	64/3,681	1.7 (1.1–2.7)	79/6,096	1.2 (0.8–1.8)	98/9,166	Ref	0.07
Knee Overall complications	12/475	1.6 (0.7–3.6)	65/3,681	1.1 (0.6–1.9)	105/6,096	1.1 (0.8–1.6)	182/9,166	Ref	0.72
Venous thromboembolism	8/475	2.4 (0.9–6.5)	27/3,681	1.0 (0.5–2.3)	63/6,096	1.4 (0.9–2.4)	92/9,166	Ref	0.21
Myocardial Infarction	0/475	Not estimable	13/3,681	1.2 (0.5–3.1)	15/6,096	0.8 (0.4–1.5)	31/9,166	Ref	0.51
Infection	4/475	3.4 (0.7–16.3)	20/3,681	2.2 (0.7–7.0)	13/6,096	0.8 (0.3–2.1)	27/9,166	Ref	0.17
Analyses restricted to patients≥65 years									
Knee 30-day mortality	0/309	Not estimable	9/2,462	0.5 (0.2–1.5)	10/3,966	0.5 (0.2–1.0)	24/5,750	Ref	0.16
Knee 1-year mortality	3/309	0.6 (0.2–2.1)	58/2,462	1.6 (1.0–2.4)	59/3,966	0.9 (0.6–1.3)	83/5,750	Ref	**0.02**
Knee Overall complications	4/309	1.0 (0.3–2.9)	48/2,462	1.2 (0.7–2.0)	68/3,966	1.1 (0.7–1.6)	123/5,750	Ref	0.95
Venous thromboembolism	3/309	1.7 (0.5–5.9)	20/2,462	1.1 (0.5–2.6)	39/3,966	1.3 (0.7–2.3)	62/5,750	Ref	0.78
Myocardial Infarction	0/309	Not estimable	11/2,462	0.9 (0.3–2.8)	13/3,966	0.7 (0.3–1.6)	27/5,750	Ref	0.72
Infection	1/309	2.6 (0.3–22.3)	13/2,462	2.7 (0.9–8.0)	8/3,966	1.0 (0.4–3.0)	15/5,750	Ref	0.23