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ORIGINAL ARTICLE

Simultaneous bilateral total knee arthroplasty has higher in-hospital complications than both staged surgeries: a nationwide propensity score matched analysis of 38,764 cases

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Abstract

Purpose To investigate (1) healthcare utilization, (2) in-hospital metrics and (3) total in-hospital costs associated with simultaneous versus staged BTKA while evaluating staged BTKA as a single process consisting of two combined episodes.

Methods The national readmissions database was reviewed for simultaneous and staged (two primary unilateral TKAs12 months apart) BTKA patients (2016–2017). A total of 19,382 simultaneous BTKAs were identified, and propensity score matched (1:1) to staged BTKA patients (19,382 patients; 38,764 surgeries) based on demographics, comorbidities, and socioeconomic determinants. Outcomes included healthcare utilization [length of stay (LOS) and discharge disposition], in-hospital periprosthetic fractures, non-mechanical complications, and costs. Staged BTKA was evaluated as one process consisting of two episodes. For each staged patient, continuous outcomes were evaluated via the sum of both episodes. Categorical outcomes were added, and percents were expressed relative to total number of surgeries ($n = 38{,}764$).

Results Simultaneous BTKA had longer LOS (5.0 days ± 4.7 vs. 4.5 days ± 3.5; $p < 0.001$), higher non-home discharge [36.9% ($n = 7150/19{,}382$) vs. 13.6% ($n = 5451/38{,}764$)], in-hospital periprosthetic fractures [0.13% (26/19,382) vs. 0.08% (31/38,764); $p = 0.049$], any non-mechanical complication [33.76% (6543/19,382) vs.15.93% (6177/38,764); $p < 0.0001$], hematoma/seroma formation [0.11% (22/19,382) vs. 0.05% (20/38,764); $p = 0.0088$], wound disruption [0.08% (16/19,382) vs. 0.04% (16/38,764); $p = 0.0454$], and any infection [1.13% (219/19,382) vs. 0.50% (194/38,764); $p < 0.0001$]. Average in-hospital costs for the two staged BTKA episodes combined were $5006 higher than those of simultaneous BTKA ($28,196 ± $18,488 vs. $33,202 ± $15,240; $p < 0.001$).

Conclusion Simultaneous BTKA had higher healthcare utilization and in-hospital complications than both episodes of staged BTKA combined, with a minimal in-hospital cost savings. Future studies are warranted to further explore patient selection who would benefit from BTKA.

Keywords Bilateral total knee arthroplasty (TKA) · Complications · Outcomes · Cost · National · Readmission

Introduction

The United States continues to age yet with increasing functional demands and expectations [1]. This trend drives an anticipated exponential increase in demand for total knee arthroplasty (TKA), projected to exceed 85% by 2030[2]. TKA is the most effective pain relief and functional restoration option among individuals with end-stage knee osteoarthritis through providing, on average, a 0.17 increase in quality-adjusted life years [3–5]. Of this exponentially growing TKA patient population, Santana et al. [6] reported that 40% would require contralateral TKA within the ensuing eight years from the index surgery [6, 7]. Bilateral TKA (BTKA) has been advocated as an effective intervention to address osteoarthritis of both knee joints within a predefined time frame, thereby mitigating the potential for hindered functional improvement by unaddressed contralateral knee osteoarthritis. Based on the second TKA's timing, BTKA can be categorized as simultaneous, which involves performing

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both procedures during the same surgical episode [5]; or staged, which affords patients a planned inter-surgical interval for recovery before the contralateral procedure [8].

Simultaneous BTKA has been associated with certain advantages such as the convenience of a single surgical intervention with a single exposure to anesthesia, and potential for mitigated cost [9–11]. In addition, recent investigations highlight non-inferiority in pain relief and patient satisfaction for simultaneous BTKA compared to unilateral and staged BTKA [11–13]. Nevertheless, there remains controversy regarding simultaneous BTKA's safety profile. Several investigations have indicated a significant association between simultaneous BTKA and pulmonary embolism, deep vein thrombosis, superficial, deep, and prosthetic joint infection, increased length of stay, need for transfusion, early revision surgery, and mortality compared to its staged counterpart [4, 14–16]. Such increase in postoperative complications led Warren et al. [17] to conclude that simultaneous BTKA may not be safe even among the healthiest of patients.

