Electronic Supplementum no 362: ISAR meeting Gothenburg 2015, Sweden
Peer-reviewed article based on study presented at the 2015 meeting of the International Congress of Arthroplasty Registries

Outcomes of unilateral and bilateral total knee arthroplasty in 238,373 patients

Eric R BOHM [1,2], Katy MOLODIANOVITSH [2], Alina DRAGAN [2], Naisu ZHU [2], Greg WEBSTER [2], Bas MASRI [3], Emil SCHEMITSCH [4], and Michael DUNBAR [2,5]

[1] Department of Surgery, University of Manitoba, Winnipeg, Manitoba; [2] Canadian Institute for Health Information, Ottawa, Ontario; [3] Department of Orthopaedic Surgery, University of British Columbia, Vancouver, British Columbia; 4 Department of Surgery, University of Toronto, Toronto, Ontario; [5] Department of Surgery, Dalhousie University, Halifax, Nova Scotia, Canada.
Correspondence: ebohm@cjrg.ca
Submitted 2015-08-02. Accepted 2016-01-29.

Background and purpose — There is no consensus about the outcome of simultaneous vs. staged bilateral total knee arthroplasty (TKA). We examined this issue by analyzing 238,373 patients.

Patients and methods — Demographic, clinical, and outcome data were evaluated for TKA patients (unilateral: 206,771; simultaneous bilateral: 6,349; staged bilateral: 25,253) from the Canadian Hospital Morbidity Database for fiscal years 2006–2007 to 2012–2013. Outcomes were adjusted for age, sex, comorbidities, and hospital TKA volume.

Results — Simultaneous bilateral TKA patients were younger than staged bilateral TKA patients (median 64 years vs. 66 years), were more likely to be male (41% vs. 39%), and had a lower frequency of having ≥ 1 comorbid condition (2.9% vs. 4.2%). They also had a higher frequency of blood transfusions (41% vs. 19%), a shorter median length of stay (6 days vs. 8 days), a higher frequency of transfer to a rehabilitation facility (46% vs. 9%), and a lower frequency of knee infection (0.5% vs. 0.9%) than staged bilateral TKA patients, but they had higher rate of cardiac complications within 90 days (2.0% vs. 1.7%). Simultaneous patients had higher in-hospital mortality compared to the second TKA in staged patients (0.16% vs. 0.06%), but they had similar rates of in-hospital mortality compared to unilateral patients (0.16% vs. 0.14%). The cumulative 3-year revision rate was highest in the unilateral group (2.3%), but it was similar in the staged and simultaneous bilateral groups (1.4%).

Interpretation — We found important differences between the outcomes of simultaneous and staged bilateral TKA. Further clarification of outcomes would be best determined in an adequately powered randomized trial, which would remove the selection bias inherent in this retrospective study design.

Patients who have bilateral knee arthritis and are candidates for total knee arthroplasty (TKA) may decide between simultaneous or staged bilateral TKA (BTKA). Conflicting outcomes have been reported for simultaneous and staged BTKA. Simultaneous BTKA has advantages that include bilateral functional recovery with only a single operation, anesthetic, hospitalization, recovery period, and analgesia regimen. It may also lead to better improvements in quality-adjusted life years, lower costs, and better outcomes (Fu et al. 2013, Odum et al. 2013). However, several meta-analyses have shown that simultaneous bilateral TKA may be associated with increased risks of cardiac complications (Restrepo et al. 2007), pulmonary embolism (Restrepo et al. 2007, Fu et al. 2013), and death (Restrepo et al. 2007, Hu et al. 2011, Fu et al. 2013) than staged bilateral TKA. In contrast, other studies have shown that complications may be more frequent with staged BTKA than with simultaneous BTKA (Memtsoudis et al. 2009), but 90-day mortality may be similar between unilateral TKA and simultaneous and staged BTKA (Walmsley et al. 2006). In addition, it may be difficult to compare simultaneous and staged BTKA because many patients (37% in one study) may not undergo the second stage of BTKA due to dissatisfaction with the first operation, unmet expectations, complications, or death (Sesen et al. 2015).

In Canada (with 35 million inhabitants), TKA is the most common type of joint replacement surgery, with 45,830 TKAs in 2012–2013 that accounted for 57,718 acute-care hospitalizations (Canadian Institute for Health Information 2014). We compared early outcomes of unilateral TKA, simultaneous BTKA, and staged BTKA using a large Canadian data set, including complications, in-hospital mortality, length of hospital stay, discharge disposition, and revision risk.

