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Original Research

Simultaneous vs Staged Procedures for Bilateral Total Knee Arthroplasty: Reduced Infection, Cost, and Readmission Rates Associated With Simultaneous Procedures

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ABSTRACT

Background: Many patients require total knee arthroplasty (TKA) bilaterally; however, there is limited data on bilateral procedures. This study aims to compare medical and surgical complications and hospital-related outcomes between simultaneous and staged bilateral TKA. We hypothesize that staged procedures will have superior outcomes.

Methods: This retrospective cohort study queried the National Readmissions Database, years 2016-2020, for patients undergoing bilateral TKA via *ICD-10* codes. For patients undergoing staged procedures, outcomes were compared in aggregate for comparison to simultaneous operations. Multivariate regression was performed to assess complications. Negative binomial regression was utilized for 30-day readmission, reoperation, and discharge disposition. Quasi-Poisson regression was performed to assess total charges. Demographics and comorbidities, measured via Elixhauser Comorbidity Index, were controlled for in our analysis.

Results: A total of 210,682 patients, 89,568 (42.51%) undergoing simultaneous bilateral and 121,115 (57.49%) undergoing staged bilateral TKA, were included. The staged cohort had higher odds of medical complications (odds ratio (OR), 1.14; $P < .001$), reduced surgical complications (OR, 0.51; $P < .001$), and increased odds of routine discharges (OR, 1.39; $P < .001$). They also had increased odds of readmission (OR, 1.25; $P < .001$), reoperation (OR, 1.56; $P < .001$), and greater total charges (OR, 1.18; $P < .001$).

Conclusions: Our results demonstrate that, for some patients, simultaneous procedures may be a viable option. While staged operations were associated with reduced surgical complications and resulted in better discharge dispositions, they were also associated with greater medical complications, readmissions, reoperations, and total cost. Surgeons should consider individual patient risks and preferences when planning bilateral TKA.

Introduction

Osteoarthritis (OA) is the most common joint disease in the United States [1]. The gold standard for treatment of late-stage knee OA is total knee arthroplasty (TKA) [2]. Due to population aging, and greater utilization, TKA is rapidly becoming more common [2,3]. Based on data from 2000 to 2014, demand for TKA is expected to grow by 85%-126% million procedures by 2030 [4]. The increasing burden of knee OA demands greater operative efficiency [5].

As patients age, knee OA often progresses to a bilateral disease [6]. In patients with bilateral disease, surgeons are presented with the choice between a simultaneous or staged operation for bilateral TKA. However, literature on the optimum strategy is inconclusive. Evidence in favor of simultaneous TKA suggests that it is more cost effective, has higher patient satisfaction, leads to a shorter overall

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length of stay, and has equal rates of mortality compared to staged [7-11]. Furthermore, while some evidence demonstrates a higher risk of certain adverse outcomes with simultaneous TKA, proponents argue adverse outcomes are uncommon and the difference in risk is minimal [7,9]. Contrarily, evidence against simultaneous TKA finds that it has higher rates of surgical and medical complications, such as postoperative anemia, deep infections, venous thromboembolism, and myocardial infarction. Still, some studies report this increased risk in only high-risk patients [8,12-14]. Opponents argue that the costs saved by doing 1 surgery are negated by increased inpatient rehabilitation utilization by simultaneous bilateral TKA recipients [15].

This study compares short-term perioperative outcomes, including medical and complications, hospital-associated outcomes, and cost, between simultaneous and staged bilateral TKA. We hypothesize that staged procedures will have superior outcomes. High-quality data comparing these disparate treatment options can aid surgeons in optimizing operative management of bilateral, end-stage knee arthritis.

Material and methods

Data source

This retrospective cohort study compared staged vs bilateral TKA procedures, drawing data from the National Readmissions Database (NRD), years 2016-2020. The NRD is one of the largest, all-payor national databases, containing discharge and readmissions data from 31 states, representative of 62.2% of the US population, and up to 32 million discharges, or 60.8% of all hospitalizations [16]. The NRD links patient-level discharge and hospitalization records within a calendar year, facilitating assessment of patient outcomes over time.

Patient selection, sampling, and data collection

International Classification of Diseases, 10th Revision, Clinical Modification/Procedure Coding System codes were used to identify patients who underwent TKA. Patients who underwent 2 procedures on the same day, simultaneous TKA on both right and left, were identified and were placed into the “bilateral” cohort. The “staged” cohort was composed of patients who underwent a second TKA on the contralateral extremity within 6 months of an initial TKA. As the NRD tracks patients for a calendar year, to ensure a minimum of 30-day follow-up, only procedures from January 1 through November 30 of each calendar year were included. For the staged cohort, this required that both procedures were completed by November 30 of the same calendar year.