However, investigations highlighting the high-risk profile predominantly utilize unilateral TKA comparison cohorts or analyze staged BTKA as two completely dissociated surgical episodes, which may misrepresent its bilateral nature. Such limitation derogated the conclusively of evidence outlining the more favorable safety profile of staged BTKA, thereby hindering a potentially widespread shift in clinical practice towards staged BTKA. Therefore, the present study aimed to investigate (1) healthcare utilization, (2) in-hospital metrics and (3) total in-hospital costs associated with simultaneous vs. staged BTKA while evaluating staged BTKA as a single process consisting of two combined episodes.

Methods

Study design and data source

The Agency of Healthcare Research and Quality's (AHRQ's) National Readmissions Database (NRD) was retrospectively queried for patients who received BTKA (January 2016–December 2017). The NRD is a nationally representative all-payer database and comprises hospitalization captured in the State Inpatient Database (SID). The NRD includes data from 28 SIDs across the nation and encompasses patients who have undergone one or more inpatient admission. Each patient is assigned a verified deidentified patient linkage number which facilitates tracking this patient from the initial hospitalization and up to one year postoperatively. Therefore, admission details, including surgical hospitalizations that occurred within one year from the index surgical episode, are captured. The NRD is a publicly available deidentified database; therefore, institutional review board approval was not required for the present investigation.

Data collection and population characteristics

All patients who received primary BTKA within the study period were eligible for inclusion. These patients were identified using ICD-10 codes (Appendix 1). Simultaneous BTKA patients were defined as those who received primary TKA on both knees during the same hospitalization. Conversely, patients who received staged BTKA were identified through isolating linkage numbers associated with two discrete hospitalizations for primary unilateral TKA. This was facilitated by NRD's temporal capture of hospitalizations for each linkage number (indicative of a single patient) for one year from the index procedure. Patient demographics, baseline comorbidities, healthcare utilization (LOS and discharge disposition), hospitalization costs, and in-hospital complications were extracted for each patient.

A total of 27,555 simultaneous and 20,279 staged BTKAs were identified. Baseline characteristics of the prematched cohorts are detailed in Table 1. Propensity score matching (1:1) was performed to obtain similar cohorts of patients who received simultaneous (Patients: $n = 19{,}382$; surgeries: $n = 19{,}382$) and staged (patients: $n = 19{,}382$; surgeries: $n = 38{,}704$) BTKA (Table 2). Propensity score matching was based on age, sex, insurance, elective status, hospital details, income percentile, and Elixhauser comorbidity score, thereby eliminating differences in baseline determinants.

Outcome measures

In-hospital metrics included LOS, discharge disposition, and in-hospital complications [intra-/postoperative periprosthetic fractures and non-mechanical complications including shock, hematoma/seroma, infections, acute hemorrhagic anemia, blood transfusion, pulmonary embolism, deep venous thrombosis (DVT), respiratory failure, and unspecified system-wide complications] [18]. In-hospital costs reflected the actual expenses incurred during the surgical hospitalization. Such outcomes were captured for the duration of the TKA admission, corresponding to either one hospitalization for simultaneous BTKA or first and second primary TKA admissions for staged BTKA. A patient was considered to have received staged bilateral TKA if the second surgery occurred within 365 days of the initial TKA and was subsequently captured as a hospital admission within the NRD. The outcomes of interest were recorded for each surgical episode of staged BTKA, and combined to provide a "net" estimate of staged BTKA as a single entity rather than two independent surgeries.