DOI 10.1080/17453674.2016.1181817

Patients and methods

The study cohort was selected from the Canadian Hospital Morbidity Database (HMDB) and contained all the patients who were discharged after primary TKA between April 2006 (fiscal year 2006–2007) and March 2013 (fiscal year 2012–2013). The HMDB is a national data holding managed by the Canadian Institute for Health Information (CIHI) that captures administrative, clinical, and demographic information on inpatient discharge or transfer from all acute-care hospitals. Primary TKA records were identified using the Canadian Classification of Health Interventions (CCI) codes 1.VG53.LA.PN.^ and 1.VG53.LA.PP.^ with status attribute primary and extent attribute bicompartmental or tricompartmental (Canadian Institute for Health Information, 2015a). The cohort was subdivided into 3 groups: (1) simultaneous BTKA (i.e. both TKAs were performed on the same day); (2) staged BTKA (i.e. both knees were replaced in 2 separate operations within a year); and (3) unilateral TKA (i.e. only 1 TKA was performed within a year). For staged BTKA, the 1-year cutoff was selected because patients who had the second-stage TKA performed within 1 year probably had sufficient bilateral symptoms to initially consider having simultaneous BTKA (Stefánsdóttir et al. 2008). We excluded unilateral TKA patients who could have been considered to be staged BTKA patients because they underwent a contralateral TKA within 12 months in either the year prior to or the year following the study period.

Explanatory variables of interest included patient age, sex, comorbidities, and hospital TKA volume quartiles. Comorbidities were defined using the Charlson comorbidity index (Quan et al. 2005) (Appendix Table A, see Supplementary data) and grouped by patients who had at least 1 predefined comorbid condition (index > 0) or no predefined comorbid conditions (index = 0). Characteristics and outcomes compared between the groups included blood transfusion during the hospitalization, length of stay in the acute-care facility, complications, discharge disposition, cumulative percentage revised during each of the 3 years following the index surgery, and inpatient mortality. To control for the possible confounding effects of length of stay, complications were determined by combining inpatient and outpatient complications. Inpatient complications were defined as complications that presented during the same hospitalization as the TKA, and included cardiac events (acute cardiac ischemia, infarction, and arrhythmia), pulmonary embolism, and infection of the TKA (Appendix Table B, see Supplementary data). Outpatient complications were defined in the same fashion, and were captured if a patient was re-admitted to an acute-care hospital (including being transferred back from a rehabilitation facility where acute complications are usually not managed) for treatment of any of these within 90 days of discharge. The 3-year follow-up data for revision rates were not available for patients who had revision TKA outside the years included. Due to coding differences, data on pulmonary embolism and re-admission were not included for patients who were discharged before March 31, 2009. Revision procedures were identified using CCI codes (1.VG.53 and 1.VP.53) and the status attribute revision. Except where noted otherwise, outcomes were calculated per patient (not per operation) to enable patient-specific comparison of complication risk in simultaneous BTKA with cumulative complication risk at both stages of staged BTKA. Thus, outcomes were reported if they occurred at least once after each TKA of staged bilateral patients. For discharge disposition, "home setting" might include a seniors' lodge, supportive housing, or assistance with meals and/or housekeeping. The cumulative risk of mortality for either the first or second stage of staged BTKA could not be accurately estimated because information on whether an operation was planned as staged was not available for patients who were intended for staged BTKA but who died after their first TKA was performed. Thus, mortality of patients who died after the first stage and before the second stage of a planned staged surgery was included in the unilateral TKA group.

Statistics

Data analysis was performed with SAS software version 9.2. Categorical variables were compared using chi-square test, and continuous variables were compared using t-test (means) and Mann-Whitney U test (medians). The p-values that are reported for outcomes included adjustment for age, sex, preoperative comorbidities, and hospital TKA volume, using linear regression for continuous outcomes, logistic regression for binary outcomes, and multinomial logistic regression for categorical outcomes. The level of significance was set at 0.05 for all tests.

Ethics

The CIHI did not require ethical approval for this analysis of its data holdings. Data sharing agreements with each Canadian province, privacy protection mechanisms, and analytical rules ensure that no individual patient information is identifiable.

