A Population-Based Comparison of the Incidence of Adverse Outcomes After Simultaneous-Bilateral and Staged-Bilateral Total Knee Arthroplasty

John P. Meehan, MD, Beate Danielsen, PhD, Daniel J. Tancredi, PhD, Sunny Kim, PhD, Amir A. Jamali, MD, and Richard H. White, MD

Investigation performed at the University of California, Davis, School of Medicine, Sacramento, California

Background: It is unclear whether simultaneous-bilateral total knee arthroplasty is as safe as staged-bilateral arthroplasty is. We are aware of no randomized trials comparing the safety of these surgical strategies. The purpose of this study was to retrospectively compare these two strategies, with use of an intention-to-treat approach for the staged-bilateral arthroplasty cohort.

Methods: We used linked hospital discharge data to compare the safety of simultaneous-bilateral and staged-bilateral knee arthroplasty procedures performed in California between 1997 and 2007. Estimates were generated to take into account patients who had planned to undergo staged-bilateral arthroplasty but never underwent the second procedure because of death, a major complication, or elective withdrawal. Hierarchical logistic regression modeling was used to adjust the comparisons for patient and hospital characteristics. The principal outcomes of interest were death, a major complication involving the cardiovascular system, and a periprosthetic knee infection or mechanical malfunction requiring revision surgery.

Results: Records were available for 11,445 simultaneous-bilateral arthroplasty procedures and 23,715 staged-bilateral procedures. On the basis of an intermediate estimate of the number of complications that occurred after the first procedure in a staged-bilateral arthroplasty, patients who underwent simultaneous-bilateral arthroplasty had a significantly higher adjusted odds ratio (OR) of myocardial infarction (OR = 1.6, 95% confidence interval [CI] = 1.2 to 2.2) and of pulmonary embolism (OR = 1.4, 95% CI = 1.1 to 1.8), similar odds of death (OR = 1.3, 95% CI = 0.9 to 1.9) and of ischemic stroke (OR = 1.0, 95% CI = 0.6 to 1.6), and significantly lower odds of major joint infection (OR = 0.6, 95% CI = 0.5 to 0.7) and of major mechanical malfunction (OR = 0.7, 95% CI = 0.6 to 0.9) compared with patients who planned to undergo staged-bilateral arthroplasty. The unadjusted thirty-day incidence of death or a coronary event was 3.2 events per thousand patients higher after simultaneous-bilateral arthroplasty than after staged-bilateral arthroplasty, but the one-year incidence of major joint infection or major mechanical malfunction was 10.5 events per thousand lower after simultaneous-bilateral arthroplasty.

Conclusions: Simultaneous-bilateral total knee arthroplasty was associated with a clinically important reduction in the incidence of periprosthetic joint infection and malfunction within one year after arthroplasty, but it was associated with a moderately higher risk of an adverse cardiovascular outcome within thirty days. If patients who are at higher risk for cardiovascular complications can be identified, simultaneous-bilateral knee arthroplasty may be the preferred surgical strategy for the remaining lower-risk patients.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

It has been estimated that over 9 million adults in the United States have symptomatic knee osteoarthritis[1]. In 2007, 611,000 total knee arthroplasties were performed in the United States[2]; approximately 7% of these were simultaneous-bilateral procedures (both arthroplasties were performed during the same surgical session), and 15% of the operations were

Disclosure: One or more of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of an aspect of this work. In addition, one or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

staged-bilateral procedures (two sequential arthroplasties performed within the twelve-month period)[3]. It has been predicted that by 2030 over 3.4 million total knee arthroplasty operations will be performed each year, a 456% increase[2]. The resulting strain on hospitals might be dramatically reduced if the number of hospitalizations and operating room sessions associated with these knee arthroplasties could be reduced by performing more simultaneous-bilateral total knee arthroplasty procedures.

Although a patient with symptomatic bilateral knee osteoarthritis can be treated by replacing both knees during a single operative session, it is unclear whether this is as safe as performing the second arthroplasty procedure only after the patient has recovered from the first procedure. The authors of several studies have attempted to compare the incidence of complications after simultaneous-bilateral total knee arthroplasty and after staged-bilateral total knee arthroplasty with those after unilateral total knee arthroplasty[4-6]. In a meta-analysis, simultaneous-bilateral total knee arthroplasty was reported to be associated with a two-fold greater risk of serious cardiac complications, pulmonary complications, and mortality compared with a single unilateral total knee arthroplasty[7]. Another study suggested that the overall incidence of complications might be lower after simultaneous-bilateral total knee arthroplasty than after staged-bilateral arthroplasty[8]. However, we are aware of no randomized trials comparing the safety of these surgical strategies.

The aim of the present study was to retrospectively compare the incidence of early cardiovascular complications and death as well as the one-year incidence of revision arthroplasty due to a major joint infection or mechanical malfunction in patients who underwent simultaneous-bilateral total knee arthroplasty and patients who underwent staged-bilateral total knee arthroplasty.

Materials and Methods

Study Design

The study involved a retrospective analysis of a large administrative database of hospital discharge data. The study was approved by the University of California Davis Human Subjects Committee and by the State of California Committee for the Protection of Human Subjects.

TABLE I Clinical Characteristics of the Arthroplasty Cohorts

	Unilateral (N = 169,125)		Simultaneous-Bilateral (N = 11,445)		Staged-Bilateral (N = 23,715)*	
Risk Factor	No.	%	No.	%	No.	%
Patient age in yr†						
<50	7048	4.2	339	3.0	689	2.9
50-64	47,602	28.1	3953	34.5	7740	32.6
65-74	60,761	35.9	4528	39.6	9295	39.2
≥75	53,714	31.8	2625	22.9	5991	25.3
Male sex	64,282	38.0	5280	46.1	9171	38.7
Race/ethnicity						
Non-Hispanic white	128,932	76.2	9229	80.6	17,650	74.4
Hispanic	22,364	13.2	1067	9.3	3370	14.2
Black	8377	5.0	386	3.4	1056	4.5
Asian or Pacific Islander	5171	3.1	427	3.7	990	4.2
Payer						
Private insurance	42,159	24.9	3913	34.2	6795	28.7
Medicaid	4583	2.7	259	2.3	895	3.8
Medicare	88,523	52.3	5585	48.8	12,066	50.9
Health maintenance organization	73,167	43.3	5430	47.4	11,003	46.4
Chronic comorbidity						
Diabetes with no complications	25,860	15.3	1381	12.1	3779	15.9
Diabetes with complications	3077	1.8	156	1.4	406	1.7
Chronic obstructive pulmonary disease	23,153	13.7	1323	11.6	3061	12.9
Congestive heart failure	5625	3.3	250	2.2	799	3.4
Morbid obesity	25,801	15.3	1923	16.8	5077	21.4
Chronic liver disease	1896	1.1	110	1.0	271	1.1
Chronic renal failure	1856	1.1	106	0.9	256	1.1

*Patients who underwent two knee arthroplasties within a one-year period. †The mean patient age was 68.6 years in the unilateral cohort, 67.2 years in the simultaneous-bilateral cohort, and 67.7 years in the staged-bilateral cohort.