For all patients, demographic and comorbidity data were collected. Demographic data included age, sex, insurance status (stratified by private, Medicare, Medicaid, or self-pay), and household income quartile assessed ZIP code. Comorbidities in the Elixhauser Comorbidity Index, identified using International Classification of Diseases, 10th Revision codes, were used to calculate a weighted summary score for each patient, reflecting overall comorbidity burden [17]. This has been validated as a powerful predictor of outcomes, including orthopaedic outcomes, in the setting of TKA [18].

Outcomes and follow-up

All significant adverse outcomes (medical complications, surgical complications, and hospital-related outcomes), both in and out of hospital, within 30 days of surgery were collected. For the staged period, follow-up included 2 separate 30-day periods following each operation. These outcomes were grouped, and each patient’s total cost and occurrence of major adverse outcome was recorded and compared to occurrences in the bilateral cohort. 100% of patients included in our analysis had a minimum of 30-day follow-up.

Medical complications included respiratory failure, pulmonary embolism, pneumonia, cardiac arrest, heart failure, myocardial infarction, deep vein thrombosis, acute kidney injury, urological infections, stroke, plegia and paresis, osteomyelitis, and sepsis. Surgical complications included wound dehiscence, postoperative infection (wound or surgical site infections), mechanical failure, postoperative neurological complications, transfusion, postoperative vascular complications, and postoperative shock. Hospital-associated outcomes included 30-day readmission, 30-day reoperation, length of hospital stay, discharge disposition, assessed as adverse (any nonhome) vs routine, home discharges, and total charges associated with hospitalization.

Statistical analysis

To ensure the validity of our analysis, we confirmed that the assumptions of a valid logistic and linear regression model were met. For logistic regression, we verified that the dependent variable was dichotomous, the absence of multicollinearity among predictor variables, and the linearity of the logit for each continuous independent variable. For linear regression, we assessed the normality of residuals, the independence of observations, the homoscedasticity of residuals, and the linearity of the relationship between each independent variable and the dependent variable.

Categorical results are reported as counts with column percentages. Continuous data are reported as means and standard deviations; standard errors are given where appropriate. Comparison of normally distributed data was performed with independent sample *t*-tests. For non-normally distributed data, the Wilcoxon rank-sum test was performed. Categorical variables were assessed with Fisher’s exact test or Chi-squared test with Kendall Tau. Where appropriate, residuals were assessed for normal distribution and no multicollinearity was observed.

For all regressions, where appropriate, patient demographics and comorbidity burden, measured via Elixhauser Comorbidity Index score, were controlled for. Multivariate regression was performed to assess postoperative complications. Negative binomial regression was performed to assess readmissions, reoperations, and discharge disposition. Gamma regression was performed to assess total charges and length of stay. Confidence intervals (CIs) were set to 95% and *P* values of .05 or less were considered significant. All analysis was performed in R Foundation for Statistical Computing software version 4.20.

No institutional review board approval was required for this study; the institutional review board exemption number is 20230793NRR. Informed consent was not required for this study.

Results

Demographics

We identified a total of 210,682 patients undergoing bilateral TKA. Of these, 89,568 (42.51%) underwent the procedures simultaneously, while 121,115 (57.49%) had staged bilateral TKAs. The mean age overall was 64.66 years (standard deviation 8.75), and 119,837 (57%) of patients were female. Full demographics can be seen in Table 1.

Table 1
Overall demographic data of simultaneous bilateral TKA vs staged bilateral TKA.