Results

During the 7 years of the study, most TKAs performed were unilateral, and the ratio of simultaneous to staged BTKA was 1:4 (Table 1). Most staged BTKAs (94%) were performed with at least 3 months between stages. From 2006–2007 to 2012–2013, the annual number of unilateral TKAs increased by 39% to 37,994, simultaneous BTKAs decreased by 8% to 954, and staged BTKAs increased by 28% to 4,505.

Simultaneous BTKA patients were younger, more often male, and had a lower frequency of comorbidity than patients who underwent staged bilateral TKA or unilateral TKA. Compared to staged bilateral and unilateral TKA, simultaneous BTKAs were more frequently performed in hospitals that

Table 1. Patient demographics and hospital stay characteristics [a]

Characteristic	Unilateral [b]	Simultaneous [b]	Bilateral [b] 1st stage	Bilateral [b] 2nd stage	p- value [c]
No. of patients	206,771	6,349	25,253		
No. of replacements	229,050	6,349	25,253		
Median age (interquartile range)	68 (61–75)	64 (58–71)	66 (60–73)	67 (60–74)	< 0.001
Sex, male (%)	39	41	39		0.01
Comorbidity present (%)	5.09	2.87	4.23	4.39	< 0.001
Percentage of operations, by hospital TKA volume					
1st quartile (lowest volume)	6	2	5		
2nd quartile	15	7	14		< 0.001
3rd quartile	27	21	26		
4th quartile (highest volume)	52	70	55		
Median total inpatient length of stay (d) [d]	4	6	8		< 0.001
Discharge disposition (%) [e]					
Transfer to acute care	2.6	2.9	2.1		
Transfer to general/special rehabilitation	10.1	46	8.7		
Transfer to chronic care facility	1.2	2.3	0.9		< 0.001
Home or home setting with support services	32.3	22	32		
Home without support services	53.8	27	56		
Other	0.1	0.2	0.1		

[a] n = 238,373 patients. Source: Hospital Morbidity Database, Canadian Institute for Health Information, 2006–2007 to 2012–2013.
[b] Unilateral: 1 knee replaced within 1 year; simultaneous bilateral: both knees replaced during the same operation; staged bilateral: both knees replaced in separate operations within 1 year.
[c] Comparison between bilateral TKA groups (simultaneous vs. staged [completed], unless otherwise specified), after adjusting for patient age at surgery, sex, Charlson-based comorbidity, and TKA volume of facility. Statistical significance was defined by $p \leq 0.05$.
[d] For staged bilateral TKA, the total inpatient length of hospital stay was the sum for both stages, calculated for each patient. Median hospitalization per hospital stay was 4 days/hospitalization.
[e] Staged bilateral TKA: only the discharge disposition after the second stage was used. The data exclude patients who died during their hospital stay.

were in the highest quartile of TKA volume. Simultaneous BTKA patients had shorter median inpatient length of stay than staged BTKA patients, and a different profile of discharge disposition. Simultaneous BTKA patients were more frequently discharged to a rehabilitation facility than staged BTKA patients, and most patients who had staged BTKA (88.2%) were discharged to home or to a home setting (Table 1).

Simultaneous BTKA patients generally had higher rates of blood transfusion and cardiac complications compared to the other groups, a higher pulmonary embolism rate than the unilateral group, and a lower frequency of knee infection than staged patients. We could not detect any difference in in-hospital mortality between the simultaneous BTKA group and the unilateral TKA group. While the staged group had the lowest in-hospital mortality rate, it underestimated the true mortality risk, since it did not include staged patients who died after their first TKA. The unilateral group had the highest revision risk at 3 years (Table 2).

Male sex, age > 75 years, and the presence of at least 1 Charlson-based comorbidity all tended to increase the odds of cardiac complication, pulmonary embolism, knee infection, and in-hospital mortality. Lower TKA volume of a facility appeared to have a protective effect regarding pulmonary embolism, but it had no clear effect on cardiac complication or infection (Tables 3 and 4).

Discussion

Over the 7-year period from April 2006 to March 2013, the volume of simultaneous BTKAs in Canada dropped, while the volume of unilateral TKA and staged bilateral TKA both increased. This trend may in part be explained by concerns regarding increased mortality risk in patients undergoing simultaneous BTKA (Stefánsdóttir et al. 2008), which is also reflected by the selection bias of younger age and fewer comorbidities in this group.