To make a fair comparison of the outcomes after simultaneous-bilateral total knee arthroplasty and after sequential staged-bilateral total knee arthroplasty, a number of sources of bias were addressed. We specifically accounted for patients who had planned to undergo staged-bilateral total knee arthroplasty but did not undergo the second arthroplasty because of death, a serious medical complication or major orthopaedic complication, or an elective decision to forego the second procedure.

The flow diagram in Figure 1 outlines the methods and steps used to assemble the cohort of patients who had planned to undergo staged-bilateral arthroplasty (the "planned-staged" cohort) that was compared with the simultaneous-bilateral arthroplasty cohort. The number of patients in the planned-staged cohort was set equal to the sum of three quantities: (1) the number of patients who successfully completed both arthroplasties, (2) the number of patients who electively declined the planned second arthroplasty (estimated to be between 10% and 20% of the total on the basis of previous studies[9-11]), and (3) the number of patients who died within thirty days or experienced a major complication after the first arthroplasty. The methods that were used to estimate the number of deaths and specific complications after the first stage of the staged-bilateral arthroplasty are described in detail below.

Inclusion Criteria

We used the California Patient Discharge database, which has been extensively described elsewhere[12,13]. This database uses ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) coding to list the diagnoses and procedures for all patients admitted to every California public hospital. Hospital records for an individual patient, as well as death records, can be linked in series with use of an encrypted social security number. This linkage allowed late complications to be identified even if the patient was treated at a different hospital.

Linked records for all patients who underwent at least one primary total knee arthroplasty (ICD-9-CM code 81.54) between January 1, 1997, and December 31, 2007, were identified. Patients who had had a prior primary total knee arthroplasty or revision total knee arthroplasty (81.55) between 1991 and 1996 were excluded, as were patients whose records indicated the presence of a prosthetic knee (V43.65), thus minimizing the likelihood of including patients who were undergoing a second primary total knee arthroplasty. Patients coded as having cancer (190-209) or a rheumatic disease (714, 710, or 696) were also excluded.

Patients identified as having undergone simultaneous-bilateral total knee arthroplasty had to have had two primary total knee arthroplasty procedure codes entered on the same day, as required by discharge coding rules. Patients identified as having undergone staged-bilateral total knee arthroplasty had to have had two primary total knee arthroplasty procedure codes entered within 365 days, with or without an intervening revision total knee arthroplasty (00.80-00.85, 81.22, or 81.55). The remaining patients were identified as having undergone a unilateral total knee arthroplasty, and these patients were separated into two groups, those who had undergone only one total knee arthroplasty during the study period and those who had undergone a second total knee arthroplasty more than 365 days after the index total knee arthroplasty.

Outcome Evaluation

Sixteen unique outcomes were specified with use of corresponding ICD-9-CM codes (see Appendix). Acute medical complications evaluated during the first thirty days of surgery included death, myocardial infarction, a composite

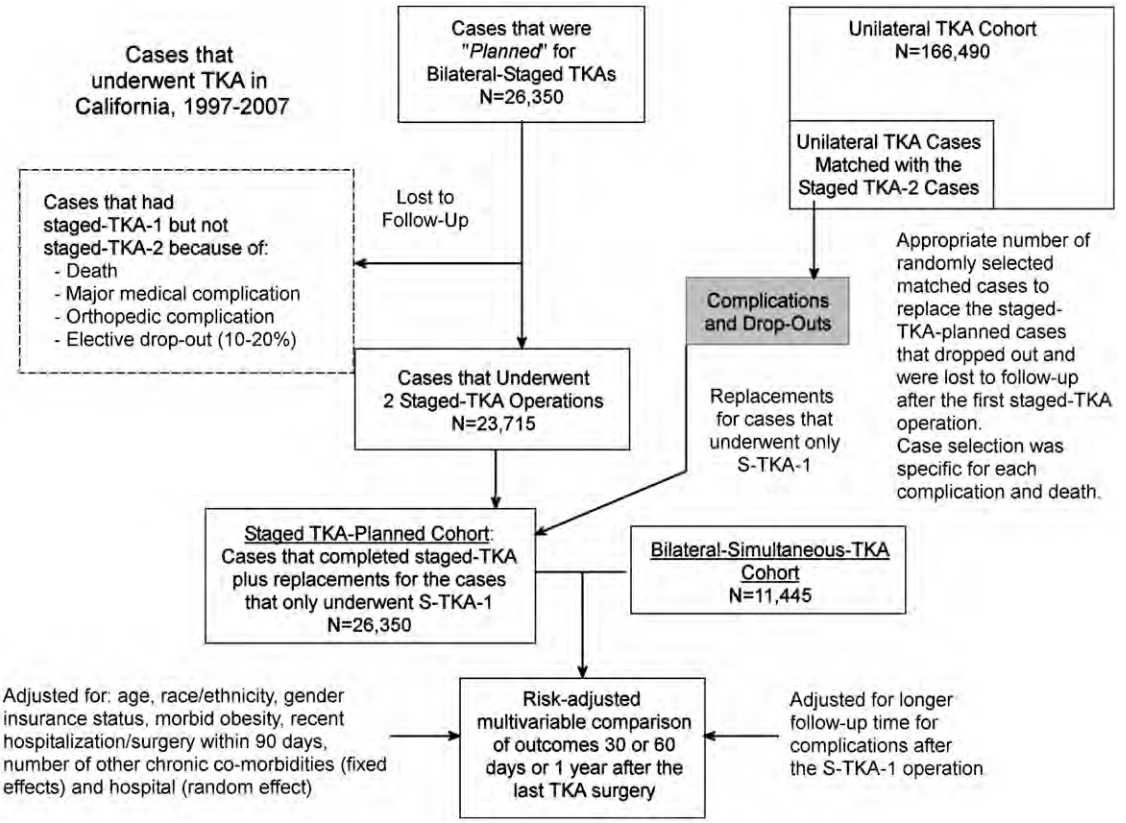


Fig. 1

Diagram depicting the assembly of the planned staged-bilateral total knee arthroplasty (S-TKA) cohort and the comparison with the simultaneous-bilateral total knee arthroplasty cohort, assuming a 10% drop-out rate. TKA-1 and TKA-2 refer to the first and second stages of the staged-bilateral procedure.