Demographics	Overall, N = 210,682[a]	Simultaneous, N = 89,568[a]	Staged, N = 121,115[a]	*P* value[b]
Age	64.66 (8.75)	63.51 (8.38)	65.51 (8.92)	**<.001**
Age category				**<.001**
<50	8033 (3.8%)	3949 (4.4%)	4084 (3.4%)	
50-64	96,391 (46%)	44,226 (49%)	52,165 (43%)	
65-79	96,353 (46%)	38,985 (44%)	57,368 (47%)	
≥80	9905 (4.7%)	2408 (2.7%)	7497 (6.2%)	
Gender				**<.001**
Female	119,837 (57%)	47,232 (53%)	72,605 (60%)	
Male	90,845 (43%)	42,336 (47%)	48,509 (40%)	
Household income by zipcode				**<.001**
0-25th percentile	40,421 (19%)	15,499 (17%)	24,922 (21%)	
26th-50th percentile	59,260 (28%)	24,660 (28%)	34,601 (29%)	
51st-75th percentile	62,075 (29%)	26,879 (30%)	35,196 (29%)	
76th-100th percentile	48,703 (23%)	22,421 (25%)	26,282 (22%)	
Payer				**<.001**
Medicaid	7857 (3.7%)	2480 (2.8%)	5377 (4.4%)	
Medicare	99,882 (47%)	38,142 (43%)	61,740 (51%)	
Other	5337 (2.5%)	2089 (2.3%)	3248 (2.7%)	
Private insurance	96,683 (46%)	46,453 (52%)	50,231 (41%)	
Self-pay	899 (0.4%)	393 (0.4%)	506 (0.4%)	
Time to procedure	0.13 (2.37)	0.21 (2.79)	0.06 (1.99)	**<.001**
Length of stay	4.26 (3.60)	4.29 (4.08)	4.23 (3.19)	**<.001**
Total charge	109,249.40 (66,832.52)	98,623.15 (65,635.53)	117,107.82 (66,623.23)	**<.001**
Discharge dispostion				**<.001**
Adverse discharge	650 (0.3%)	423 (0.5%)	227 (0.2%)	
Home discharge with care	83,969 (40%)	32,181 (36%)	51,788 (43%)	
Routine discharge	86,289 (41%)	30,863 (34%)	55,426 (46%)	
Transfer to skilled facility	39,773 (19%)	26,100 (29%)	13,673 (11%)	
Mortality				**.021**
Died	48 (<0.1%)	33 (<0.1%)	15 (<0.1%)	
Elixhauser Comorbidity Index	0.12 (4.21)	0.16 (4.13)	0.08 (4.27)	**<.001**
30-day readmission	16,630 (7.9%)	5994 (6.7%)	10,636 (8.8%)	**<.001**
30-day reoperation	4683 (2.2%)	1504 (1.7%)	3179 (2.6%)	**<.001**

TKA, total knee arthroplasty.
Bold values indicate statistical significance ($P < .05$).
[a] Mean (SD); n (%).
[b] Wilcoxon rank-sum test for complex survey samples; chi-squared test with Rao & Scott's second-order correction.

Medical and surgical complications

Patients undergoing staged operations had higher all-cause medical complications (odds ratio [OR] 1.14; 95% CI 1.09-1.20; $P < .001$) between the 2 cohorts, including heart failure (OR 2.12; 95% CI 1.96-2.30; $P < .001$). However, patients undergoing staged operations had reduced all-cause surgical complications (OR 0.51; 95% CI 0.47-0.56; $P < .001$). Specifically, the staged cohort had reduced odds of blood transfusion (OR 0.28; 95% CI 0.25-0.32; $P < .001$).

Conversely, patients who underwent staged TKA had a greater risk of postoperative infection (OR 1.67; 95% CI 1.35-2.07; $P < .001$) and joint infection (OR 1.45; 95% CI 1.26-1.66; $P < .001$). They also had higher odds of periprosthetic fracture (OR 2.13; 95% CI 1.55-2.93; $P < .001$). Results of univariate analysis, and counts and proportions, can be seen in Table 2. Results of multivariate analysis can be seen in Figure 1.