The observation that patients were older in the staged BTKA group than in the simultaneous BTKA group (Table 1) is consistent with the results of previous studies (Stefánsdóttir et al. 2008, Odum et al. 2013). Surgeons may offer simultaneous procedures to younger and healthier patients, thus creating a selection bias and possibly contributing to better outcomes for simultaneous BTKA than would otherwise be observed. The greater proportion of male patients in the simultaneous BTKA group than in the staged BTKA group (Table 1) is similar to observations made in several previous studies (Ritter et al. 2003, Barrett et al. 2006, Hutchinson et al. 2006, Stefánsdóttir et al. 2008, Fu et al. 2013, Odum et al. 2013).

The findings that after simultaneous BTKA, patients had a higher frequency of discharge to a rehabilitation facility and a lower frequency of discharge to home than staged BTKA patients are consistent with those in other studies; however,

Table 2. Transfusion, complications, in-hospital mortality, and revision risk following unilateral and bilateral TKA

Outcome	Unilateral TKA	Bilateral TKA		p-value [a]	p-value [b]
		Simultaneous	Staged	Sim. vs. Staged	Sim. vs. Unilat
Blood transfusion (% of patients)	13.3	41	18.6 [c]	< 0.001	< 0.001
Inpatient complication rate (% of patients) [d]					
Cardiac complications	1.3	1.8	1.7 [c]	0.1	< 0.001
Pulmonary embolism	0.7	1.1	0.8 [c]	0.1	0.004
Knee infection	0.06	N/R [g] (< 0.14% but ≥ 0.06%, n < 5)	0.04 [c]	– [e]	– [e]
Outpatient complication rate (% of patients) (defined as 90-day re-admission for treatment of same) [d]					
Cardiac complications	0.05	N/R [g] (< 0.14% but ≥ 0.05%, n < 5)	0.04 [c]	– [e]	– [e]
Pulmonary embolism	0.14	0.23	0.13 [c]	– [e]	0.2
Knee Infection	0.6	0.4	0.8 [c]	0.02	0.2
Overall complication rate (inpatient plus outpatient)f (% of patients) [d]					
Cardiac complications	1.4	2.0	1.7 [c]	0.04	< 0.001
Pulmonary embolism	0.8	1.2	0.9 [c]	0.12	0.01
Knee infection	0.7	0.5	0.9 [c]	0.02	0.3
In-hospital mortality (%) [h]	0.14	0.16	0.06	0.005	0.2
Cumulative revision rate (%) i					
Year 1	1.07	0.68	0.63	0.6	< 0.001
Year 2	1.84	1.00	0.96	0.8	< 0.001
Year 3	2.34	1.41	1.37	0.9	< 0.001

[a] Comparison between bilateral TKA groups (simultaneous vs. staged). p-value after adjusting for patient age at time of surgery, sex, Charlson-based comorbidity, and TKA volume of facility. Significance level set at 0.05.
[b] Comparison between bilateral TKA groups (simultaneous vs. unilateral). p-value after adjusting for patient age at time of surgery, sex, Charlson-based comorbidity, and TKA volume of facility. Significance level set at 0.05.
[c] Outcomes could be at one or both stages, but they were counted if present at least once.
[d] Patients discharged before 2009–2010 were excluded due to coding differences (diagnosis cluster was not available).
[e] p-value not reported due to a possible bias in the logistic regression model estimates arising from the relative rarity of the observed event.
[f] If a patient experienced a complication event (cardiac, PE, or infection) in hospital and/or was re-admitted with it within 90 days, one combined event was coded.
[g] N/R: not reportable. In accordance with the CIHI privacy policy, cells with counts of 1–4 were suppressed. Suppressed cells were included in the totals.
[h] Mortality during hospitalization for TKA. Patients who had planned staged bilateral TKA but had died after the first stage and before the second stage were included with mortality data for unilateral TKA.
i Does not include patients who had revision outside of the years included.