Table 1 Comparison of baseline determinants among included patients within the study period before propensity score matching

Variable	Simultaneous TKA		Aggregated stage		*p* value
	N	27,555 patients	*N*	20,279 patients	
	Mean	SD or %	Mean	SD or %	
Average age	64	8	65	9	
Age category					
40 and under	118	0.4	81	0.4	$p < 0.0001$
41–50	1446	5.2	900	4.4	
51–60	8316	30.2	5468	27.0	
61–70	12,044	43.7	8634	42.6	
71–80	5013	18.2	4351	21.5	
81 and over	618	2.2	845	4.2	
Sex					
Male	12,791	46.4	8175	40.3	$p < 0.0001$
Female	14,764	53.6	12,104	59.7	
Missing	0	0.0	0	0.0	
Insurance					
Medicaid	787	2.9	980	4.8	$p < 0.0001$
Medicare	11,875	43.1	9831	48.5	
Other	602	2.2	615	3.0	
Private	14,164	51.4	8759	43.2	
Self	96	0.3	74	0.4	
Missing	31	0.1	20	0.1	
Elective					
Non-elective	662	2.4	730	3.6	$p < 0.0001$
Elective	26,870	97.5	19,515	96.2	
Missing	23	0.1	34	0.2	
Hospital ownership					
Government, nonfederal	2114	7.7	1822	9.0	$p < 0.0001$
Private, not-profit	21,686	78.7	15,480	76.3	
Private, invest-own	3755	13.6	2977	14.7	
Missing					
Teaching status of urban hospitals					
Metropolitan non-teaching	7317	26.6	6259	30.9	$p < 0.0001$
Metropolitan teaching	17,662	64.1	12,307	60.7	
Non-metropolitan hospital	2576	9.3	1713	8.4	
Hospital urban–rural designation					
Large metropolitan areas with at least 1 million residents	14,800	53.7	10,177	50.2	< 0.0001
Small metropolitan areas with less than 1 million residents	10,179	36.9	8389	41.4	
Micropolitan areas	1990	7.2	1284	6.3	
Not metropolitan or micropolitan	586	2.1	429	2.1	
Hospital bed size					
Small	7420	26.9	4928	24.3	$p < 0.0001$
Medium	7998	29.0	6081	30.0	
Large	12,137	44.0	9270	45.7	
Missing	0	0.0	0	0.0	

Statistical analysis

Univariate analysis was conducted to compare the distribution of demographic determinants and healthcare settings among patients who received simultaneous versus staged BTKA. Propensity score matching (PSM) was

Table 1 (continued)

Variable	Simultaneous TKA		Aggregated stage		*p* value
	N	27,555 patients	*N*	20,279 patients	
	Mean	SD or %	Mean	SD or %	
Income					
0–25th percentile	4712	17.1	3967	19.6	$p < 0.0001$
26–50th percentile (median)	7076	25.7	5570	27.5	
51st to 75th percentile	7802	28.3	5857	28.9	
76–100th percentile	7606	27.6	4600	22.7	
Missing	359	1.3	285	1.4	
Elixhauser risk group					
Low	25,419	81.8	18,834	90.7	0.0006
Medium	1955	14.5	1360	8.3	
High	181	3.7	85	1.1	
Comorbidities					
Aids	*	*	*	*	0.9721
Alcohol abuse	380	1.4	209	1.0	0.0006
Arrhythmia	1383	5.0	780	3.8	< 0.0001
Deficiency anemia	3716	13.5	1471	7.3	< 0.0001
Rheumatoid arthritis	1102	4.0	938	4.6	0.0008
Blood loss anemia	489	1.8	89	0.4	< 0.0001
Congestive heart failure	424	1.5	433	2.1	< 0.0001
Chronic lung disease	3468	12.6	2900	14.3	< 0.0001
Coagulopathy	30	0.1	26	0.1	0.541
Depression	3726	13.5	2939	14.5	0.0024
Diabetes mellitus-uncomplicated	3071	11.1	3116	15.4	< 0.0001
Diabetes mellitus-complicated	1214	4.4	983	4.8	0.0226
Drug abuse	164	0.6	118	0.6	0.8512
Hypertension	16,793	60.9	13,501	66.6	< 0.0001
Hypothyroidism	4024	14.6	3197	15.8	0.0005
Liver disease	383	1.4	270	1.3	0.5857
Lymphoma	43	0.2	35	0.2	0.6577
Fluid and electrolyte imbalance	2886	10.5	1042	5.1	< 0.0001
Metastatic cancer	25	0.1	*	*	0.0094
Neurological disorders	1089	4.0	818	4.0	0.652
Obesity	9226	33.5	7211	35.6	< 0.0001
Paralysis	53	0.2	43	0.2	0.6343
Peripheral vascular disease	584	2.1	407	2.0	0.3937
Psychoses	434	1.6	368	1.8	0.0579
Pulmonary circulation disorders	214	0.8	29	0.1	< 0.0001
Renal failure	1097	4.0	995	4.9	< 0.0001
Solid tumor without metastasis	152	0.6	104	0.5	0.5657
Peptic ulcer disease	152	0.6	73	0.4	0.0025
Valvular disease	843	3.1	557	2.7	0.045
Weight loss	154	0.6	44	0.2	< 0.0001