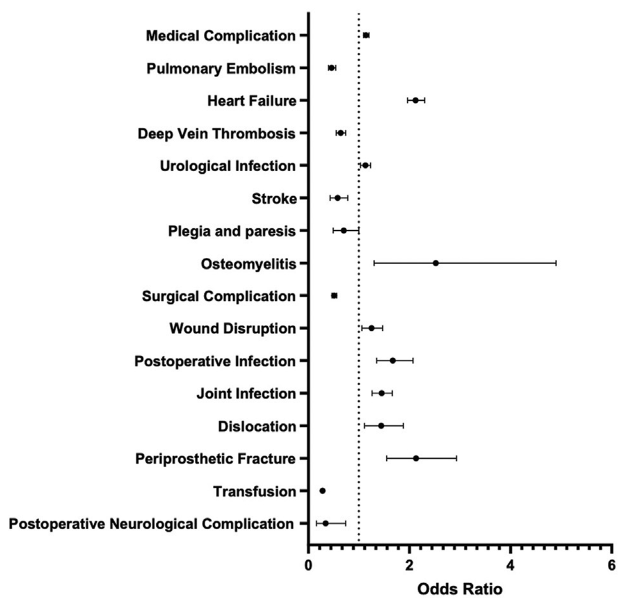
Hospital-related outcomes

With respect to hospital-related outcomes, patients who underwent staged bilateral TKA had increased odds of routine discharges (OR 1.39; 95% CI 1.31-1.46; $P < .001$) and lower odds of mortality ($P = .021$). However, they had increased odds of 30-day readmission (OR 1.25; 95% CI 1.19-1.31; $P < .001$) and 30-day reoperation (OR 1.56; 95% CI 1.42-1.71; $P < .001$). As well, patients in the staged cohort had significantly greater total charges (OR 1.18; 95% CI 1.14-1.21; $P < .001$). Mortality rate was less than

Table 2
Adverse events of simultaneous bilateral TKA vs staged bilateral TKA.

Characteristic	Overall, N = 210,682[a]	Simultaneous, N = 89,568[a]	Staged, N = 121,115[a]	*P* value[b]
Medical complications	20,093 (9.5%)	7528 (8.4%)	12,565 (10%)	**<.001**
Respiratory failure	2425 (1.2%)	945 (1.1%)	1480 (1.2%)	**.033**
Pulmonary embolism	1519 (0.7%)	932 (1.0%)	587 (0.5%)	**<.001**
Pneumonia	1276 (0.6%)	500 (0.6%)	776 (0.6%)	.10
Cardiac arrest	126 (<0.1%)	62 (<0.1%)	64 (<0.1%)	.3
Heart failure	6494 (3.1%)	1563 (1.7%)	4931 (4.1%)	**<.001**
Myocardial infarction	576 (0.3%)	258 (0.3%)	318 (0.3%)	.4
Transfusion	7995 (3.8%)	5624 (6.3%)	2371 (2.0%)	**<.001**
Deep vein thrombosis	1375 (0.7%)	736 (0.8%)	639 (0.5%)	**<.001**
Acute kidney disease	6829 (3.2%)	2864 (3.2%)	3965 (3.3%)	.6
Urological infections	4344 (2.1%)	1586 (1.8%)	2758 (2.3%)	**<.001**
Stroke	388 (0.2%)	210 (0.2%)	178 (0.1%)	**.002**
Plegia and paresis	293 (0.1%)	145 (0.2%)	149 (0.1%)	.11
Osteomyelitis	114 (<0.1%)	24 (<0.1%)	90 (<0.1%)	**.001**
Sepsis	1960 (0.9%)	801 (0.9%)	1159 (1.0%)	.3
Surgical	12,659 (6.0%)	7273 (8.1%)	5387 (4.4%)	**<.001**
Wound disruption	1280 (0.6%)	461 (0.5%)	819 (0.7%)	**<.001**
Postoperative infection	845 (0.4%)	253 (0.3%)	593 (0.5%)	**<.001**
Joint infection	1799 (0.9%)	604 (0.7%)	1195 (1.0%)	**<.001**
Dislocation	478 (0.2%)	157 (0.2%)	322 (0.3%)	**.002**
Periprosthetic fracture	383 (0.2%)	87 (<0.1%)	296 (0.2%)	**<.001**
Postoperative shock	1083 (0.5%)	447 (0.5%)	636 (0.5%)	.6
Postoperative vascular complications	1296 (0.6%)	583 (0.7%)	713 (0.6%)	.3

TKA, total knee arthroplasty.
Bold values indicate statistical significance ($P < .05$).
[a] n (%).
[b] Chi-squared test with Rao & Scott's second-order correction.



	OR	95% Lower CI	95% Upper CI	P
Medical Complication	1.14	1.09	1.20	**<0.001**
Pulmonary Embolism	0.46	0.40	0.54	**<0.001**
Heart Failure	2.12	1.96	2.30	**<0.001**
Deep Vein Thrombosis	0.64	0.55	0.74	**<0.001**
Urological Infection	1.13	1.03	1.23	**0.01**
Stroke	0.58	0.43	0.78	**<0.001**
Plegia and paresis	0.70	0.49	1.00	**0.05**
Osteomyelitis	2.52	1.30	4.90	**0.007**
Surgical Complication	0.51	0.47	0.56	**<0.001**
Wound Disruption	1.25	1.06	1.47	**0.007**
Postoperative Infection	1.67	1.35	2.07	**<0.001**
Joint Infection	1.45	1.26	1.66	**<0.001**
Dislocation	1.44	1.11	1.88	**0.006**
Periprosthetic Fracture	2.13	1.55	2.93	**<0.001**
Transfusion	0.28	0.25	0.32	**<0.001**
Postoperative Neurological Complication	0.34	0.16	0.74	**0.007**

Figure 1. Forest plot of multivariate regression analysis of adverse events. Odds of outcomes are given as staged bilateral TKA relative to simultaneous bilateral TKA. TKA, total knee arthroplasty.