Table 3. Logistic regression model for combined complication risk (inpatient plus outpatient)

Variable	Cardiac complication			Pulmonary embolism			Knee infection		
	Odds ratio	95%CI	p-value	Odds ratio	95%CI	p-value	Odds ratio	95%CI	p-value
Group (simultaneous BTKA vs. unilateral TKA)	1.7	1.4–2.2	< 0.001	1.5	1.1–2.0	0.01	0.8	0.5–1.2	0.3
Sex (male vs. female)	1.3	1.2–1.4	< 0.001	0.8	0.7–0.9	< 0.001	1.6	1.4–1.9	< 0.001
Age group (≥ 75 vs. < 75)	2.4	2.2–2.6	< 0.001	1.4	1.2–1.6	< 0.001	1.0	0.9–1.2	0.6
Charlson-based comorbidity present (yes vs. no)	3.4	3.0–3.8	< 0.001	1.9	1.5–2.3	< 0.001	1.9	1.5–2.3	< 0.001
TKA volume of facility (quartile 1 vs. quartile 4)	0.8	0.7–1.0	0.1	0.6	0.4–0.8	< 0.001	1.0	0.7–1.3	0.9

Table 4. Multiple logistic regression model for in-hospital mortality risk

Variable	In-hospital mortality		
	Odds ratio	95%CI	p-value
Group (simultaneous vs. unilateral)	1.5	0.8–2.9	0.2
Sex (male vs. female)	1.9	1.5–2.4	< 0.001
Age group (≥ 75 vs. < 75)	3.6	2.9–4.5	< 0.001
Charlson-based comorbidity present (yes vs. no)	7.8	6.2–9.8	< 0.001
TKA volume of facility (quartile 1 vs. quartile 4)	0.7	0.4–1.2	1.00

previous studies found that more than one-third of simultaneous BTKA patients were discharged to inpatient rehabilitation (Lombardi et al. 2001, Bullock et al. 2003, Cushner et al. 2005).

The more than doubled transfusion rate with simultaneous BTKA than with staged BTKA (Table 2) may have resulted from greater blood loss from the bilateral bone cuts and surgical trauma with simultaneous

BTKA, which is consistent with the previous observation of lower blood loss after staged BTKA than after simultaneous BTKA (Forster et al. 2006). In staged BTKA, a sufficient interval between stages may enable hematopoiesis to replenish blood loss from the first surgery (Fu et al. 2013). In our study, > 90% of staged patients waited more than 3 months between procedures, probably allowing normalization of hemoglobin before the second procedure. There were no data available about the volume of blood transfused, but previous studies have shown a greater likelihood and greater volume of blood transfusion with simultaneous BTKA than with staged BTKA (Lombardi et al. 2001, Bullock et al. 2003, Yoon et al. 2010). However, these results should be interpreted with caution because blood transfusion practices and reporting may vary between hospitals and between surgeons (Patil and Wakankar 2008, Fu et al. 2013).

The cardiac complication rate and pulmonary embolism rate were highest in the simultaneous bilateral group than in the other 2 groups, with the exception of the comparison between pulmonary embolism rates in the simultaneous and staged groups, which did not reach statistical significance ($p = 0.1$). These differences are generally consistent with some meta-analyses that have shown higher risks of cardiac complications (Restrepo et al. 2007) and pulmonary embolism (Restrepo et al. 2007, Fu et al. 2013) in simultaneous BTKA than in staged BTKA. However, the literature is equivocal, with 3 large meta-analyses not finding evidence for increased cardiac risk (Hu et al. 2011, Fu et al. 2013, Hussain et al. 2013), and 2 not finding an increased risk of pulmonary embolism (Hu et al. 2011, Hussain et al. 2013). The reasons for these differences are unclear, but there was a lack of consistency in either selection of the control group (staged bilateral vs. unilateral) and/or in controlling for possible confounding factors (such as age, sex, length of stay, and comorbidities) in both the meta-analyses and the studies they included in their analysis.

The lower frequency of knee infections in the simultaneous BTKA group than in the staged BTKA group (Table 2) is consistent with results of previous studies (Ritter et al. 1997, Meehan et al. 2011, Fu et al. 2013). In contrast, other studies have not shown any difference in the frequency of superficial infection (Yoon et al. 2010, Fu et al. 2013). However, a case-control study involving 72 bilateral simultaneous TKA patients matched to 144 unilateral TKA patients, based on age and sex, showed a greater frequency of superficial and deep infection after simultaneous BTKA than after unilateral TKA with a minimum of 6 months follow-up. The authors suggested that contributory factors may have included longer operating time, more personnel in the operating room, and rescrubbing, redraping, and changing of instruments between the simultaneous procedures (Luscombe et al. 2009).