* Values <11 were deidentified per database use regulations

performed on a nearest-neighbor, 1:1 basis and utilized a caliper of 0.1. Matched variables included age, sex, insurance status, elective status, income quartile, hospital details, and Exhauster comorbidity category [19]. Matching eliminated differences in baseline characteristics between both cohorts, as outlined in Table 2. All outcomes were compared between the propensity score-matched cohorts.

Table 2 Comparison of baseline determinants among included patients within the study period after propensity score matching

Variable	Simultaneous TKA		Aggregate staged TKA		*p*-value
	N	19,382 patients	*N*	19,382 patients	
	Mean or count	SD or %	Mean or count	SD or %	
Average age	65	9	65	9	0.83
Age category					
40 and under	81	0.4	76	0.4	0.4305
41–50	828	4.3	865	4.5	
51–60	5176	26.7	5286	27.3	
61–70	8448	43.6	8368	43.2	
71–80	4266	22.0	4162	21.5	
81 and over	592	3.1	625	3.2	
Sex					
Male	7990	41.2	7937	41.0	0.5843
Female	11,392	58.8	11,445	59.0	
Insurance					
Medicaid	739	3.8	785	4.1	0.5935
Medicare	9407	48.5	9356	48.3	
Other	528	2.7	564	2.9	
Private	8635	44.6	8606	44.4	
Self	73	0.4	71	0.4	
Elective					
Non-elective	593	3.1	622	3.2	0.3979
Elective	18,789	96.9	18,760	96.8	
Missing	0	0.0	0	0.0	
Hospital ownership					
Government, nonfederal	1669	8.6	1702	8.8	0.8332
Private, not-profit	14,884	76.8	14,849	76.6	
Private, invest-own	2829	14.6	2831	14.6	
Teaching status of urban hospital					
Metropolitan non-teaching	5828	30.1	5849	30.2	0.6581
Metropolitan teaching	11,933	61.6	11,867	61.2	
Non-metropolitan hospital	1621	8.4	1666	8.6	
Hospital urban–rural designation					
Large metropolitan areas with at least 1 million residents	9643	49.8	9760	50.4	0.3966
Small metropolitan areas with less than 1 million residents	8118	41.9	7956	41.0	
Micropolitan areas	1222	6.3	1253	6.5	
Not metropolitan or micropolitan	399	2.1	413	2.1	
Hospital bedsize					
Small	4468	23.1	4767	24.6	0.0011
Medium	5809	30.0	5770	29.8	
Large	9105	47.0	8845	45.6	
Income					
0–25th percentile	3760	19.4	3802	19.6	0.6815
26–50th percentile (median)	5429	28.0	5370	27.7	
51st to 75th percentile	5738	29.6	5679	29.3	
76–100th percentile	4455	23.0	4531	23.4	

Table 2 (continued)

