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Clinical Outcomes and Complications of Simultaneous Bilateral Total Knee Arthroplasty Compared with Staged Total Knee Arthroplasty in Patients with Severe Knee Osteoarthritis

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Abstract

Osteoarthritis (OA), the most common degenerative joint disease and a leading cause of disability, primarily affects the knee joint. In severe knee OA, total knee arthroplasty (TKA) is an effective treatment option; bilateral cases may be managed through simultaneous bilateral total knee arthroplasty (simBTKA) or staged total knee arthroplasty (staTKA), depending on patient characteristics and risk profiles. simBTKA may reduce overall treatment duration and healthcare costs but is associated with a higher risk of short-term mortality, venous thromboembolism, increased transfusion requirements, and more complex rehabilitation. Evidence remains limited regarding which patients derive the greatest benefit, medium- to long-term outcomes (patient-reported outcome measures [PROMs], including the Oxford Knee Score [OKS], Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC], and range of motion [ROM]), and total treatment costs. This study aimed to compare the clinical outcomes and complications of simBTKA and staTKA in patients with severe knee OA using a retrospective cohort design based on medical records of patients with severe bilateral OA who underwent either simBTKA or staTKA at RSCM, Fatmawati Central General Hospital, and St. Carolus Hospital between January 2021 and September 2024, according to predefined eligibility criteria. The assessed outcomes included OKS, WOMAC, ROM, length of stay (LOS), and complication incidence, which were analyzed using SPSS version 25 for Windows. Before adjustment, WOMAC scores were higher in the simBTKA group than in the staTKA group (median 28 vs. 14; $p = 0.012$), with no significant differences observed in OKS or ROM. Following ANCOVA adjustment, WOMAC scores were lower in the simBTKA group than in the staTKA group (adjusted mean 22.31 vs. 28.72; $p = 0.04$), and ROM was superior in the simBTKA group (adjusted mean 119.42 vs. 112.80; $p = 0.03$). Blood loss was greater in the staTKA group than in the simBTKA group (median 650 vs. 200 cc; $p < 0.001$). Overall, after adjustment, WOMAC scores and ROM outcomes were better in the simBTKA group than in the staTKA group, whereas blood loss was greater in the staTKA group.

INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease most commonly found among the elderly population and is one of the leading causes of disability worldwide. Based on the Global Burden of Disease data from 2019, it is estimated that approximately 528 million people are living with OA, of whom about 73% are over 55 years of age and 60% are women. Among all affected joints, the knee has the highest prevalence, with an estimated 365 million cases, followed by the hip and hand joints. Along with global population aging, the increasing prevalence of obesity, and the rising incidence of musculoskeletal trauma, the incidence of OA is projected to continue increasing in the coming decades (Jin et al., 2024; Qiao et al., 2025;

Steinmetz et al., 2023; Xie et al., 2025; Zhao et al., 2025). In the Asian region—including East and Southeast Asia—the epidemiological burden of knee OA is reported to be higher than that in Western populations. Large-scale population studies have shown that the prevalence of knee OA among adults in Asia ranges from 19–23%, with rates tending to be higher in East Asian and Southeast Asian countries. Geopopulation factors, such as floor activity habits (squatting, cross-legged sitting, and kneeling), a higher prevalence of varus alignment, increasing obesity rates, and repetitive physical workloads, contribute to the high prevalence of knee OA in this region. In Southeast Asia, the prevalence of knee OA among individuals over 40 years of age reaches 20–30% and increases to 35–40% among those over 60 years old. Indonesia, with its growing elderly population and increasing prevalence of obesity, is expected to experience a rising demand for knee OA management services over the next two decades. The burden of moderate-to-severe OA requiring surgical intervention is also anticipated to increase. A projected study of orthopedic needs in Asia indicates that the demand for total knee arthroplasty (TKA) will increase by more than 25% by 2050, particularly in highly populated countries such as Indonesia, China, and India.

