acta orthopaedica belgica, 2023, 89, 455-461

ORIGINAL STUDY

doi.org/10.52628/89.3.11954

Comparison of safety and efficiency between sequential simultaneous bilateral and staged bilateral total knee arthroplasty at a high-volume center: a retrospective cohort study

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The treatment strategy remains controversial for bilateral end-stage osteoarthritis, particularly with regard to patient safety. The aim of this study was to compare the safety and clinical results of sequential simultaneous bilateral total knee arthroplasty (ssBTKA) and staged bilateral total knee arthroplasty (staBTKA). Patients who underwent either simultaneous (n=168) or staged (n=63) bilateral total knee arthroplasty in a single center between February 2017 and April 2021 were identified retrospectively. Data related to age, gender, body mass index, ASA score, comorbidities, operative time, transfusion rate, length of stay, knee range of motion (ROM), Knee Society Score (KSS), complications, and mortality rates were evaluated. Mean follow-up duration was 39.0±14.7 months. Preoperative characteristics were similar among cohorts. Transfused units were significantly higher in the ssBTKA group ($p<0.001$). Operative time and length of stay were significantly higher in the staBTKA group (respectively, $p<0.001$ and $p=0.004$). Complication rates (except superficial infection rate which was significantly higher in the staBTKA group), revision rates, mortality rates and functional outcomes were statistically similar between the groups ($p>0.05$). Presence of preoperative coronary artery disease comorbidity was significantly associated with increased postoperative myocardial infarction risk ($p=0.001$). ssBTKA provided similar functional results, shorter cumulative hospital stay and shorter operative time without increasing complications and mortality rates compared to staBTKA procedure. For patients with pre-existing coronary artery disease, a more cautious approach should be preferred to decrease complications.

Keywords: sequential, simultaneous, staged, total knee arthroplasty, osteoarthritis.

INTRODUCTION

One-third of patients requiring total knee arthroplasty (TKA) exhibit bilateral symptoms at initial presentation, and another 20% of patients who undergo unilateral TKA require contralateral TKA within two years after index surgery[1,2]. For patients suffering from bilateral end-stage osteoarthritis, there are three main surgical strategies: (i) truly simultaneous bilateral TKA under the same anesthesia with two surgical teams; (ii) sequential simultaneous bilateral TKA in which knees are replaced one after the other under the same anesthesia with one surgical team; and (iii) staged bilateral TKA under separate anesthetics and separate hospitalizations, 1 to 12 months apart between two surgeries[3].

Both sequential and truly simultaneous bilateral TKA (simBTKA) are advantageous as they provide reduced cumulative hospital stay, increased cost effectiveness for the healthcare system, patient convenience and satisfaction, single anesthesia and hospitalization, less total anesthesia time, faster postoperative recovery, and symmetrical postoperative rehabilitation among both knees[4,5]. In addition, simultaneous procedures provide an average of six months to patients' quality-adjusted life years[6]. If the second TKA surgery is performed after a long time interval, this may cause the first knee to loosen earlier[7]. StaBTKA means two separate efforts for operations, two painful postoperative periods, and being distanced from work for both patients and their families. The functional outcomes of simBTKA patients have been reported to be comparable to staBTKA[8]. One study reported that 98% of patients with bilateral knee osteoarthritis would prefer simBTKA when given a choice of either simBTKA or staBTKA[9]. From this perspective, it is ideal to offer simBTKA instead of staBTKA. However, only if the simBTKA is as safe as its staged alternative.

Controversies over which treatment strategy is the gold standard are far from being resolved as different results have been reported in previous studies, particularly in terms of patient safety. Two recent meta-analysis studies including studies conducted in the last two decades, concluded that simBTKA may be associated with higher mortality and thromboembolic events, and decreased infection rates[10,11]. On the other hand, another systematic review that included only studies from the last decade and had comparable preoperative characteristics, reported no difference in mortality, overall complications, thromboembolic events, cardiac complications, and revision rates between simBTKA and staBTKA[12]. In addition, two recent studies reported that complication rates were not affected by the choice for simultaneous or staged arthroplasty[4,5]. The lack of randomized controlled trials causes this debate to continue.