Variable	Simultaneous TKA		Aggregate staged TKA		*p*-value
	N	19,382 patients	*N*	19,382 patients	
	Mean or count	SD or %	Mean or count	SD or %	
Elixhauser risk group					
Low	17,993	81.8	17,991	90.7	0.6631
Medium	1318	14.5	1309	8.3	
High	71	3.7	82	1.1	
Comorbidities					
Aids	*	*	*	*	0.527
Alcohol abuse	258	1.3	199	1.0	0.0055
Arrhythmia	947	4.9	740	3.8	< 0.0001
Deficiency anemia	2705	14.0	1404	7.2	< 0.0001
Rheumatoid arthritis	806	4.2	895	4.6	0.0273
Blood loss anemia	359	1.9	84	0.4	< 0.0001
Congestive heart failure	282	1.5	411	2.1	< 0.0001
Chronic lung disease	2510	13.0	2761	14.2	0.0002
Coagulopathy	16	0.1	25	0.1	0.1596
Depression	2825	14.6	2807	14.5	0.7953
Diabetes mellitus-uncomplicated	2271	11.7	2972	15.3	< 0.0001
Diabetes mellitus-complicated	868	4.5	942	4.9	0.0748
Drug abuse	102	0.5	112	0.6	0.493
Hypertension	12,010	62.0	12,886	66.5	< 0.0001
Hypothyroidism	3035	15.7	3039	15.7	0.9554
Liver disease	222	1.1	264	1.4	0.0552
Lymphoma	22	0.1	34	0.2	0.1086
Fluid and electrolyte imbalance	2018	10.4	994	5.1	< 0.0001
Metastatic cancer	12	0.1	*	*	0.1572
Neurological disorders	757	3.9	796	4.1	0.3125
Obesity	6377	32.9	6947	35.8	< 0.0001
Paralysis	29	0.1	43	0.2	0.0986
Peripheral vascular disease	429	2.2	386	2.0	0.1279
Psychoses	323	1.7	348	1.8	0.3303
Pulmonary circulation disorders	145	0.7	28	0.1	< 0.0001
Renal failure	802	4.1	941	4.9	0.0007
Solid tumor without metastasis	114	0.6	97	0.5	0.2406
Peptic ulcer disease	109	0.6	69	0.4	0.0027
Valvular disease	617	3.2	526	2.7	0.0063
Weight loss	111	0.6	39	0.2	< 0.0001

Continuous variables, including length of stay and in-hospital costs for patients who received simultaneous BTKA, were reported as the hospitalization duration/expenses associated with this single surgical episode. Similarly, categorical variables (discharge status and in-hospital complications) for simultaneous BTKA were those specific to this individual surgery. Conversely, continuous variables for each patient who underwent staged BTKA were recorded as a sum of both surgical episodes' hospitalization duration/expenses. Categorical variables in staged BTKA were evaluated relative to both procedures, and percentages were reported relative to the total number of surgical episodes. This allowed for evaluating staged BTKA as a single entity despite consisting of two separate surgeries.

Continuous variables were assessed via means ± standard deviation (SD) and compared using independent 2-sample *t* tests. Categorical variables were evaluated via counts (%) and compared through chi-squared tests. All tests were 2-sided and statistical significance was set at an alpha-level of 0.05 ($p < 0.05$). All analyses were performed using SAS, v9.4 (SAS Institute, Cary, NC).

Results

In-hospital healthcare utilization associated with simultaneous versus staged BTKA

Simultaneous BTKA was associated with a longer length of stay (5.0 days ± 4.7 vs. 4.5 days ± 3.5; $p < 0.0001$), and higher non-home discharge rates (36.9% vs. 13.6%; $p < 0.001$) compared to staged BTKA (Table 3). The rates of intra-/perioperative periprosthetic fractures were significantly higher within the simultaneous BTKA cohort (0.13% vs. 0.08%; $p = 0.0491$). Simultaneous BTKA exhibited higher rates of any in-hospital non-mechanical complications (33.76% vs. 15.93%; $p < 0.0001$). Specifically, patients who received simultaneous BTKA had a higher incidence of developing hematomas/seromas (0.11% vs. 0.05%; $p = 0.0088$), wound dehiscence (0.08% vs. 0.04%; $p = 0.0454$), and any postoperative infection (1.13% vs. 0.50%; $p < 0.0001$) compared to patients who underwent staged BTKA. The simultaneous BTKA cohort demonstrated more than a two-fold increase in the incidence of acute post-hemorrhagic anemia (25.63% vs. 10.88%; $p < 0.0001$) and a seven-fold increase in blood transfusion rates (7.23% vs. 1.12%; $p < 0.0001$) compared to staged BTKA. Simultaneous BTKA demonstrated higher