TABLE II Unadjusted Rate of Specific Complications in the Study Cohorts*

Complication	Principal Study Cohorts *(complications/1000 patients)*		
	Simultaneous-Bilateral (N = 11,445)	Planned Staged-Bilateral (Intermed. Estimate) (N = 26,350†)	Unilateral (N = 166,490)
Death (≤30 d)	3.8	3.2	2.3
Composite of coronary events (≤30 d)‡	7.1	4.6	4.7
Myocardial infarction (≤30 d)	6.1	4.1	4.2
Ischemic stroke (≤30 d)	2.5	2.6	1.5
Deep vein thrombosis (≤60 d)	8.7	8.0	5.9
Pulmonary embolism (≤60 d)	9.6	6.8	5.2
Perioperative cardiac complications	20.4	17.0	12.2
Major knee infection (≤1 yr)	8.7	16.5	8.9
With knee revision (≤1 yr)	5.3	10.7	5.2
Minor knee infection (≤1 yr)	2.4	2.5	2.0
Major mechanical malfunction (≤1 yr)	10.4	14.7	10.2
Minor mechanical malfunction (≤1 yr)	5.1	6.2	5.3
Other bacterial infection (not knee) (≤30 d)	10.4	17.9	10.5
Hematoma (≤30 d)	7.0	11.5	7.5
Respiratory complications (≤30 d)	11.5	16.5	11.0
Digestive complications (≤30 d)	21.1	13.7	11.4
Urinary complications (≤30 d)	15.2	11.7	7.7
Death or composite of coronary events (≤30 d)	10.7	7.5	6.5
Major knee infection or mechanical malfunction (≤1 y)	18.5	29.1	18.0
Death (≤30 d) or major knee infection with knee revision (≤1 yr)	9.1	13.9	7.5

*A patient in the staged cohort could have more than one complication, and could have the same complication after the first and the second arthroplasty. †Assuming 10% of patients who had planned to undergo staged-bilateral total knee arthroplasty elected to forego the second arthroplasty procedure. ‡Myocardial infarction or coronary artery bypass surgery or coronary stent placement or shock within thirty days.

coronary outcome (acute myocardial infarction, coronary angioplasty or stent implantation, coronary artery bypass surgery, or postoperative shock), ischemic stroke, other perioperative cardiac complications, respiratory complications, digestive complications, and urinary complications. Complications evaluated during the first sixty days of the total knee arthroplasty were deep-vein thrombosis and pulmonary embolism.

Minor orthopaedic complications were periprosthetic joint infection that occurred within thirty days requiring liner removal, arthrotomy, debridement, synovectomy, or other excision but not subsequent revision knee arthroplasty; and "other bacterial infections," which included osteomyelitis of the lower limb, an infected seroma, pyogenic arthritis, cellulitis of the lower limb, an infection involving the prosthesis or another device that did not require surgery, an infection caused by Staphylococcus or Pseudomonas, an infected pressure ulcer, and a urinary tract infection within thirty days.

Major orthopaedic complications included (1) a periprosthetic joint infection coupled with revision knee arthroplasty, or a periprosthetic joint infection coupled with liner removal, arthrotomy, debridement, synovectomy, or other excision more than thirty days after the arthroplasty; (2) mechanical malfunction of the prosthetic joint requiring revision arthroplasty; and (3) mechanical dysfunction of the prosthetic joint requiring either lysis of joint adhesions or manipulation of the knee under anesthesia. A major orthopaedic complication had to occur within one year after the date of the simultaneous-bilateral arthroplasty or the date of the second stage of the staged-bilateral arthroplasty.

Patients with Complications After the First Stage of a Planned Staged-Bilateral Arthroplasty

To estimate the number of patients who had an adverse outcome and dropped out after the first stage of a planned staged-bilateral total knee arthroplasty, we first generated low, intermediate, and high estimates for the death rate and the rate of each major complication after the first stage. The low estimate for each complication rate was the rate that was actually observed after the first stage of a completed staged-bilateral procedure. To generate the intermediate and the high estimate, we assembled a cohort of unilateral total knee arthroplasty patients who were matched with the patients who underwent the second stage of the staged-bilateral procedure. Each patient was matched with respect to age (within five years), sex, race and ethnicity, insurance status, the occurrence of surgery or hospitalization for other reasons within the previous ninety days, the ratio of staged-bilateral to unilateral total knee arthroplasties performed at the index hospital (by decile), calendar year (±2 years), and seven specific chronic comorbidities from the Elixhauser comorbidity index[14,15] (see Appendix). The high estimate was the rate derived from the matched unilateral arthroplasty cohort, and the intermediate estimate was set equal to 75% of the high estimate, based on the reasoning that the patients selected for two sequential total knee

TABLE II (*continued*)

Planned Staged-Bilateral Arthroplasty Cohort *(complications/1000 patients)*			
First Stage			Second Stage
High Estimate (N = 26,350†)	Intermed. Estimate (N = 26,350†)	Low Estimate = Observed (N = 23,715)	Observed (N = 23,715)
2.4	1.7	0.0	1.7
3.9	2.9	1.6	1.9
3.5	2.6	1.2	1.7
2.0	1.5	0.3	1.2
6.5	4.9	3.3	3.5
5.2	3.9	2.4	3.3
10.5	9.4	8.8	8.5
10.2	7.7	2.8	10.0
6.7	5.0	1.1	6.5
1.8	1.3	0.9	1.3
10.7	8.0	1.6	7.5
5.9	4.4	1.3	1.9
10.2	9.3	9.3	9.6
6.5	6.0	5.7	6.2
9.4	9.2	9.3	8.1
10.3	7.7	8.4	6.6
7.7	7.4	7.6	4.8
6.0	4.5	1.6	3.4
19.9	14.9	4.2	15.8
9.1	6.7	1.1	8.2

arthroplasties were likely to be healthier than the patients undergoing a unilateral arthroplasty. The number of deaths and complications after the first planned-staged operation was then obtained by multiplying the estimated complication rate by the projected size of the planned-staged cohort. The number of complications in the planned-staged cohort was the sum of the complications after each arthroplasty.

Follow-up of staged-bilateral arthroplasty patients until one year after the second stage resulted in a longer duration of follow-up for the first arthroplasty than for the second. To adjust for this bias, we used life-table methods to determine whether to assign any knee complication that occurred more than one year after the first arthroplasty but less than one year after the second to the first or the second arthroplasty; the outcomes assigned to the first arthroplasty were then excluded since they did not occur within one year of the procedure. This adjustment reduced the number of major joint infections in the planned-staged cohort by 8%, and it reduced the number of mechanical malfunctions by 17%.

Statistical Analysis

In order to perform a multivariate analysis, specific patients had to be selected to replace the patients who had planned to undergo staged-bilateral arthroplasty but never underwent the second arthroplasty. First, substitutes were selected for the patients who opted out of the planned second arthroplasty, estimated in the principal analysis to be 10% of the number of patients who successfully underwent staged arthroplasty. Next, the number of patients who dropped out because of a major complication was calculated with use of the low, intermediate, and high estimates. The number of patients who dropped out for this reason was set equal to the expected number of complications minus the observed number of complications that occurred after the first stage of the staged-bilateral procedure and before the second stage. For example, if the intermediate estimate of the rate of major mechanical failure was ten events per thousand patients, and if 20,000 patients were in the planned-staged cohort, the expected number of major mechanical failures would equal 200. If only forty cases of major mechanical failure were actually observed, an additional 160 patients with mechanical failure were selected from the unilateral arthroplasty cohort and added to the planned-staged cohort.