Existing meta-analyses consisted of large retrospective national registry data studies, and only a very small percentage of patients comprised longitudinal follow-up data[10-14]. Miscoding is a potential source of error in administrative databases, and also most of these studies do not include preoperative patient characteristics such as body mass index or patient comorbidity status[12,15]. Furthermore, these systematic reviews and the majority of previous studies did not distinguish between the truly simBTKA and sequential simBTKA. These two different single-anesthetic methods may produce significant different physiological loads and thus different complication rates[16]. Our study compares the results of sequential simultaneous bilateral TKA (ssBTKA) with staBTKA, which is known as the safe method[14].

The aim of this study was to compare the safety and clinical outcomes of ssBTKA and staBTKA. We hypothesized that ssBTKA was as safe as staBKTA.

MATERIALS AND METHODS

All patients who underwent either simultaneous (under the same anesthesia) or staged (<1 year apart) bilateral TKA in a single center between February 2017 and April 2021 were identified retrospectively. Dates corresponded to when hospital electronic medical records were available, which was necessary to enable efficient data extraction. More precisely, the patients included were those who had grade 3 or more bilateral gonarthrosis based on the Kellgren-Lawrance classification and a postoperative follow-up period of at least 12 months. Both knees were sufficiently symptomatic to warrant BTKA in all patients.

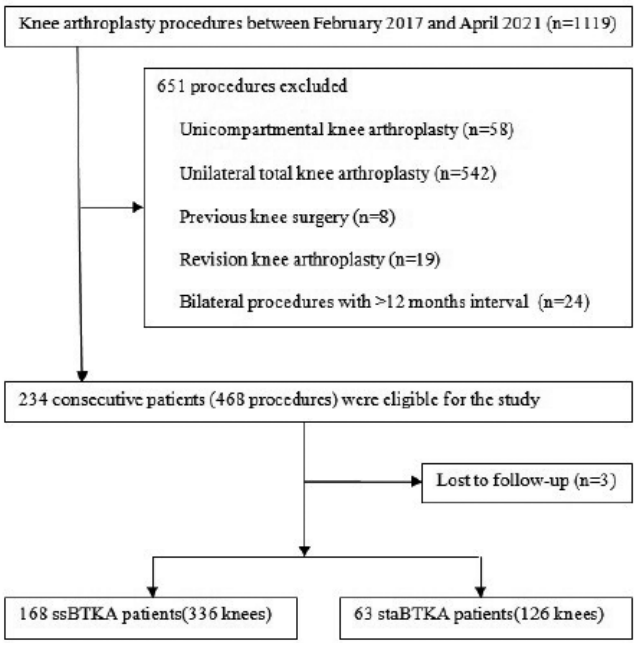

Figure 1 Flow-chart of patient selection. ssBTKA=sequential simultaneous bilateral total knee arthroplasty, staBTKA=staged bilateral total knee arthroplasty.

Patients with unilateral TKA, unicompartmental knee arthroplasty, revision knee arthroplasty, previous knee surgery, and a postoperative follow-up period of less than 12 months (except six patients who died within the first year) were excluded. Patients who underwent BTKA at intervals longer than 12 months were not accounted as staged and were excluded. Approval for this study was granted by the Institutional Review Board (Approval Number: 2022-1/24).

A total of 1119 knee arthroplasty procedures were performed between February 2017 and April 2021 in our hospital. One hundred and sixty-eight ssBTKA (336 knees) and 63 staBTKA (126 knees) patients were included in the final analysis. The flowchart of patient selection is shown in Figure 1.

Data related to age, gender, BMI (body mass index), ASA (American Society of Anesthesiologists) score, comorbidities, operative time, transfusion rate, units transfused, length of stay, medical complications for the first one year postoperatively after each surgery, and surgically-related complications were collected from hospital records. Knee Society Score (KSS), including knee subscore and function subscore, and knee range of motion (ROM) were routinely assessed preoperatively and at the last follow-up. At a mean follow-up of 39.0±14.7 months (range, 2 to 62 months), the incidence of revision rates and mortality rates were assessed.