Table 3 Comparison of in-hospital metrics including healthcare utilization parameters, complications, and cost between simultaneous vs. staged bilateral total knee arthroplasty (BTKA)

Variable	Simultaneous BTKA ($N = 19{,}382$; patients with 19,382 surgeries)		Aggregated staged BTKA ($N = 19{,}382$ patients with 38,764 surgeries)		*p* value
	N	%	*N*	%	
Discharge status					
Home/home health	12,232	63.1	33,499	86.42	< 0.0001
Short-term hospital	81	0.4	40	0.10	
Transfer to other, SNF	7038	36.3	5179	13.36	
Other	30	0.2	232	0.60	
Missing	*	*	*	*	
Length of stay (days)	5.0	4.7	4.5	3.5	< 0.0001
Total cost 2019	$28,196	$18,488	$33,202	$15,240	< 0.0001
Periprosthetic fracture	26	0.13	31	0.08	**0.0491**
Non-mechanical complications	**6543**	**33.76**	**6177**	**15.93**	**< 0.0001**
Postoperative shock	*	*	*	*	0.1573
Hematoma/seroma	22	0.11	20	0.05	**0.0088**
Wound dehiscence	16	0.08	16	0.04	**0.0454**
Infection	**219**	**1.13**	**194**	**0.50**	**< 0.0001**
Postoperative infection	14	0.07	*	*	**0.0005**
Infection/inflammatory reaction	0	0.00	0	0.00	N.A
Urinary tract infection	206	1.06	188	0.48	**< 0.0001**
Cellulitis/abscess	0	0.00	0	0.00	N.A
Acute posthemorrhagic anemia	4968	25.63	4218	10.88	**< 0.0001**
Pulmonary embolism and infarction	0	0.00	0	0.00	N.A
Lower extremity DVT	76	0.39	31	0.08	**< 0.0001**
Pulmonary insufficiency	0	0.00	0	0.00	N.A
Transfusion of blood and products	1401	7.23	433	1.12	**< 0.0001**
System wise unspecified complication					
Central nervous system	63	0.33	70	0.18	**0.0006**
Cardiac	1789	9.23	2157	5.56	**< 0.0001**
Peripheral vascular	0	0.00	0	0.00	N.A
Respiratory	104	0.54	60	0.15	**< 0.0001**
Gastrointestinal	72	0.37	29	0.07	**< 0.0001**
Genitourinary	36	0.19	30	0.08	**0.0003**
Other organ-specific complications	0	0.00	0	0.00	N.A

Statistically significant values are in bold

* Values <11 were deidentified per database use regulations

rates of system-specific complications, including the central nervous (0.33% vs. 0.18%; $p=0.0006$), cardiac (9.23% vs. 5.56%; $p<0.0001$), respiratory (0.54% vs. 0.15%; $p<0.0001$), gastrointestinal (0.37% vs. 0.07%; $p<0.0001$), and genitourinary (0.19% vs. 0.08%; $p=0.0003$) systems.

Net in-hospital costs associated with simultaneous versus staged BTKA

Compared to the combined in-hospital costs of the two surgical episodes comprising the staged BTKA, the mean cost of a single surgical episode of simultaneous BTKA was $5006 less (simultaneous BTKA: $28,196 ± 18,488 vs. staged BTKA: $33,202 ± 15,240; $p<0.0001$; Table 3).