To select the specific unilateral arthroplasty patients to be added to the planned-staged cohort, a logistic regression model was developed that predicted the probability that a patient who had undergone a unilateral arthroplasty would undergo an arthroplasty of the contralateral knee. The parameters used in the modeling were similar to those that were used for patient matching in the complication rate estimation. The necessary number of patients was selected from the unilateral arthroplasty cohort with use of a stratified unequal-probability sampling design in which the sampling probability, or weight, for each unilateral arthroplasty patient was proportional to the patient's predicted probability of undergoing a subsequent arthroplasty. Sampling was performed in a stratified fashion by first selecting the necessary number of patients with a specific complication and then selecting the necessary number of patients without this complication.

Separate hierarchical multivariate logistic regression analyses were performed for each outcome to compare the risk in the simultaneous-bilateral cohort with that in the planned-staged cohort. The regression analyses adjusted for age, sex, race, ethnicity, insurance status, morbid obesity, surgery within the

previous ninety days, hospitalization for another reason within the previous ninety days, and the number of Elixhauser comorbidities (all treated as fixed effects) as well as for the hospital (treated as a random effect).

The incidence of major joint infection and the incidence of major malfunction of the prosthetic joint during the first two postoperative years in the unilateral arthroplasty cohort and the simultaneous-bilateral arthroplasty cohort were also calculated with use of the life-table method and compared with use of the log-rank test.

Source of Funding

This study was funded by the University of California Davis Board of Advisors; no external funding was received.

Results

Descriptive Statistics

From 1997 through 2007, 204,285 patients who met the inclusion criteria (and thus did not appear to have previously undergone total knee arthroplasty) underwent unilateral total knee arthroplasty (n = 169,125), simultaneous-bilateral total knee arthroplasty (n = 11,445), or staged-bilateral total knee arthroplasty (n = 23,715) (Table I). The mean age of the patients who underwent simultaneous-bilateral arthroplasty was similar to that of the patients who underwent staged-bilateral arthroplasty, but a higher percentage of the former group was male, white, and had private insurance. There were moderate differences in the prevalence of specific comorbidities between the staged-bilateral and the simultaneous-bilateral cohort.

Table II shows the unadjusted rate (per thousand cases) of each specific complication or combination of complications in the simultaneous-bilateral, planned-staged, and unilateral cohorts. For the planned-staged cohort, it was assumed that 10% of patients who planned to undergo staged-bilateral total knee arthroplasty elected to forego the second arthroplasty. Table II also shows the high, intermediate, and low estimates of the true complication rates in the planned-staged cohort after the first arthroplasty. The calculated intermediate estimates were similar to the complication rates that were actually observed after the second stage of the completed staged arthroplasties. The observed rate of major orthopaedic complications