Three experienced high-volume arthroplasty surgeons performed the procedures. Before surgery,

a full explanation was given to the patients about simultaneous and staged operations and a joint decision was made on which procedure would be chosen. All patients were assessed in terms of comorbidities. Consultations were conducted with relevant departments. ASA 4 patients were canceled and treated according to the recommendations of the relevant departments. In case the risk diminished, the patient was re-evaluated.

All surgical procedures were performed under spinal anesthesia using an anterior midline skin incision and medial parapatellar arthrotomy. A posterior stabilized cemented implant and a pneumatic tourniquet were used in all patients. All simBTKA operations were performed by a single team, sequentially (one by one), under the same anesthesia. During ssBTKA, the installation of the first knee prosthesis and wound closure was completed, the tourniquet deflated, and the same procedures by the same surgeon started on the second knee. Patellar resurfacing was not performed in any patients. Hemovac drain was utilized after all procedures. Drains were removed at 24 hours postoperatively. Blood transfusion was performed if the hemoglobin value was below 8 g/dL or if clinical symptoms of anemia were present. Intravenous 1g tranexamic acid was used just before incision to reduce blood loss. Venous thromboembolism prophylaxis was started at the postoperative 12th hour with low molecular weight heparin and continued for 4 weeks after surgery. Antibiotic prophylaxis was administered with 1g cefazolin i.v. preoperatively before the induction of anesthesia and every 8 hours throughout 24 hours postoperatively. On the postoperative first day, patients were encouraged to start exercise with a continuous passive motion (CPM) device and to start active range of motion (ROM) exercises on their knees, quadriceps and hamstrings for strengthening. The patients were mobilized with the help of a walker on the postoperative first day. Physiotherapy was continued throughout the hospitalization period under the supervision of an experienced physiotherapist to improve knee ROM and surrounding muscle strength. All patients were discharged directly to their homes and recommended for regular outpatient follow-up. Follow-up examinations were carried out at 3-week intervals until the third month and thereafter every three months until the end of the year. After one year, all patients were examined annually. The patients were informed that data from the research would be submitted for publication, and gave their written consent.

Data were included in a database created by the Excel 2007 programme by Microsoft (Microsoft Corporation, Redmond, Washington, USA). Statistical analysis was performed using PASW statistics for Windows (version 18, USA). Student T-test (for normally distributed variables) and Mann-Whitney U test (for non-normally distributed variables) were used for continuous variables, and Chi Square or Fisher's exact test for categorical data. A p-value of <0.05 was considered statistically significant. We further performed a post hoc power analysis using G-power version 3.1.9.7. The analysis showed sufficient power with a power of 80% and a significance level of 0.05 in all studied variables regarding perioperative and postoperative data of patients, with the exception of perioperative complications where insufficient power was observed.

RESULTS

The study included 168 patients (336 knees) in the ssBTKA group and 63 patients (126 knees) in the staBTKA group. The mean age was 67.2±6.6 years (range, 45-84 years). The mean time between two operations in the staBTKA group was 6.5±3.4 months (range, 1-12 months). The two groups were statistically similar in terms of age, gender, and BMI (p=0.793, 0.514, 0.228, respectively). Mean preoperative ROM, KSS Knee and Function subscores were similar between the groups (p=0.207, 0.518, 0.453, respectively). The two groups had statistically similar preoperative ASA scores (p=0.265). The most common comorbidity was hypertension (54.1%). Comorbidities and other preoperative characteristics are shown in Table I.

Mean transfused units were higher in the ssBTKA group ($p<0.001$). The mean cumulative operative time was higher in the staBTKA group ($p<0.001$). The median cumulative length of stay was higher in the staBTKA group (p=0.004). Mean ROM, KSS Knee and Function subscores were similar between the groups at the postoperative one year (p=0.183, 0.288, 0.325, respectively). (Table II).