Discussion

The safety, efficacy, and cost differential of performing BTKA in a single-episode as opposed to 2 staged procedures has been extensively debated [4, 20–22]. The use of simultaneous BTKA gained initial momentum owing to its elimination of a second surgery with the associated re-hospitalization, anesthesia, and recovery duration [10, 11, 23]. However, emerging evidence of simultaneous BTKA's higher risk profile compared to unilateral TKA prompted surgeons to reassess its utility and value [17]. The present study utilized an extensive nationwide propensity score-matched sample and found that simultaneous BTKA exhibited longer LOS, higher rates of non-home discharge, intra-/perioperative periprosthetic fractures, and in-hospital non-mechanical complications including hematoma/seromas wound dehiscence, infection, and system-specific complications compared to both surgical episodes of staged BTKA combined.

Contemporary investigations question the safety of simultaneous BTKA. Warren et al. [17] retrospectively analyzed 30-day mortality and any complications using a cohort of 8291 patients who underwent bilateral TKA matched 1:1 by morbidity probability with a unilateral TKA control cohort ($n=315,219$). The authors found that BTKA was associated with higher risk for all complications [odds ratio (OR): 3.58, 95% confidence interval (CI): 3.22–3.9; $p<0.001$] and major complications (OR: 2.02, 95% CI: 1.66–2.47; $p<0.001$) versus unilateral TKA regardless of health status. Furthermore, the incidence of mortality in unilateral TKA varied from 0.0% in the first quartile of comorbidity burden (least comorbidities) to 0.2% in the fourth quartile of comorbidity burden (highest comorbidities), while in simultaneous BTKA, it varied from < 0.1% in the first quartile to 0.2% in the fourth quartile. Similarly, Tsay et al. [5] analyzed 27,301 simultaneous and 45,419 staged BTKA patients from national discharge hospital data between 2005 and 2014 and found that simultaneous BTKA was associated with higher odds of mortality (OR: 1.36; 95% CI: 1.06–1.75; $p=0.015$), myocardial infarction (OR: 2.74, 95% CI: 2.15–3.49; $p<0.001$), ischemic stroke (OR: 2.33, 95% CI: 1.64–3.3); $p<0.001$, cardiac complications (OR: 1.34; 95% CI: 1.16–1.55; $p<0.001$), respiratory complications (OR: 1.26; 95% CI: 1.02–1.55; $p=0.034$), digestive complications (OR: 1.91; 95% CI: 1.65–2.2; $p<0.001$), urinary complications (OR: 1.37; 95% CI: 1.15–1.63; $p<0.001$), hematoma formation (OR: 0.58; 95% CI: 0.47–0.7; $p<0.001$) as well as deep infection (OR: 0.71; 95% CI: 0.6–0.85; $p<0.001$) and major mechanical complications (OR: 0.75; 95% CI: 0.58–0.98; $p=0.036$) up to one-year postoperatively. These findings were evident despite the better baseline health status of simultaneous BTKA recipients compared to their staged BTKA counterparts. Liu et al. [4] conducted recent systematic review of 18 studies comparing simultaneous ($n=73,617$) staged ($n=61,838$) BTKA. The authors found that simultaneous BTKA was associated with increased mortality (OR: 1.41; 95% CI: 1.10–1.80; $p=0.006$), pulmonary embolism (OR: 1.39; 95% CI: 1.16–1.67; $p<0.001$), and deep vein thrombosis (OR: 1.21; 95% CI: 1.06–1.39; $p=0.006$) compared with staged BTKA. Notably, a stark limitation common to the aforementioned reports is the use of unilateral TKA (isolated unilateral or only the second surgical episode of the staged BTKA process) as a benchmark that is representative of staged BTKA. The present study's findings demonstrate added value and increased safety with staged BTKA. As such, an approach that involved pre-planned staged procedures or one that addresses the more severely affected knee followed by a delayed "as-needed" intervention for a less severely impacted contralateral joint may be reasonable. The latter approach may be particularly feasible among bilateral knee osteoarthritis with substantially dissimilar involvement of both joints; a pattern frequently encountered in clinical settings. Indeed, among patients with dissimilar bilateral joint involvement, performing simultaneous BTKA routinely may promote potentially premature or even unnecessary contralateral TKA in up to 60% of patients. Therefore, future investigations are required to outline appropriate use criteria for performing simultaneous BTKA. Such criteria should account for extent of joint degeneration, pain/functional limitations, and patients' comorbidity burden.