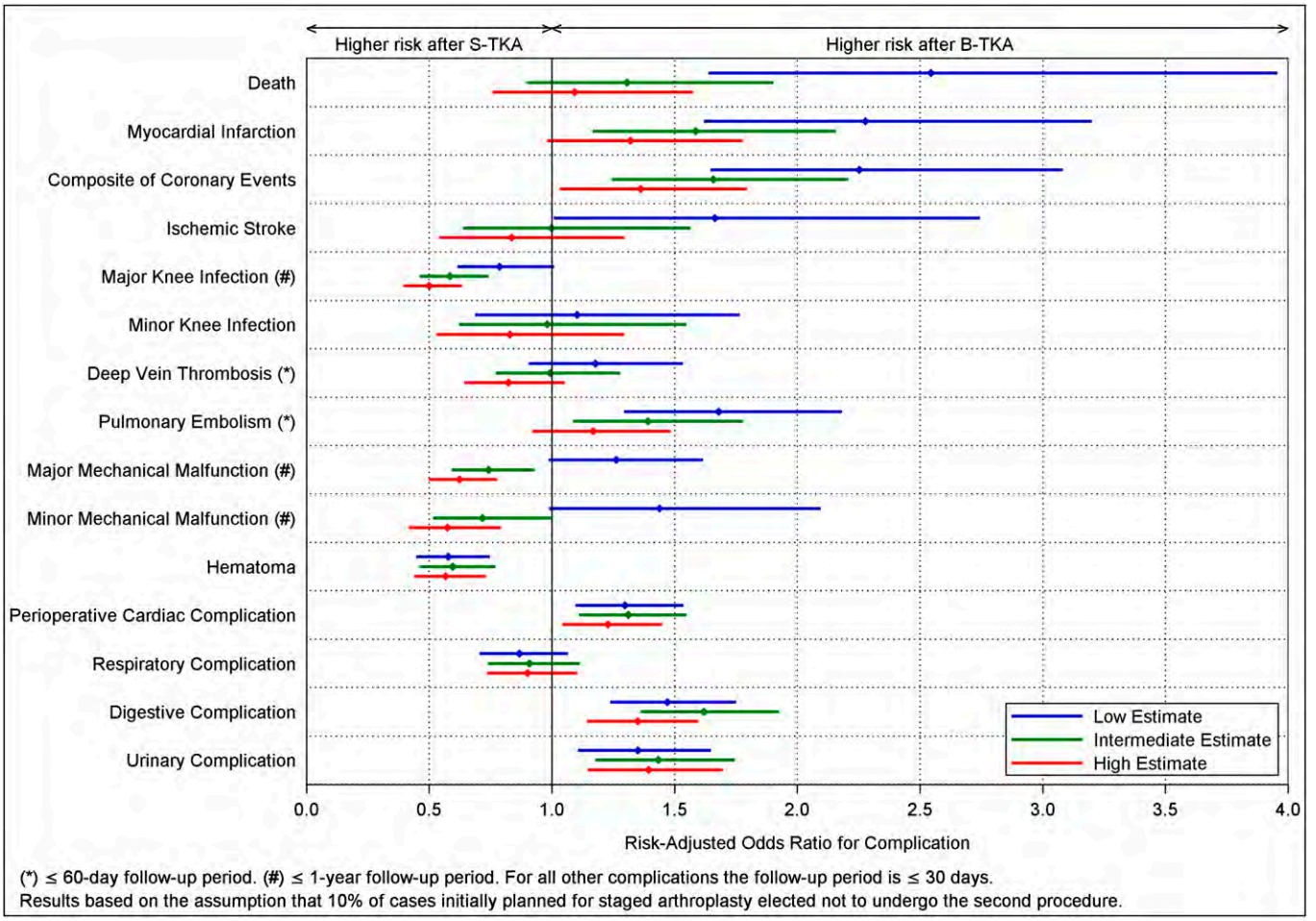


Fig. 2

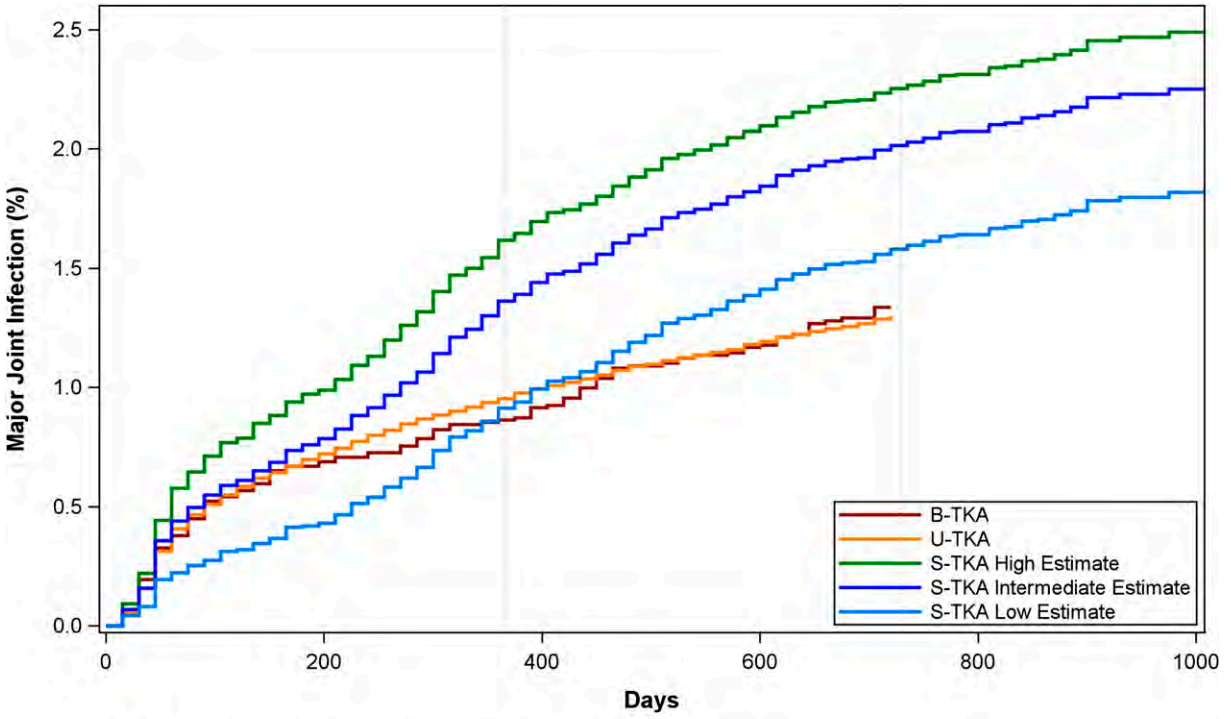
Adjusted relative odds of complications occurring during the specified time period after simultaneous-bilateral total knee arthroplasty (B-TKA) compared with staged-bilateral arthroplasty (S-TKA), assuming that 10% of the staged arthroplasty cases electively declined the second arthroplasty. The bars represent the 95% confidence interval.

among the staged-bilateral patients was higher after the second arthroplasty than after the first arthroplasty because some of the complications observed after the second arthroplasty were associated with the knee that underwent the first arthroplasty. For major orthopaedic complications, the complication rate after simultaneous-bilateral arthroplasty was similar to that after unilateral arthroplasty.

Overall, the unadjusted rate of death or an adverse coronary event (myocardial infarction, coronary artery bypass surgery, coronary stent placement, or shock) within thirty days, calculated with use of the intermediate complication rate estimate, was 3.2 events per thousand patients higher in the simultaneous-bilateral cohort than in the planned-staged cohort, but the rate of developing either a major joint infection or a major mechanical malfunction was 10.5 events per thousand lower. The unadjusted one-year rate of knee infection requiring revision arthroplasty was 5.3 per thousand patients in the simultaneous-bilateral cohort compared with 10.7 per thousand in the planned-staged cohort, again using the intermediate estimate. Death or major periprosthetic knee infection requiring revision arthroplasty occurred in 9.1 patients per thousand in the simultaneous-bilateral cohort and 13.9 per thousand in the planned-staged cohort. The risk of pulmonary embolism, a digestive complication, or a urinary complication was higher in the simultaneous-bilateral cohort, but the risk of hematoma or a respiratory complication was higher in the planned-staged cohort.

Multivariate Analysis

Figure 2 shows the odds of specific complications occurring in the simultaneous-bilateral cohort compared with the planned-staged cohort, as calculated by multivariate analysis, with use of the high, intermediate, and low (observed) estimates of the complication rates for the planned-staged cohort. Although the adjusted odds of death were significantly higher in the simultaneous-bilateral cohort than in the planned-staged cohort when the low estimate was used (odds ratio [OR] = 2.6, 95% confidence interval [CI] = 1.6 to 4.0), the risk of death was substantially less elevated when the intermediate estimate (OR = 1.3, 95% CI = 0.9 to 1.9) or the high estimate was used



B-TKA - bilateral total knee arthroplasty, performed on day 0
U-TKA – unilateral total knee arthroplasty, performed on day 0
S-TKA – staged total knee arthroplasty, first staged operation on day 0,
second staged arthroplasty within 365 days of the first arthroplasty;
for the staged arthroplasty group, follow up was two years after the second staged arthroplasty.
High estimate - based on complication rate in matched UTKA cohort
Intermediate estimate - equal to 75% of the high rate
Low estimate - equal to the observed rate after first staged arthroplasty
B-TKA versus U-TKA at 730 days, log-rank = 1.56 , P = 0.89

Fig. 3

Life-table plots of the two-year incidence of major periprosthetic joint infection requiring revision after unilateral, simultaneous-bilateral, or staged-bilateral total knee arthroplasty.