Clinically, OA is characterized by chronic pain, restricted joint range of motion, progressive deformities, and a substantial reduction in quality of life. The lifetime risk of developing symptomatic knee OA is reported to be 45%, with a higher risk among individuals with a history of knee injury and obesity. The management of OA requires a multimodal approach, including lifestyle modification, physiotherapy, pharmacological therapy, and surgical intervention in cases involving persistent symptoms and advanced joint damage. In patients with severe knee OA, total knee arthroplasty (TKA) has been proven to be an effective definitive intervention for reducing pain, improving function, and enhancing patients' quality of life. Technically, TKA is generally performed through an anterior midline incision with a medial parapatellar arthrotomy, followed by resection of the damaged articular surfaces of the femur and tibia and implantation of prosthetic components. The types of implants used vary, including cruciate-retaining (CR) and posterior-stabilized (PS) designs, with selection based on ligament integrity and the required level of knee stability. Functional recovery after TKA occurs gradually, and most patients achieve independence in basic activities within several weeks, whereas full recovery generally requires 6–12 months postoperatively (Castrodad et al., 2019; Chiriac et al., 2025; Fortier et al., 2021; Mehta et al., 2025; Patterson et al., 2021).

In patients with severe bilateral knee OA, surgical management often involves bilateral total knee arthroplasty (BTKA), which can be performed using two main strategies: simultaneous bilateral total knee arthroplasty (simBTKA), in which both knees are operated on during a single anesthesia session, and staged bilateral total knee arthroplasty (staBTKA), in which the two procedures are performed separately. The selection of these strategies is influenced by various factors, including patient characteristics (age, comorbidities, and functional status), patient and surgeon preferences, and healthcare system considerations such as resource availability and financial factors. The choice between simBTKA and staBTKA remains a subject of ongoing debate, primarily due to conflicting evidence regarding their comparative safety and efficacy. Theoretically, simBTKA provides several advantages, including a single anesthetic exposure, one rehabilitation period, and shorter overall hospitalization, which may result in substantial cost savings. However, these potential benefits must be balanced against concerns regarding increased physiological stress and a potentially

higher risk of perioperative complications, including mortality, cardiovascular events, and venous thromboembolism (Farooq et al., 2025; Guasti et al., 2025; Iwaszczuk et al., 2021; Pinto et al., 2019; Smilowitz & Berger, 2020). Conversely, staBTKA distributes surgical risk across two separate procedures but exposes patients to two episodes of anesthesia and a longer overall recovery period, potentially increasing healthcare costs and the risk of infection associated with multiple hospital admissions.

Several recent large-scale studies and meta-analyses have attempted to clarify the comparative outcomes of these two surgical strategies; however, their findings remain conflicting. A 2025 meta-analysis by Boutros et al. involving 567,915 patients found that simBTKA was associated with significantly higher odds of transfusion (OR 3.99), first-year neurological complications (OR 1.48), and first-year mortality (OR 2.43), while simultaneously demonstrating lower rates of joint infection (OR 0.59), reoperation (OR 0.65), and in-hospital costs. Similarly, a 2026 meta-analysis by Zhang et al., incorporating 53 cohort studies with 572,881 patients, confirmed that simBTKA was associated with higher short-term mortality (OR 2.35), higher rates of deep vein thrombosis (DVT) (OR 1.45), and greater transfusion requirements (OR 4.42), whereas staBTKA was paradoxically associated with higher rates of superficial and deep infections (OR 0.69 for simBTKA vs. staBTKA). A large retrospective cohort study using the National Readmissions Database (2016–2020) that analyzed 210,682 patients demonstrated that staged procedures were associated with higher medical complications (OR 1.14), readmissions (OR 1.25), reoperations (OR 1.56), and total healthcare charges (OR 1.18), but lower surgical complications (OR 0.51) and more favorable discharge dispositions. However, a Japanese propensity score-matched study by Matsumura et al. (2024) found that simultaneous BTKA was associated with higher overall complication rates (26% vs. 13%, $p = 0.026$) and cardiovascular complications (4.3% vs. 0%, $p = 0.043$), despite shorter operative times and hospital stays. A single-institution study also confirmed that, after adjusting for baseline differences, simultaneous surgery was associated with higher complication risks, particularly among patients older than 70 years (Bruno et al., 2022; Giaccherini et al., 2019; Lenga et al., 2022, 2024; Ravi et al., 2018).

Despite extensive research, a significant evidence gap persists regarding functional outcomes, which have received relatively less attention compared with analyses of safety and complications. A systematic review by Qadir et al. (2021) concluded that moderate evidence suggested both simBTKA and staBTKA resulted in comparable improvements in functional scores, including the Knee Society Score (KSS), range of motion (ROM), Oxford Knee Score (OKS), and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), with no significant differences between the two procedures. However, this conclusion was based on only ten articles, all of which were retrospective studies involving heterogeneous patient populations, variable staging intervals, and limited long-term follow-up. The review emphasized that functional outcomes remain an underexplored aspect of the debate and that further high-quality studies are required to establish definitive conclusions. Furthermore, previous studies have rarely applied statistical methods to adjust for baseline differences, such as age, body mass index (BMI), and comorbidities, when comparing functional outcomes, potentially obscuring the true differences in treatment effects.