Surgery-related complications included prosthesis infection, periprosthetic fracture, superficial infection, and arthrofibrosis (Table III). Medical complications included deep vein thrombosis, pulmonary thromboembolism, myocardial infarction, congestive heart failure, cerebrovascular event, atrial fibrillation necessitating cardioversion, and pneumonia (Table III). Superficial infection rate was statistically higher in the staBTKA group (7.9% vs 0.1%, p=0.002). The incidence of other aforementioned complications, revision rates and death rates were statistically similar between the groups ($p>0.05$) (Table III).

Table I. — Preoperative characteristics of the patients

Characteristics	ssBTKA (n=168)	staBTKA (n=63)	P value
Mean age, years	67.3±6.5	67.1±6.9	0.793
Sex (M:F)	26:142	12:51	0.514
Mean BMI, kg/m^2	33.2±5.2	34.1±4.5	0.228
ASA score			0.265
ASA I	57	20	-
ASA II	77	24	-
ASA III	34	19	-
Comorbidity (n, %)			-
Diabetes mellitus	40 (23.8 %)	19 (30.1 %)	0.324
Hypertension	90 (53.6 %)	35 (55.5 %)	0.788
Coronary artery disease	12 (7.1 %)	9 (14.3 %)	0.093
Cerebrovascular event history	4 (2.4 %)	1 (1.6 %)	0.712
Obstructive lung disease	15 (8.9 %)	7 (11.1 %)	0.615
Mean preoperative knee ROM	91.5±12.3	89.5±10.4	0.207
Mean preoperative KSS Knee subscore	34.3±7.5	35.0±7.0	0.518
Mean preoperative KSS Function subscore	44.4±12.7	43.0±11.7	0.453

Abbreviations: ssBTKA=sequential simultaneous bilateral total knee arthroplasty, staBTKA=staged bilateral total knee arthroplasty, BMI=body mass index, ASA=American Society of Anesthesiologists, ROM=range of motion, KSS=Knee Society Score.

Table II. — Perioperative and postoperative data of the patients

Characteristics	ssBTKA (n=168)	staBTKA (n=63)	P value
Transfusion rate (yes:no)	71:97	15:48	**0.010**
Mean transfused units	0.7±1.0	0.3±0.5	**<0.001**
Mean operative time, min	83.6±9.8	101.2±10.5	**<0.001**
Median length of stay (IQR), days	6 (5.0-11.5)	9 (6.0-12.0)	**0.004**
Mean follow-up, months	38.5±15.4	40.4±11.7	0.328
Mean postoperative ROM	113.0±6.8	111.6±8.4	0.183
Mean postoperative KSS Knee subscore	88.8±8.4	87.4±8.9	0.288
Mean postoperative KSS Function subscore	84.8±8.2	83.6±8.9	0.325

Abbreviations: ssBTKA=sequential simultaneous bilateral total knee arthroplasty, staBTKA=staged bilateral total knee arthroplasty, IQR: interquartile range, ROM=range of motion, KSS=Knee Society Score.

There were 2 (3.1%) patients in the staBTKA group who died within the first year due to pneumonia and myocardial infarction. The causes of death of 4 (2.5%) patients in the ssBTKA group who died within the first year were myocardial infarction, cerebrovascular event, pulmonary thromboembolism, and congestive heart failure.

We detected an association between the presence of preoperative coronary artery disease and the risk of postoperative myocardial infarction (p=0.001, RR: 1.16, CI: 0.98-1.39). There were 3 (14.3%) cases of myocardial infarction in 21 patients with preoperative coronary artery disease. No complications of myocardial infarction were observed in 210 patients without a preoperative history of coronary artery disease. However, ssBTKA and staBTKA groups were statistically similar in terms of myocardial infarction rate (p=0.123) (Table 3).