The present study found approximately a $5000 cost savings with simultaneous BTKA, which may be explained by the need for a single surgical episode compared to 2 discrete hospitalizations and surgical episodes with staged BTKA. However, this number does not account for the additional costs of non-home discharge (costs associated with residing in a skilled nursing facility or post-discharge institutional healthcare), which was found to be significantly higher among simultaneous BTKA recipients.

Indeed, discharge to a skilled nursing facility has been shown to incur an average cost of $6620 as opposed to $3709 and $3241 for discharge to home and home health and home, respectively [24]. In addition, the cost differential demonstrated in the current study does not consider the additional management expenses, nor those incurred from readmission and/or reoperation secondary to postoperative complications. Notably, in a recent study by Kahlenberg et al. [25], the authors demonstrated significantly fewer total days of missed work for employed patients (17 fewer days of total missed work) with simultaneous BTKA as opposed to bilateral TKA in a staged fashion. As cost-effective high-value care provision is becoming a tenet of the U.S. healthcare system, future prospective investigations may be warranted to analyze the financial implications of both surgeries while accounting for the multitude of peri- and postoperative expenses and sources of lost income [26–28].

There are several limitations to the current investigation. First, the retrospective nature of our database study confers some selection biases. However, given the large sample size and data from patients nationwide, coupled with the propensity score matching process performed to eliminate differences between cohorts, we anticipate that these biases are unlikely to impact the study's findings. Notably, given the large sample size, some findings may demonstrate statistical significance despite having limited clinical relevance. The present study leveraged nationwide data from the National Readmissions Database (NRD) [29]. Patient records in this dataset are matched by linkage numbers associated with each episode of care and provide up to one year follow-up. Therefore, the present study was limited to capturing hospitalizations only up to one year following the index procedure, and repeat hospitalizations beyond this timeframe may be missed. Finally, the present study did not analyze differences in patient-reported outcomes, functional or pain scores, thus comparing only discharge state, complication profile, and cost associated with stage bilateral versus simultaneous TKA. However, we aimed to highlight multiple important complications occurring at significantly higher rates with simultaneous bilateral TKA compared to staged TKA as well as cost comparison between staged versus simultaneous bilateral TKA.

Simultaneous BTKA is associated with a higher risk profile than staged BKTA. Specifically, the simultaneous bilateral procedures confer higher healthcare utilization and in-hospital complications than both episodes of staged BTKA combined. Total in-hospital costs are higher in staged BTKA owing to the need for two discrete hospitalizations and surgical episodes. However, such cost differential may be offset by simultaneous BTKA's post-discharge expenses, evidenced by its higher non-home discharge and overall complication rates. Therefore, simultaneous BTKA should be considered as the exception rather than the rule. Further prospective investigations are warranted to investigate the net cost differential between both surgeries while accounting for post-discharge expenses, rehabilitation cost, and the value of missed workdays (missed income).

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Declarations

Conflict of interest *AKE, ME, AKK, GJ, and SK* have nothing to disclose. *NSP* has the following disclosures, none of which are related to the topic of the present study: American Association of Hip and Knee Surgeons: Board or committee member. ISCT: Board or committee member. Journal of Hip Surgery: Editorial or governing board. Journal of Knee Surgery: Editorial or governing board. Orthopaedic Research Society: Board or committee member. Regeneron: Paid consultant. RegenLab: Research support. Stryker: Paid consultant. Zimmer: Research support. *RMM* has the following disclosures none of which are related to the topic of the present study: American Association of Hip and Knee Surgeons: Board or committee member. Stryker: Paid consultant; Paid presenter or speaker; Research support. Zimmer: Research support.

Ethical statement The present study utilized a publicly available deidentified database; therefore, institutional review board approval was not required. All research activities conformed to the Helsinki Accord (1964) and all subsequent amendments.

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