The primary gap addressed by this study is the limited and often contradictory evidence regarding comparative functional outcomes (ROM, WOMAC, and OKS) between simBTKA

and staBTKA after accounting for patient-specific confounding factors. Previous studies have frequently reported inconsistent findings, with some demonstrating no differences and others favoring one approach based on unadjusted bivariate analyses. The novelty of this study lies in its application of analysis of covariance (ANCOVA) to statistically control for key baseline differences (BMI, sex, and age) between patient groups, thereby providing a clearer assessment of the independent effect of surgical strategy on clinical outcomes. This approach is particularly relevant in the context of Indonesia's increasing healthcare burden associated with knee OA, as it may support clinical decision-making and health policy by providing more robust evidence regarding which procedure offers the optimal balance between functional recovery, safety, and resource utilization. The primary objective of this study is to compare clinical outcomes and complications between simBTKA and staBTKA in patients with severe knee OA, specifically by evaluating these outcomes after controlling for potential confounding variables to achieve a more valid comparison.

This research aims to provide robust evidence that can assist surgeons in selecting the most appropriate surgical strategy for individual patients, ultimately improving patient care and optimizing healthcare resource allocation. The findings are expected to have important practical implications: for surgeons, the results may support evidence-based patient selection and shared decision-making; for patients, a clearer understanding of the benefits and risks associated with each strategy may facilitate informed consent; and for healthcare systems, particularly those in resource-limited settings, evidence regarding the comparative efficiency and safety of simBTKA may inform policy decisions related to resource allocation and surgical prioritization. Additionally, this study contributes to the limited body of evidence regarding bilateral TKA outcomes in Southeast Asian populations, where cultural factors, such as kneeling during prayer, may influence functional expectations, postoperative demands, and recovery trajectories.

METHOD

Research Design

This study employed a retrospective cohort design to compare clinical outcomes, safety, and postoperative recovery between patients who underwent simBTKA and staTKA for severe bilateral knee OA. The study was conducted at dr. Cipto Mangunkusumo National Central General Hospital (RSCM), St. Carolus Hospital, and Fatmawati Central General Hospital from September 2024 to September 2025, using medical records from January 2021 to September 2024.

Population and Sample

Affordable Population

The affordable population comprised all patients with severe stage bilateral knee OA who underwent simBTKA or staTKA at the participating hospitals during the study period. The sample was a total sampling of all medical record data that met the eligibility criteria. Inclusion criteria were: adult patients aged 50–80 years, diagnosed with Kellgren-Lawrence grade IV bilateral OA, American Society of Anesthesiologists (ASA) class ≤ III, Body Mass Index (BMI) 18–35 kg/m², estimated glomerular filtration rate (eGFR) ≥ 60 mL/min/1.73m², those who underwent simBTKA or staTKA (with a 6–12 month interval between surgeries), and had a minimum one-year follow-up. Exclusion criteria were: history of active joint infection or

periprosthetic joint infection (PJI), previous knee surgery (including unicompartmental TKA, arthrodesis, osteotomy, or revision TKA), severe knee deformities (varus/valgus >20° or flexion contracture >20°), severe neuromuscular disorders affecting gait or function, and active systemic autoimmune diseases or malignancies. The dependent variables were the Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), incidence of complications (up to 36 months), range of motion (ROM), and length of stay (LOS). The independent variable was the type of surgery (simBTKA vs. staTKA). All data were collected from medical records, coded, and compiled. Data analysis was performed using SPSS version 25 for Windows. Numerical data were presented as mean ± standard deviation (SD) for normally distributed data or median (min-max) for non-normally distributed data. Normality was assessed using the Shapiro-Wilk test. For bivariate analysis, the independent T-test or Mann-Whitney U test was used as appropriate. To address potential confounding from baseline characteristic differences inherent in the retrospective design, an Analysis of Covariance (ANCOVA) was performed, adjusting for the covariates of BMI and sex to compare the primary outcomes between the two groups. A p-value of <0.05 was considered statistically significant.

Sample

The sample in this study is all medical record data of patients with severe bilateral OA who underwent simBTKA and staTKA surgery at the dr. Cipto Mangunkusumo National Central General Hospital (RSCM), Fatmawati Central General Hospital, and St. Carolus Hospital in the period January 2021 – September 2024 that meet the inclusion and exclusion criteria.