DISCUSSION

The most important finding of the present study was that ssBTKA provided comparable results in terms of complication and mortality rates compared to staBTKA procedure. In addition, similar functional results, a shorter cumulative hospital stay, and a

Table III. — The comparison of complication rates between the sequential simultaneous and staged bilateral total knee arthroplasty

Complications	ssBTKA (n=168)	staBTKA (n=63)	P value
Surgically related	11 (6.5%)	7 (11.1%)	0.249
Revision arthroplasty(at last follow-up)	5	1	0.544
Prosthesis infection (at last follow-up)	1	0	0.539
Periprosthetic fracture (at last follow-up)	3	0	0.286
Superficial infection (at last follow-up)	1	5	**0.002**
Arthrofibrosis (at last follow-up)	1	1	0.469
Medically related	7 (4.2%)	5 (7.9%)	0.250
Deep vein thrombosis (≤1 y)	1	1	0.469
Pulmonary thromboembolism (≤1 y)	1	1	0.469
Myocardial infarction (≤1 y)	1	2	0.123
Congestive heart failure (≤1 y)	1	0	0.539
Cerebrovascular event (≤1 y)	2	0	0.384
Atrial fibrillation (≤1 y)	1	0	0.539
Pneumonia (≤1 y)	0	1	0.102
Death (at last follow-up)	6 (3.6%)	5 (7.9%)	0.165
Death (≤ 1 y)	4	2	0.736
Death (≤ 90 d)	1	0	0.539
Death (≤ 30 d)	0	0	1.000
Abbreviations: ssBTKA=sequential simultaneous bilateral total knee arthroplasty, staBTKA=staged bilateral total knee arthroplasty			

shorter cumulative operative time were obtained with the ssBTKA method. Although transfusion rates were higher in the ssBTKA group, these higher rates were not reflected in the complication rates.

We observed an association between the presence of preoperative coronary artery disease and the risk of postoperative myocardial infarction (p=0.001). However, ssBTKA and staBTKA groups were statistically similar in terms of myocardial infarction risk (p=0.123). Similar to our results, there is substantial literature knowledge that the surgical procedure (simBTKA or staBTKA) is not a predictive factor for cardiac complications[10-14,17]. On the other hand, there are studies that have reported that preexisting cardiopulmonary disease may increase the risk of cardiovascular complications[18-20]. In the light of our findings and current literature, we think that both procedures can be safely applied with similar results in terms of cardiac complications in patients with bilateral symptomatic gonarthrosis and no history of preoperative coronary artery disease. Patients with pre-existing coronary artery disease may be managed with unilateral total knee arthroplasty or conservatively, to minimize complication risk.

Previous literature is controversial due to conflicting results in terms of infection rates[12]. We did not find a significant relationship between the surgical procedure and deep infection rates (p>0.05). However, the staBTKA group had higher superficial infection rates than the ssBTKA group (p=0.002). Poultsides et al reported that longer length of stay may be a predictor for the development of infection[1]. We can hypothesize that the higher superficial infection rate in our study may be related to the longer cumulative hospital stay and cumulative operative time in the staBTKA group.

Previous studies reported no difference in revision rates between the two procedures[11,12,15,17]. Similarly, no difference was observed in our study with a mean follow-up of 39 months (p=0.544). Rates of arthrofibrosis were also similar in a previous meta-analysis[10]. In the present study, there was one case of arthrofibrosis in each group and there was no significant difference between the groups (p=0.469).

We did not find any significant difference in venous thromboembolism rates between the groups (p=0.469). Similarly, in a recent study, no significant relationship was found between the two methods in terms of pulmonary embolism and deep vein thrombosis rates[17]. On the other hand, higher deep vein thrombosis and pulmonary embolism rates have been reported with simBTKA compared to staBTKA in other studies[10,11,13,21]. Furthermore, similar to our study, in some previous

studies, no statistically significant difference was found between the two procedures in terms of neurological complications including stroke[10,13,17]. However, other studies found higher cerebrovascular event in the simBTKA group[11,21]. These conflicting results may be the result of methodological differences, including the use of tranexamic acid, patient selection, and different operative times between studies.