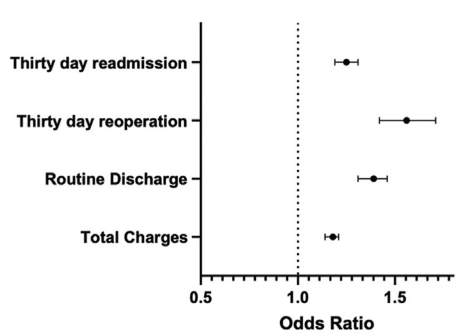
0.1% for both staged and simultaneous. Results of multivariate analysis can be seen in Figure 2.

Discussion

The purpose of this study was to further investigate the safety and feasibility of simultaneous bilateral TKA when compared to staged. In one of the largest studies on the subject to date, we found that staged TKA had higher overall medical complications; however, staged TKA had lower overall surgical complications, including risk of transfusion. In contrast, patients undergoing staged surgery had a greater risk of postoperative infection and joint infection, as well as higher odds of 30-day readmission and reoperation. Staged TKA had statistically lower odds of mortality, but this may not be clinically meaningful as the mortality rate was less than 0.1% for both cohorts.

The increased cost-efficiency of bilateral procedures makes TKA an attractive option to payers, hospitals, and patients alike. Reuben et al. found that a bilateral simultaneous TKA resulted in a 36% cost reduction [11]. They concluded that if all bilateral total joint procedures were treated with simultaneous procedures, cost savings would exceed 1 billion dollars annually [11]. However, claims of cost savings have been questioned due to increased in-patient rehabilitation utilization. Sobh et al. found that, when the number of patients discharged to in-patient rehabilitation is taken into account, the average hospital cost was the same for both simultaneous and staged bilateral TKAs [15]. Contrarily, a study by Odum et al. found that overall hospital costs were still significantly higher for staged procedures, accounting for a broad range of factors contributing to additional cost [19]. They estimated the mean cost of simultaneous bilateral TKA to be $43,401 in 2012 US dollars, compared to $72,233 for the staged procedure [19]. Similarly, in the present study, staged procedures were associated with an 18.7% increase in total charges for inpatient hospital stay.

While cost efficiency is important, ensuring patient safety remains the priority. Our data suggest that simultaneous and staged bilateral procedures have similar rates of adverse outcomes. We found that patients in the staged cohort had greater overall medical complications; however, patients undergoing staged operations had reduced all-cause surgical complications, most notably blood transfusions. This is to be expected, as a simultaneous procedure is longer and will inevitably lead to higher blood loss in a single setting [8]. Still, mortality was less than 0.1% for both procedures.



	OR	95% Lower CI	95% Upper CI	P
Thirty day readmission	1.25	1.19	1.31	**<0.001**
Thirty day reoperation	1.56	1.42	1.71	**<0.001**
Routine Discharge	1.39	1.31	1.46	**<0.001**
Total Charges	1.18	1.14	1.21	**<0.001**

Figure 2. Forest plot of multivariate regression analysis of hospital variables. Odds of outcomes are given as staged bilateral TKA relative to simultaneous bilateral TKA. TKA, total knee arthroplasty.

Furthermore, staged procedures were associated with increased odds of reoperation, exposing patients to increased morbidity, anesthesia risks, and the burden of additional surgery. This tradeoff suggests that patient selection and perhaps preferences may be the deciding factor in this case.

A commonly reported benefit of simultaneous over staged bilateral TKA is the lower rate of infection [7,20,21]. We found that staged bilateral TKA had higher odds of postoperative joint infection. Bilateral TKA spares patients an additional trip to the operating room, which is frequently a source of infection [21]. Fu et al. further elaborated that the lower infection rates could contribute to the lower revision rates that are often seen with simultaneous bilateral TKAs [22]. This finding coincides with our results, which found that staged operations had higher odds of 30-day readmission and reoperation.