Inclusion Criteria

1. Adult patients aged at least 50 years to 80 years.
2. Patients diagnosed with severe bilateral osteoarthritis (Kellgren-Lawrence degree IV) that require TKA in both knees.
3. Physical status of American Society of Anesthesiologists (ASA) class ≤ III.
4. Patients with BMI (Body Mass Index) 18–35 kg/m².
5. Patients with *estimated glomerular filtration rate* / (eGFR) ≥ 60 mL/min/1.73m².
6. Patients undergoing simBTKA (two knees in one surgical session) or staTKA (two surgical sessions with a time interval of 6-12 months).
7. Patients with a *follow-up period* of at least 1 year.

Exclusion Criteria

1. Patients with a history of active joint infections, including osteomyelitis or PJI.
2. Patients with a history of previous knee surgery such as single-compartment TKA, arthrodesis, osteotomy, or revision TKA.
3. Patients with severe knee deformities such as varus/valgus deformity >20° or contracture flexion >20°.
4. Patients with severe neuromuscular disorders such as stroke with persistent neurological deficits that may affect the ability to walk or evaluate functional outputs.
5. Patients with active systemic autoimmune diseases such as rheumatoid arthritis, lupus, or malignancies.

Research Variables

Independent variables

In this study, the groups studied were the simTKA surgery group and the staTKA surgery group in severe knee OA.

Bound variables

The variables bound to this study are:

a. *Oxford Knee Score* (OKS) 12 months postoperatively, 12-24 months postoperatively and more than 24-36 months postoperatively.
b. *Western Ontario and McMaster Universities Osteoarthritis Index* (WOMAC) 12 months postoperatively, 12-24 months postoperatively and more than 24-36 months postoperatively.
c. The incidence of complications is up to 12-36 months postoperatively.
d. *Range of motion* (ROM) 12 months postoperatively, 12-24 months postoperatively and more than 24-36 months postoperatively.
e. Duration of stay (LOS)

Data Analysis

All examination data is collected, coded, compiled and processed with *the Statistical Package for the Social Sciences* (SPSS) 25 *for Windows* software. OKS, WOMAC, ROM, height, weight, and age data will be displayed numerically with the mean ± standard deviation (SD) for normally distributed data or median (min-max) for non-normally distributed data. Categorical data in the form of gender, BMI, and comorbidities will be displayed in the form of n (%). Numerical data will be tested normality with the Shapiro Wilk test for variables with less than 30 data counts or Smirnov Kolmogorov tests for more than 30 data counts. In each follow-up period, data from each group will be compared with the unpaired T-Test if it is normally distributed or with the Mann-Whitney U test if it is not normally distributed. Analysis in 1 treatment group will also be compared with the Anova One-Way test if the data are normally distributed or with the Kruskal Wallis test if the data are not normally distributed. If there are significant differences in the Anova One-Way test, the analysis will be followed by *a post-hoc* analysis. The significant value used in this study was a $p<0.05$ value.

RESULTS AND DISCUSSION

This section presents the results of the bound variables measured in both groups, according to the research objectives.

1. Clinical External Comparison

Luaran klinis dievaluasi menggunakan Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoartritis Index (WOMAC) dan Range of Motion (ROM) sendi lutut.

Table 1. Clinical External Comparison

Variabel	SimBTKA group (n = 31)	StaTKA group (n = 31)	Value p
OKS	11 (3 – 31)	7 (3 – 37)	0,067*
WOMAC	28 (9 – 61)	14 (7 – 82)	0,012*
Postoperative Knee ROM (degree)	113.87 ± 16.16	116.46 ± 11.05	0,465**
Follow-Up Time			0,091*
≤12 months	4	1	
13-24 months	12	9	
>24 months	15	21	

Source: Prepared by the authors based on retrospective patient medical records from RSCM, St. Carolus Hospital, and Fatmawati General Hospital, analyzed using IBM SPSS Statistics (2025).

Mann Whitney **Independent T-test

Based on table 6, there was no significant difference in the clinical outcomes of OKS and postoperative knee ROM (p = 0.067 and 0.465, respectively). In this study, the Range of Motion (ROM) in the SimBTKA group was measured as a bilateral average at the final follow-up of at least 12 months postoperatively, where both knees were operated on in one anesthesia session. In contrast, in the StaBTKA group, the ROM was calculated as a bilateral average after the second surgical cure at the final follow-up of at least 12 months postoperatively. Thus, the comparison of ROMs between the two groups represents the final functional outputs of both knees assessed symmetrically at the time of full recovery of each procedure.