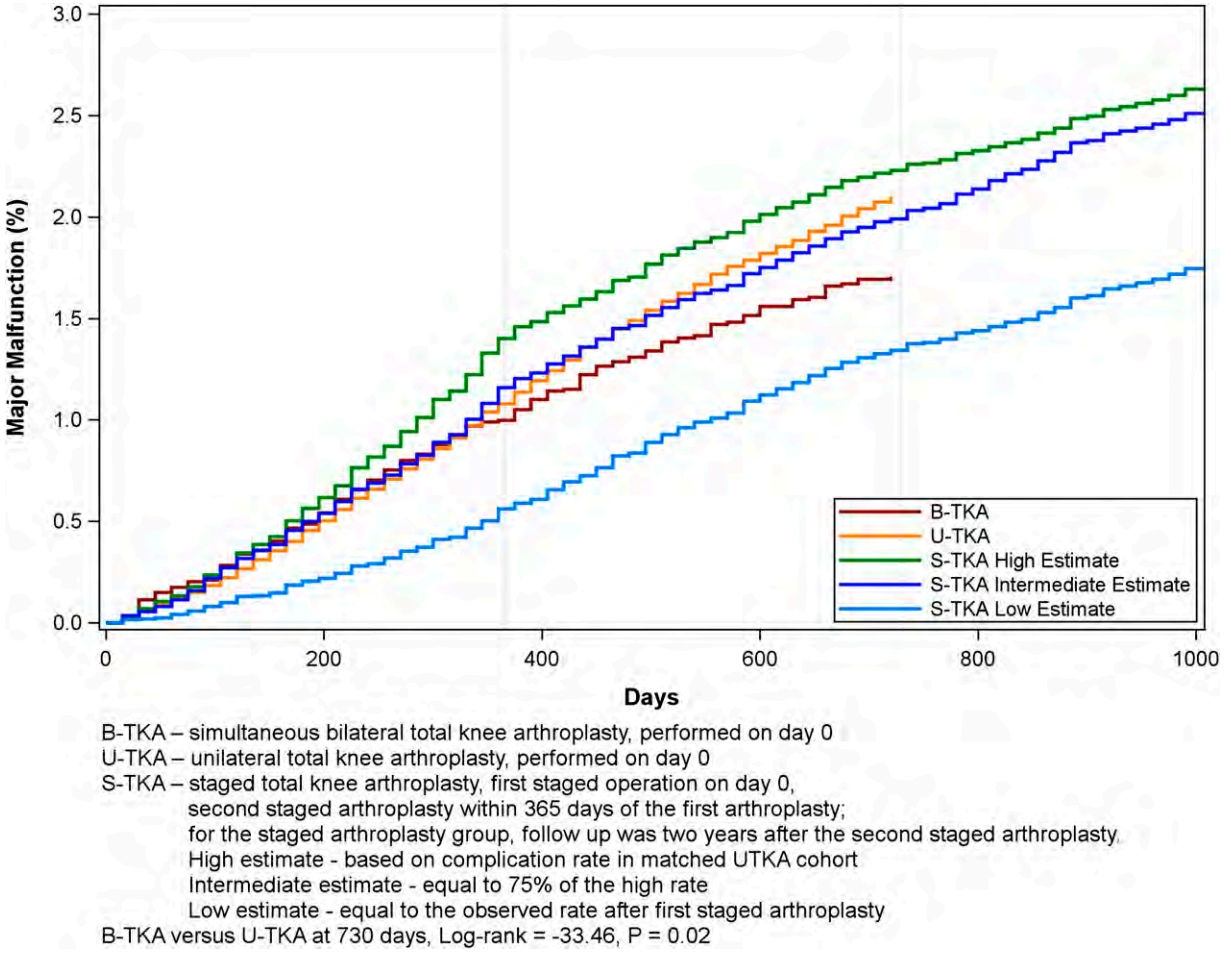


Fig. 4

Life-table plots of the two-year incidence of major mechanical malfunction requiring revision after unilateral, simultaneous-bilateral, or staged-bilateral total knee arthroplasty.

(OR = 1.1, 95% CI = 0.8 to 1.6). In a sensitivity analysis, increasing the percentage of patients who elected to forego the second stage of the planned staged-bilateral arthroplasty from 10% to 20% had a minor effect on the relative risk of dying within thirty days in the simultaneous-bilateral cohort compared with the planned-staged cohort (OR = 1.09 [95% CI = 0.8 to 1.6] for a 10% drop-out rate compared with OR = 1.14 [95% CI = 0.8 to 1.6] for a 20% drop-out rate, using the intermediate estimate for the complication rate).

Similarly, using the intermediate complication rate estimate, the simultaneous-bilateral cohort had higher risk-adjusted odds of myocardial infarction (OR = 1.6, 95% CI = 1.2 to 2.2), higher odds of a composite adverse coronary disease outcome (OR = 1.7, 95% CI = 1.2 to 2.2), higher odds of a pulmonary embolism (OR = 1.4, 95% CI = 1.1 to 1.8), and higher odds of a perioperative cardiac complication (OR = 1.3, 95% CI = 1.1 to 1.6); however, all of these relative odds were less elevated when the high estimate was used. There was no significant difference in the incidence of stroke between these cohorts when either the intermediate or the high estimate was used (OR = 1.0, 95% CI = 0.6 to 1.6).

Without adjusting for confounding influences, patients in the simultaneous-bilateral cohort were significantly less likely to develop a major periprosthetic knee infection requiring revision within one year (5.3 per thousand) than patients in the planned-staged cohort were (10.7 per thousand), using the intermediate estimate. After risk adjustment, the odds of developing such a knee infection were 40% lower in the simultaneous-bilateral cohort than in the planned-staged cohort (OR = 0.6, 95% CI = 0.5 to 0.7).

The simultaneous-bilateral cohort had a lower unadjusted rate of major mechanical malfunction (10.4 per thousand) than the planned-staged cohort did (14.7 per thousand), using the intermediate estimate, and the corresponding adjusted odds were significantly lower (OR = 0.7, 95% CI = 0.6 to 0.9). If the low (observed) estimate was used instead, the adjusted risk of major mechanical malfunction was higher in the simultaneous-bilateral cohort than in the planned-staged cohort (OR = 1.3, 95% CI = 0.99 to 1.6). There was no significant difference between these two cohorts in the adjusted risk of minor knee infection, deep-vein thrombosis, or respiratory complications with use of any of the estimates.

Figure 3 shows an unadjusted life-table plot of the incidence of major knee infection over a two-year time period in the simultaneous-bilateral, unilateral, and planned-staged cohorts. The time in the planned-staged cohort is measured from the date of the first arthroplasty, and separate plots are shown for the high, intermediate, and low complication rates estimates. Complications that were attributed to the first arthroplasty but that occurred more than two years after this arthroplasty (and still within the two-year period after the second arthroplasty) were not included. The observed unadjusted incidence of major knee infection within two years did not differ significantly between the unilateral cohort and the simultaneous-bilateral cohort (log rank = 1.56, p = 0.89).

Figure 4 shows a similar unadjusted life-table plot of the incidence of major mechanical malfunction over a two-year time period. Interestingly, the unadjusted incidence of major mechanical malfunction within two years was significantly lower in the simultaneous-bilateral cohort than in the unilateral cohort (log rank = –33.5, p = 0.02).

Discussion

The present study was designed to minimize the sources of bias inherent in a retrospective comparison of adverse outcomes after simultaneous-bilateral total knee arthroplasty compared with two sequential unilateral arthroplasties. A cohort of patients approximating those who were intended to have been treated with staged-bilateral total knee arthroplasty was assembled. After making adjustments for risk factors likely to confound a direct comparison, this cohort was compared with patients who underwent simultaneous-bilateral total knee arthroplasty.

Prior studies have indicated a significantly higher incidence of cardiovascular complications in patients who underwent simultaneous-bilateral total knee arthroplasty compared with unilateral total knee arthroplasty or with sequential staged-bilateral total knee arthroplasty[6,7,16-23]. However, these previous studies of staged-bilateral total knee arthroplasty did not take into account patients who died or experienced a major complication after the first arthroplasty, and they also did not take into account patients who electively declined the second staged arthroplasty. In our study, using an intermediate estimate of the total number of deaths after the first staged knee replacement, the number of deaths in the planned-staged cohort (3.2 per thousand) did not differ significantly from the number in the simultaneous-bilateral cohort (3.8 per thousand). However, after risk adjustment, the odds of myocardial infarction and pulmonary embolism were 60% and 40% higher, respectively, after simultaneous-bilateral arthroplasty.

There were distinct advantages and disadvantages associated with simultaneous-bilateral total knee arthroplasty. The clearest advantage was a significantly lower one-year incidence of major periprosthetic joint infection. The overall rate of serious joint infection requiring revision arthroplasty was 5.3 per thousand patients in the simultaneous-bilateral cohort compared with 10.7 per thousand in the planned-staged cohort (approximately a two-fold difference). Coupled with the finding that the unadjusted incidence of major joint infection after simultaneous-bilateral arthroplasty did not differ significantly from the incidence after unilateral arthroplasty, these findings strongly suggest that the risk of periprosthetic knee joint infection is not a function of the number of joints replaced. Instead, the risk reflects the number of times that a patient undergoing knee arthroplasty enters an operating room, which is likely to represent the main source of infection[24-26].