We found a lower revision rate in the simultaneous BTKA group than in the unilateral TKA group, but we did not detect a difference in revision rates between the 2 BTKA groups. A previous meta-analysis and population-based study found that simultaneous procedures were associated with a lower frequency of revision in simultaneous BTKA than in staged BTKA (Meehan et al. 2011, Fu et al. 2013). However, 4 smaller studies showed no difference in the frequency of revision between patients who had simultaneous BTKA and those who had staged BTKA, which is similar to our findings (Table 2) (Leonard et al. 2003, Ritter et al. 2003, Hutchinson et al. 2006, Taylor et al. 2010). Kreder et al. (2003) have found higher revision risk to be associated with lower volume facilities. The higher revision risk in our unilateral group may simply reflect the fact that a larger proportion of these cases were performed in lower volume facilities. or simply that patients who had intended to undergo staged TKA but underwent early revision of the first side and declined the contralateral procedure were captured in the unilateral group.

A clear understanding of true differences in mortality risk between the 3 groups (unilateral TKA, staged BTKA, and simultaneous BTKA) is difficult to gain from the literature. There have been no adequately powered prospective studies, and the remaining literature consists of either large retrospective studies that were subject to the same types of selection bias as our work, inadequately powered small prospective series, or meta-analyses that incorporated these imperfect studies. Several recent meta-analyses (Restrepo et al. 2007, Hu et al. 2011, Fu et al. 2013) and large retrospective series (Memtsoudis et al. 2008, 2009, Stefánsdóttir et al. 2008) have shown increased in-hospital and 30-day mortality risk in simultaneous BTKA patients, but some were limited by the use of only a unilateral TKA comparison group (Restrepo et al. 2007, Memtsoudis et al. 2008, 2009), or did not adjust for the confounding effect of comorbidities (Stefánsdóttir et al. 2008). Other meta-analyses are consistent with the results of the present study, and found no increased risk of in-hospital mortality in the simultaneous BTKA group (Hussain et al. 2013). The only large case series that attempted to control for the effect of planned staged BTKA patients who did not proceed to the second side found that there was no increased mortality risk in the simultaneous BTKA group than in the staged BTKA group (Meehan et al. 2011). While our findings do not resolve this controversy, we have found similar in-hospital mortality rates and risk in patients undergoing unilateral TKA and simultaneous BTKA—similarities that remained when we adjusted for age, sex, comorbidities, and hospital volume. This may also reflect the marked decrease in mortality rates in elective TKA patients that has occurred since the 1990s (Lalmohamed et al. 2014). We feel that the statistically significantly lower mortality rate in the staged group may have been the result of selection bias in those who proceeded with TKA surgery on the second side, and it should therefore be interpreted with caution.

The limitations of our study included the absence of information about patients who had intended to have staged BTKA but deferred the second side. In-hospital mortality in the staged BTKA group was underestimated, and in the unilat-

eral group it was probably overestimated because patients who died after the first stage and before the second stage were excluded from the staged group and included in the unilateral group by default. Similarly, the complications and revisions of those patients who declined to proceed with the planned second TKA would have been included in the unilateral group, thus leading to overestimation of these risks in the unilateral group and to underestimation in the staged group. Mortality data were limited to in-hospital deaths, and early postoperative mortality may have been underestimated because of the typically brief postoperative length of hospital stay (median 4–6 days). In addition, the study may have underestimated the frequency of patients who had comorbidities; the low frequency of patients who had Charlson comorbidity index ≥ 1 (Table 1) may have occurred because several common and important medical conditions such as diabetes (without complications), previous myocardial infarction, and peripheral vascular disease had a weight factor of 0 in the index (Table A, see Supplementary data). However, changing of the 0 weight factors to 1 for these conditions and re-running the analysis did not change our findings (data not shown). Another concern may be that a comorbidity is detected only after admission to hospital; however, pre-admission clinics that screen the patient's fitness for surgery are ubiquitous across Canada, and it would be very unusual for a patient to undergo elective surgery without a clinically relevant comorbidity being identified prior to admission. We also recognize that it was not possible to adjust for possible confounding factors that were not captured in our data set, such as body mass index, physical fitness, or others. Furthermore, comparison of perioperative care between patient groups was not possible because these data were not available.