Still, the literature is largely equivocal. Multiple studies have found no significant difference in major complications after either surgery [10,23]. Major complications that are the highest concern include deep vein thrombosis, pulmonary embolism, cardiovascular events, and mortality [19]. Dhiren et al. found that simultaneous bilateral TKA did not carry a higher risk for death within 90 days, septic or aseptic failure, acute myocardial infarction, stroke, venous thromboembolism, or other medical complications [9]. Similarly, Kim et al. found no difference in the number of major complications [23].

Lindberg-Larsen et al. suggested that these findings of similar outcomes may be due to patient selection rather than inherent equality of risk [8]. A simultaneous procedure is lengthier and more extensive, so there is concern that it could increase the risk for medical and surgical complications [22]. However, if the patient has no cardiopulmonary comorbidities, studies indicate that simultaneous bilateral TKA is an equally safe option for them [8]. A study by Yoon et al. demonstrated the importance of patient selection by comparing major complications in low-risk (American Society of Anesthesiologists 1 or 2) vs high-risk (American Society of Anesthesiologists 3 or 4) patients undergoing simultaneous vs staged bilateral TKAs [13]. Yoon et al. found that high-risk patients undergoing a simultaneous procedure experienced more systemic complications than those undergoing a staged procedure, while low-risk patients had no difference in the rate of systemic complications between the 2 operations [13]. Conversely, Warren et al. found that simultaneous TKA had a 2-fold increase in major complications compared to staged in even the healthiest cohort of patients [14]. However, Tsay et al. found that, although simultaneous bilateral TKA did have higher risks of certain adverse outcomes than staged, the overall risk was low and the risk difference between the 2 patient populations was small [7].

While there may be statistically significant differences in complications, the clinical relevance is uncertain, as the overall risk of either operative approach is relatively low. Individual patient risk and preferences should be accounted for and will likely drive the decision-making. For either operation, there is a risk of cardiopulmonary complications and mortality, but for both procedures, that risk is relatively low [9]. Overall, our results suggest that simultaneous TKA is a preferable option for appropriately selected patients, but thorough, evidence-based discussions of the risks and benefits of these competing options are warranted.

Limitations

A major limitation of our study is an inability to assess patients with planned, but incomplete staged TKA. Patients may have undergone a unilateral procedure, but opted not to continue with the contralateral due to major complications, death (related to the initial procedure or not), or other significant events precluding completion of the second procedure. This survivor-selection bias may result in only the healthiest patients proceeding with the second half of a staged procedure, leaving complications and costs from failed initial procedures unaccounted for in our analysis.

Second, our cost analysis was limited to total hospital charges. While this is an important measure in and of itself, more robust cost comparisons ought to consider other costs associated with TKA, such as outpatient physical therapy or rehabilitation and time away from work. These costs may be considerably different and important to assess as a staged procedure demands 2 postoperative recovery periods. In contrast, a bilateral procedure may allow patients to recover and receive postoperative care in a more time-efficient manner. Future studies should work to incorporate these considerations and provide more meaningful, comprehensive analysis of the total economic costs of these disparate strategies.

Still, our study has strengths which make our results and contribution to the literature meaningful. First, this is likely the largest study on the subject to date, using a nationally representative sample, greatly enhancing the generalizability of our findings. Much of the extant literature is too underpowered to appreciate significant differences in rare, but serious complications. Second, we were able to assess a number of important outcomes, including joint infections, periprosthetic fracture, and total charges, which many studies fail to capture.

Conclusions

We report increased overall medical complications in patients undergoing staged over simultaneous bilateral TKA in one of the largest studies of this topic to date. Although patients undergoing staged operation had a slight reduction in surgical complications, namely blood transfusions, they also had increased odds of readmission and reoperation. With appropriate patient selection, simultaneous bilateral TKA is an excellent treatment option due to its associated cost savings, lower odds of infection and reoperation, and acceptable cardiopulmonary complication and mortality risk.

Conflicts of interest

Frank Buttacavoli is in the speakers bureau/paid presentations for Zimmer Biomet, KCl, Sanara MedTech, Medtronic, and Heraeus Medical; is a paid consultant for Zimmer Biomet, KCl, Sanara MedTech, Medtronic, and Heraeus Medical; and is the AAOS Hip and Knee Evaluation Committee Member. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Aaron Singh: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Travis M. Kotzur:** Visualization, Methodology, Data curation, Conceptualization. **Kathleen Lundquist:** Validation, Methodology, Investigation. **Blaire C. Peterson:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **William H. Young:** Writing – review & editing, Validation, Investigation. **Chance C. Moore:** Validation, Supervision. **Frank Buttacavoli:** Validation, Supervision.

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