Prior studies have focused on the incidence of local wound infections rather than major periprosthetic infections. For example, Ritter et al. reported that surgical complications (wound infection, dehiscence, major hemorrhage, or mechanical complications) were less common after simultaneous-bilateral total knee arthroplasty than after staged-bilateral total knee arthroplasty[6]. Malinzak et al. reported that patients who underwent simultaneous-bilateral arthroplasties were three times less likely than patients who underwent staged-bilateral arthroplasties to develop a deep joint infection, but this analysis included hip and knee arthroplasties and did not adjust for other risk factors[27]. Other studies comparing simultaneous-bilateral and staged-bilateral total knee arthroplasties have indicated conflicting results; one suggested that simultaneous arthroplasties were associated with a higher risk of periprosthetic joint infections[28], whereas another indicated that they were associated with a lower risk of superficial wound infections[29].

An unexpected finding was the significantly lower one-year incidence of major mechanical failure in the simultaneous-bilateral cohort than in the planned-staged cohort. Even after risk adjustment, with use of the intermediate estimate, major mechanical failure was 26% less frequent in the simultaneous-bilateral cohort. Interestingly, the one-year incidence of major mechanical failure was 10.4 per thousand after simultaneous-bilateral total knee arthroplasty compared with 10.2 per thousand after unilateral total knee arthroplasty, and the incidence within two years was significantly lower in the simultaneous-bilateral cohort than in the unilateral cohort. Potential explanations for the lower incidence of mechanical failure after simultaneous-bilateral total knee arthroplasty than after staged-bilateral arthroplasty include a lower prevalence of morbid obesity, more intensive hospital-based physical therapy, and perhaps improved intraoperative surgical technique.

The strengths of this study include the inclusion of all patients in California who underwent total knee arthroplasty for the first time during a ten-year time period, the capability of identifying all deaths with use of a master death registry, and the capability of identifying all of the major complications that were treated at any public hospital in the state. All complications were explicitly defined with use of ICD-9-CM coding[30,31], and the major orthopaedic complication codes, which have high predictive value[32], were coupled to major procedure codes,

which are even more reliable. By using ICD-9-CM codes to define important complications, each outcome was identified in an identical fashion in both cohorts, minimizing the likelihood that miscoding biased the findings. Important outcomes, particularly the incidence of death[6,33] and of major periprosthetic joint infection after unilateral total knee arthroplasty[34-36], were comparable with published rates. Most importantly, we estimated the number of complications among patients for whom staged-bilateral total knee arthroplasty was the intended treatment.

The limitations of this study include the retrospective design, the reliance on administrative data, the inability to account for the effect of individual surgeons, and the absence of measures that could characterize the severity of the nonfatal complications. Also, we could not adjust for potential confounders such as the severity of the joint disease, the use of perioperative medications, and the type, timing of administration, or duration of antibacterial prophylaxis.

In conclusion, compared with staged-bilateral total knee arthroplasty, simultaneous-bilateral total knee arthroplasty was associated with a notable reduction in the incidence of periprosthetic knee infection and mechanical failure. Because infection is now recognized as the leading cause of revision knee arthroplasty[37-39], the need to develop strategies to minimize the substantial patient morbidity and economic cost associated with this complication is paramount[40,41]. Simultaneous-bilateral total knee arthroplasty was associated with a moderately higher risk of adverse cardiovascular outcomes within thirty days compared with staged-bilateral arthroplasty, but if patients who are at higher risk for cardiovascular complications can be identified, simultaneous-bilateral knee arthroplasty may be the preferred surgical strategy for the remaining lower-risk patients.

Appendix

eA A table showing the ICD-9-CM codes used to define the specified outcomes after total knee arthroplasty is available with the online version of this article as a data supplement at jbjs.org. ■

John P. Meehan, MD
Department of Orthopedic Surgery,
University of California, Davis,
2801 K Street, Suite 310, Sacramento, CA 95816

Sunny Kim, PhD
University of California, Davis, CTSC Annex,
Room 1117, 2921 Stockton Boulevard,
Sacramento, CA 95817

Amir A. Jamali, MD
Joint Preservation Institute, 2825 J Street #440,
Sacramento, CA 95816

Beate Danielsen, PhD
Health Information Solutions, 2545 Clubhouse Drive,
Rocklin, CA 95765

Daniel J. Tancredi, PhD
Center for Healthcare Policy and Research,
2103 Stockton Boulevard, Suite 2224,
Sacramento, CA 95817

Richard H. White, MD
Department of Medicine, University of California,
Davis, Suite 2400, PSSB, 4150 V Street,
Sacramento, CA 95817

References

1. Jacobs J, Andersson G, Bell J, Weinstein S, Dormans JP, Gnatz SM, Furman M, Lane N, Puzas J, Clair E. United States Bone and Joint Decade: the burden of musculoskeletal diseases in the United States. Rosemont, IL: American Academy of Orthopaedic Surgery;2008.

2. Levit K, Wier L, Stranges E, Ryan K, Elixhauser A. HCUP facts and figures: statistics on hospital-based care in the United States 2007. http://www.hcup-us.ahrq.gov/reports/factsandfigures/2007/exhibit3_1.jsp. Accessed 2011 Mar 17.

3. Barrett J, Baron JA, Losina E, Wright J, Mahomed NN, Katz JN. Bilateral total knee replacement: staging and pulmonary embolism. J Bone Joint Surg Am. 2006;88:2146–51.

4. Jankiewicz JJ, Sculco TP, Ranawat CS, Behr C, Tarrentino S. One-stage versus 2-stage bilateral total knee arthroplasty. Clin Orthop Relat Res. 1994;309:94–101.

5. Morrey BF, Adams RA, Ilstrup DM, Bryan RS. Complications and mortality associated with bilateral or unilateral total knee arthroplasty. J Bone Joint Surg Am. 1987;69:484–8.

6. Ritter M, Mamlin LA, Melfi CA, Katz BP, Freund DA, Arthur DS. Outcome implications for the timing of bilateral total knee arthroplasties. Clin Orthop Relat Res. 1997;345:99–105.

7. Restrepo C, Parvizi J, Dietrich T, Einhorn TA. Safety of simultaneous bilateral total knee arthroplasty. A meta-analysis. J Bone Joint Surg Am. 2007;89:1220–6.

8. Memtsoudis SG, González Della Valle A, Besculides MC, Gaber L, Sculco TP. In-hospital complications and mortality of unilateral, bilateral, and revision TKA: based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res. 2008;466:2617–27.

9. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KD. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not?. Clin Orthop Relat Res. 2010;468:57–63.

10. Chesworth BM, Mahomed NN, Bourne RB, Davis AM. OJRR Study Group. Willingness to go through surgery again validated the WOMAC clinically important difference from THR/TKR surgery. J Clin Epidemiol. 2008;61:907–18.