Miscoding is a potential source of error in administrative databases, but CIHI has a comprehensive data quality program that involves a continuous process of data improvement (Canadian Institute for Health Information, 2009 and 2015b). While there are no published data on the accuracy of coding of total knee replacements, an assessment of coding for hip fracture admissions revealed a positive predictive value (PPV) of 97% (Canadian Institute for Health Information, 2010). This same data quality assessment found that diagnosis of a post-admission acute myocardial infarction had a PPV of 82%, and that diagnosis of a post-admission deep venous thrombosis or pulmonary embolism had a PPV of 84%. Coding of comorbidity level also appeared good, with an overall agreement rate of 90%. The reported sensitivities of capturing an in-hospital acute myocardial infarction (68%) and deep venous thrombosis (66%) are lower; however, we have no reason to believe that there would be any systemic bias in the capture rates between the 3 groups (Canadian Institute for Health Information, 2010). Another concern might be an artificially low acute-care hospital length of stay in the simultaneous BTKA group due to a planned transfer to a rehabilitation facility; however, the availability of rehabilitation beds in Canada is not always predictable and is therefore unlikely to have artificially reduced the length of stay.

In summary, our study has shown important differences between outcomes of simultaneous BTKA and staged BTKA, with simultaneous BTKA having a higher frequency of blood transfusion, a lower median hospital length of stay, a higher proportion of discharge to a rehabilitation facility, a lower 90-day risk of knee infection, and higher 90-day risk of cardiac complication. Simultaneous BTKA patients appear to have similar rates of in-hospital mortality compared to patients undergoing unilateral TKA, but a lower risk of revision at 3 years. Generally speaking, patients having simultaneous BTKA were younger, were more often male, had a lower frequency of preoperative comorbidities, and more often had surgery in a high-volume center than patients having staged BTKA, which possibly contributed to selection bias in this study. Further investigation of outcomes would best be done in an adequately powered randomized trial.

Supplementary data

Tables A and B are available on the Acta Orthopaedica website at www.actaorthop.org, identification number 9269.

All the authors designed the study. Data were collected and submitted to CIHI by provincial health ministries. The CIHI staff analyzed and interpreted the data. EB wrote the manuscript. All the authors approved the final manuscript.

We are grateful to Dr. Elly Trepman for his assistance with manuscript preparation. This study received modest financial support from the Canadian Orthopaedic Association.

No competing interests declared.

Barrett J, Baron J A, Losina E, Wright J, Mahomed N N, Katz J N. Bilateral total knee replacement: staging and pulmonary embolism. J Bone Joint Surg (Am) 2006; 88(10): 2146-51.

Bullock D P, Sporer S M, Shirreffs T G Jr. Comparison of simultaneous bilateral with unilateral total knee arthroplasty in terms of perioperative complications. J Bone Joint Surg (Am) 2003; 85(10): 1981-6.

Canadian Institute for Health Information. The CIHI Data Quality Framework, 2009. Ottawa, Ontario: Canadian Institute for Health Information, 2009.

Canadian Institute for Health Information. CIHI Data Quality Study of the 2007-2008 Discharge Abstract Database. Ottawa, Ontario: Canadian Institute for Health Information, 2010.

Canadian Institute for Health Information. Hip and Knee Replacements in Canada: Canadian Joint Replacement Registry 2014 Annual Report. Ottawa, Ontario: Canadian Institute for Health Information, 2014.

Canadian Institute for Health Information. Canadian Classification of Health Interventions. (https://www.cihi.ca/en/data-and-standards/standards/classification-and-coding/canadian-classification-of-health) 2015a.

Canadian Institute for Health Information. Data Quality. (https://www.cihi.ca/en/data-and-standards/data-quality) 2015b.

Cushner F D, Scott W N, Scuderi G, Hill K, Insall J N. Blood loss and transfusion rates in bilateral total knee arthroplasty. J Knee Surg 2005; 18(2): 102-7.

Forster M C, Bauze AJ, Bailie A G, Falworth M S, Oakeshott R D. A retrospective comparative study of bilateral total knee replacement staged at a one-week interval. J Bone Joint Surg (Br) 2006; 88(8):1006-10.

Fu D, Li G, Chen K, Zeng H, Zhang X, Cai Z. Comparison of clinical outcome between simultaneous-bilateral and staged-bilateral total knee arthroplasty: a systematic review of retrospective studies. J Arthroplasty 2013; 28(7): 1141-7.

Hu J, Liu Y, Lv Z, Li X, Qin X, Fan W. Mortality and morbidity associated with simultaneous bilateral or staged bilateral total knee arthroplasty: a meta-analysis. Arch Orthop Trauma Surg 2011; 131(9): 1291-8.

Hussain N, Chien T, Hussain F, Bookwala A, Simunovic N, Shetty V, Bhandari M. Simultaneous versus staged bilateral total knee arthroplasty: a meta-analysis evaluating mortality, peri-operative complications and infection rates. HSS J 2013; 9(1): 50-9.