Bilateral bone cuts and high levels of trauma may increase the amount of bleeding in patients treated with simBTKA. In staBTKA, the interval between stages may enable hematopoiesis to replenish blood loss from the first surgery, and hematopoietic agents may be recovered within this period[13]. A meta-analysis suggested that BTKA candidates diagnosed with preoperative anemia should be warned of the risk of higher blood transfusion rates if they choose simBTKA[12]. We observed higher blood transfusion rates and higher transfused units in the ssBTKA group ($p=0.010$, $p<0.001$, respectively). Similar to our results, previous studies have found higher blood transfusion rates in the simBTKA patients compared to staBTKA[12,13,15,22].

Older studies reported an increased risk of mortality with simBTKA[10,11,13,14,21]. However, a meta-analysis including only studies from the last decade and a recent study reported no difference between groups [12,22]. The reason for this may be recent developments in surgical technique, anesthesiology, and postoperative care, which provide a decrease in complication rates. We found no significant difference in the mortality rates. We believe that completing the first knee prior to the beginning of the second ensures a carefully controlled procedure, which may affect outcomes including complications and mortality.

Shorter length of stay has been shown to save costs to the healthcare system[5]. The cumulative length of hospital stay in our patients was longer in the staBTKA group ($p=0.004$). Previous literature has also reported longer length of stay with staBTKA procedures[11,12,23]. In our study, the cumulative operative time was shorter in the ssBTKA group ($p<0.001$). This was consistent with previous literature[23]. We did not find any difference between the groups in terms of postoperative ROM, KSS Knee Subscore, and KSS Function subscore ($p>0.05$). Similar to our findings, a systematic review reported equivalent functional results with both procedures[8].

The present study was conducted in the setting of a high-volume state hospital with experienced surgeons. In the literature, one previous study compared ssBTKA with unilateral TKA, and reported no difference in complication rates in a high-volume community hospital[24]. The study did not include patients treated with staBTKA and the follow-up period of the study was 3 months *(24)*. Similarly, another recent study compared 53 ssBTKA and 64 staBTKA patients, and reported no difference in terms of in-hospital complications at a specialized high-volume center[25]. The study had the limitation of absence of preoperative comorbidities and ASA scores of the patients[25]. Consistent with these studies, we observed no difference in complication rates between the ssBTKA and staBTKA procedures. We think that volume of hospital and as well as surgeons may be directly related to the decrease in complication rates, especially in simultaneous procedures.

Although it would not be proper to compare simBTKA and unilateral TKA, this comparison has been made in a considerable number of studies[26-29]. One previous study compared ssBTKA with unilateral TKA and suggested performing ssBTKA in appropriately selected patients[26]. However, the authors also noted that it may be simplistic to consider simBTKA as the sum of two unilateral procedures[26]. In this regard, comparing simBTKA and staBTKA provides a more accurate assessment of patient safety as long as the interval between surgeries is not excessive.

Our surgeons who performed ssBTKA also performed the staBTKA procedures, reducing the effect of different surgical techniques on the outcomes. Both groups had comparable preoperative patient characteristics. In addition, our study was a longitudinal study and did not have the limitations of large database studies that depend on the accuracy of medical claims. However, this study has several limitations. First, the study was designed retrospectively. Second, because the study cohort was relatively small compared to large registry data analyses, and complication rates were low, this limited the study's statistical power and its ability to detect infrequent complications such as mortality. Third, although all three surgeons in the present study were experienced high-volume arthroplasty surgeons comfortable performing both procedures, outcomes may not be representative of all orthopaedic surgeons and results may differ in patients operated on by low-volume general orthopaedic surgeons. Finally, we did not consider a cost analysis when comparing simBTKA with staBTKA.

CONCLUSION

ssBTKA provided similar functional results, shorter cumulative hospital stay and shorter operative time without increasing complications and mortality rates

compared to staBTKA procedure. Unilateral or conservative methods may be suggested for patients with coronary artery disease. When the prevention of perioperative complications is implemented properly, ssBTKA is a viable option in carefully selected patients.

Funding: No funding was received for conducting this study.

Conflict of interest: None.

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