11. Nilsdotter AK, Toksvig-Larsen S, Roos EM. Knee arthroplasty: are patients' expectations fulfilled? A prospective study of pain and function in 102 patients with 5-year follow-up. Acta Orthop. 2009;80:55–61.

12. White RH, Romano PS, Zhou H, Rodrigo J, Bargar W. Incidence and time course of thromboembolic outcomes following total hip or knee arthroplasty. Arch Intern Med. 1998;158:1525–31.

13. Parker JP, Li Z, Damberg CL, Danielsen B, Carlisle DM. Administrative versus clinical data for coronary artery bypass graft surgery report cards: the view from California. Med Care. 2006;44:687–95.

14. Health Care Utilization Project. Comorbidity Software, Version 3.6. 2011. http://www.hcup-us.ahrq.gov/toolssoftware/comorbidity/comorbidity.jsp. Accessed 2011 Mar 17

15. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care 1998;36:8–27.

16. Bullock DP, Sporer SM, Shirreffs TG Jr. Comparison of simultaneous bilateral with unilateral total knee arthroplasty in terms of perioperative complications. J Bone Joint Surg Am. 2003;85:1981–6.

17. Lane GJ, Hozack WJ, Shah S, Rothman RH, Booth RE Jr, Eng K, Smith P. Simultaneous bilateral versus unilateral total knee arthroplasty. Outcomes analysis. Clin Orthop Relat Res. 1997;345:106–12.

18. Leonard L, Williamson DM, Ivory JP, Jennison C. An evaluation of the safety and efficacy of simultaneous bilateral total knee arthroplasty. J Arthroplasty. 2003;18:972–8.

19. Memtsoudis SG, Ma Y, González Della Valle A, Mazumdar M, Gaber-Baylis LK, MacKenzie CR, Sculco TP. Perioperative outcomes after unilateral and bilateral total knee arthroplasty. Anesthesiology. 2009;111:1206–16.

20. Pavone V, Johnson T, Saulog PS, Sculco TP, Bottner F. Perioperative morbidity in bilateral one-stage total knee replacements. Clin Orthop Relat Res. 2004;421:155–61.

21. Stefánsdóttir A, Lidgren L, Robertsson O. Higher early mortality with simultaneous rather than staged bilateral TKAs: results from the Swedish Knee Arthroplasty Register. Clin Orthop Relat Res. 2008;466:3066–70.

22. Yoon HS, Han CD, Yang IH. Comparison of simultaneous bilateral and staged bilateral total knee arthroplasty in terms of perioperative complications. J Arthroplasty. 2010;25:179–85.

23. Oakes DA, Hanssen AD. Bilateral total knee replacement using the same anesthetic is not justified by assessment of the risks. Clin Orthop Relat Res. 2004; 428:87–91.

24. Babkin Y, Raveh D, Lifschitz M, Itzchaki M, Wiener-Well Y, Kopuit P, Jerassy Z, Yinnon AM. Incidence and risk factors for surgical infection after total knee replacement. Scand J Infect Dis. 2007;39:890–5.

25. Gordon SM, Culver DH, Simmons BP, Jarvis WR. Risk factors for wound infections after total knee arthroplasty. Am J Epidemiol. 1990;131:905–16.

26. Lazzarini L, Pellizzer G, Stecca C, Viola R, de Lalla F. Postoperative infections following total knee replacement: an epidemiological study. J Chemother. 2001; 13:182–7.

27. Malinzak RA, Ritter MA, Berend ME, Meding JB, Olberding EM, Davis KE. Morbidly obese, diabetic, younger, and unilateral joint arthroplasty patients have elevated total joint arthroplasty infection rates. J Arthroplasty. 2009;24(6 Suppl): 84–8.

28. Pulido L, Ghanem E, Joshi A, Purtill JJ, Parvizi J. Periprosthetic joint infection: the incidence, timing, and predisposing factors. Clin Orthop Relat Res. 2008;466: 1710–5.

29. Ritter MA, Harty LD, Davis KE, Meding JB, Berend M. Simultaneous bilateral, staged bilateral, and unilateral total knee arthroplasty. A survival analysis. J Bone Joint Surg Am. 2003;85:1532–7.

30. Birman-Deych E, Waterman AD, Yan Y, Nilasena DS, Radford MJ, Gage BF. Accuracy of ICD-9-CM codes for identifying cardiovascular and stroke risk factors. Med Care. 2005;43:480–5.

31. White RH, Garcia M, Sadeghi B, Tancredi DJ, Zrelak P, Cuny J, Sama P, Gammon H, Schmaltz S, Romano PS. Evaluation of the predictive value of ICD-9-CM coded administrative data for venous thromboembolism in the United States. Thromb Res. 2010;126:61–7.

32. Bozic KJ, Chiu VW, Takemoto SK, Greenbaum JN, Smith TM, Jerabek SA, Berry DJ. The validity of using administrative claims data in total joint arthroplasty outcomes research. J Arthroplasty. 201025(6 Suppl):58–61.

33. Parvizi J, Sullivan TA, Trousdale RT, Lewallen DG. Thirty-day mortality after total knee arthroplasty. J Bone Joint Surg Am. 2001;83:1157–61.

34. Furnes O, Espehaug B, Lie SA, Vollset SE, Engesaeter LB, Havelin LI. Failure mechanisms after unicompartmental and tricompartmental primary knee replacement with cement. J Bone Joint Surg Am. 2007;89:519–25.

35. Huotari K, Agthe N, Lyytikäinen O. Validation of surgical site infection surveillance in orthopedic procedures. Am J Infect Control. 2007;35:216–21.

36. Jämsen E, Varonen M, Huhtala H, Lehto MU, Lumio J, Konttinen YT, Moilanen T. Incidence of prosthetic joint infections after primary knee arthroplasty. J Arthroplasty. 2010;25:87–92.

37. Bozic KJ, Kurtz SM, Lau E, Ong K, Chiu V, Vail TP, Rubash HE, Berry DJ. The epidemiology of revision total knee arthroplasty in the United States. Clin Orthop Relat Res. 2010;468:45–51.

38. Kurtz SM, Lau E, Schmier J, Ong KL, Zhao K, Parvizi J. Infection burden for hip and knee arthroplasty in the United States. J Arthroplasty. 2008;23:984–91.

39. Kurtz SM, Ong KL, Lau E, Bozic KJ, Berry D, Parvizi J. Prosthetic joint infection risk after TKA in the Medicare population. Clin Orthop Relat Res. 2010;468:52–6.

40. Hellmann M, Mehta SD, Bishai DM, Mears SC, Zenilman JM. The estimated magnitude and direct hospital costs of prosthetic joint infections in the United States, 1997 to 2004. J Arthroplasty. 2010;25:766–71.e1.

41. Parvizi J, Pawasarat IM, Azzam KA, Joshi A, Hansen EN, Bozic KJ. J Periprosthetic joint infection: the economic impact of methicillin-resistant infections. J Arthroplasty. 2010;25(6 Suppl):103–7.