Hutchinson J R, Parish E N, Cross M J. A comparison of bilateral uncemented total knee arthroplasty: simultaneous or staged? J Bone Joint Surg (Br) 2006; 88(1): 40-3.

International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10), Canadian version. Ottawa: Canadian Institute for Health Information; 2012.

Kreder H J, Grosso P, William J I, Jaglal S, Axcell T, Wai E K, Stephen D J G. Provider volume and other predictors of outcome after total knee arthroplasty: a population study in Ontario. Can J Surg 2003; 46(1): 15-22.

Lalmohamed A, Vestergaard P, de Boer A, Leufkens H G M, van Staa T P, de Vries F. Changes in mortality patterns following hip or knee arthroplasty over the past two decades. Arthritis Rheumatol 2014; 66(2): 311-8

Leonard L, Williamson D M, Ivory J P, Jennison C. An evaluation of the safety and efficacy of simultaneous bilateral total knee arthroplasty. J Arthroplasty 2003; 18(8): 972-8.

Lombardi A V, Mallory T H, Fada R A, Hartman J F, Capps S G, Kefauver C A, Dodds K, Adams J B. Simultaneous bilateral total knee arthroplasties: who decides? Clin Orthop Relat Res 2001; (392): 319-29.

Luscombe J C, Theivendran K, Abudu A, Carter S R. The relative safety of one-stage bilateral total knee arthroplasty. Int Orthop 2009; 33(1): 101-4.

Meehan J P, Danielsen B, Tancredi D J, Kim S, Jamali A A, White R H. A population-based comparison of the incidence of adverse outcomes after simultaneous-bilateral and staged-bilateral total knee arthroplasty. J Bone Joint Surg (Am) 2011; 93(23): 2203-13.

Memtsoudis S G, González Della Valle A, Besculides M C, Gaber L, Sculco T P. 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(11): 2617-27.

Memtsoudis S G, Ma Y, González Della Valle A, Mazumdar M, Gaber-Baylis L K, MacKenzie C R, Sculco T P. Perioperative outcomes after unilateral and bilateral total knee arthroplasty. Anesthesiology 2009; 111(6): 1206-16.

Odum S M, Troyer J L, Kelly M P, Dedini R D, Bozic K J. A cost-utility analysis comparing the cost-effectiveness of simultaneous and staged bilateral total knee arthroplasty. J Bone Joint Surg (Am) 2013; 95(16): 1441-9.

Patil N, Wakankar H. Morbidity and mortality of simultaneous bilateral total knee arthroplasty. Orthopedics 2008; 31(8): 780-9.

Quan H, Sundararajan V, Halfon P, Fong A, Burnand B, Luthi J C, Saunders L D, Beck C A, Feasby T E, Ghali W A. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care 2005; 43(11): 1130-9.

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

Ritter M, Mamlin LA, Melfi C A, Katz B P, Freund D A, Arthur D S. Outcome implications for the timing of bilateral total knee arthroplasties. Clin Orthop Relat Res 1997; 345: 99-105.

Ritter M A, Harty L D, Davis K E, Meding J B, Berend M. Simultaneous bilateral, staged bilateral, and unilateral total knee arthroplasty. A survival analysis. J Bone Joint Surg (Am) 2003; 85(8): 1532-7.

Sesen H, Demirkale I, Karaduman M, Vural C A, Okkaoglu M C, Altay M. Why two-thirds of patients accepted the second session in staged bilateral total knee arthroplasty: a prospective analysis of 111 patients. Knee Surg Sports Traumatol Arthrosc 2015; 23(12): 3585-90.

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; 446(12): 3066-70.

Taylor B C, Dimitris C, Mowbray J G, Gaines S T, Steensen N. Perioperative safety of two-team simultaneous bilateral total knee arthroplasty in the obese patient. J Orthop Surg Res 2010; 5: 38.

Walmsley P, Murray A, Brenkel I J. The practice of bilateral, simultaneous total knee replacement in Scotland over the last decade. Data from the Scottish Arthroplasty Project. Knee 2006; 13(2): 102-5.

Yoon H S, Han C D, Yang I H. Comparison of simultaneous bilateral and staged bilateral total knee arthroplasty in terms of perioperative complications. J Arthroplasty 2010; 25(2): 179-85.