Significant differences in WOMAC clinical outcomes were found between the two groups, where the simBTKA group had a higher score (median = 28) compared to the staTKA group (median = 14). There was no difference in follow-up time in the two groups, so clinical outcomes could be compared without the time-confounding variables of follow-up.

2. Comparison of Postoperative Complications

Perioperative and postoperative complications were evaluated in both groups.

Table 2. Comparison of Postoperative Complications.

Complications	SimBTKA group (n = 31)	StaTKA group (n = 31)	Value p
Perdarahan (cc)	200 (100 – 300)	650 (200 – 1100)	<0.001*
Infection	0	0	N/A
DVT	0	0	N/A
Heart Complications	0	0	N/A

Source: Prepared by the authors based on retrospective clinical data from RSCM, St. Carolus Hospital, and Fatmawati General Hospital, analyzed using IBM SPSS Statistics (2025).

*Mann Whitney

Based on the data available, there are 2 cases of infection in the staTKA group (2/31; 6.45%) that have been excluded and no cases in the simBTKA group (0/31; 0%). No complications of deep vein thrombosis occurred in either group. Therefore, the p-value for such complications cannot be calculated (N/A). The amount of bleeding was found to be significantly higher in the staTKA group (median = 650 cc) compared to the simBTKA group (median = 200 cc) with a p value of <0.001.

3. Length of Stay (LOS)

Length of Stay was one of the variables evaluated. In this study, the StaBTKA group was analyzed based on the combined average LOS of two hospitalizations (first and second surgery), while the SimBTKA group had one hospitalization for both knees.

a. Calculation Method

1) SimBTKA Group (St. Carolus Hospital): LOS is taken from the number of days of hospitalization for one hospitalization for one episode of surgery.
2) StaBTKA GROUP (RSCM): LOS is calculated as an average of two hospitalizations per patient, namely: (right surgery LOS + left surgery LOS) / 2

b. LOS Calculation Results

Based on the results of the analysis of the master data of St. Carolus Hospital (SimBTKA) and RSCM (StaBTKA), the following results were obtained:

Table 3. LOS Comparison

Parameter	**SimBTKA group (n = 31)**	**StaTKA group (n = 31)**	**Value p**
Rerata LOS (hari)	4,90	3,16	—
Standard Deviation (SD)	1,80	0,55	—
Median (P50)	5	3	—
Range (Min–Max)	2 – 10	2,0 – 4,5	—
Statistical test*	t = 5,147	df = 35,55	Welch’s t-test
p-value*	0,00000988	—	Significance (p < 0.001)

Source: Prepared by the authors based on retrospective hospitalization data from RSCM and St. Carolus Hospital, analyzed using Welch's t-test in IBM SPSS Statistics (2025).

Description:

(*) The comparison of LOS between the simBTKA and staTKA groups was carried out using Welch's t-test because both groups had inhomogeneous variance (SD).

The duration of hospitalization was found to be longer in the simBTKA group compared to the staTKA group through the Mann Whitney test (p = <0.001).

Because this study was a non-randomized retrospective cohort, the basic characteristics between groups were inhomogeneous (e.g., simBTKA patients tended to be younger and healthier) and the outcomes were continuous (OKS, WOMAC, ROM, LOS). With the aim of making the results obtained more valid and controlled for confounders such as age, sex, and BMI, an ANCOVA (Analysis of Covariance) test was carried out so that the effect of the intervention (simBTKA vs staTKA) was purer.

4. ANCOVA Analysis

ANCOVA analysis was performed to compare clinical outcomes between the simBTKA and staTKA groups with adjustments for BMI and sex covariates. The adjusted mean values, 95% confidence interval (CI), and p-values of group effects are shown below:

Table 4. ANCOVA Analysis Results of simBTKA vs staTKA Clinical Outcomes

Exterior	*Adjusted Mean* (simBTKA)	*Adjusted Mean* (staTKA)	*Adjusted Difference* (simBTKA-staTKA)	*p-value (Group)*	Kovariat
OKS	10.85 [8.91, 12.79]	12.21 [10.38, 14.04]	−1.36	0.3221	BMI + gender
WOMAC	22.31 [18.20, 26.42]	28.72 [24.10, 33.34]	−6.41	0.0483	BMI + gender
ROM (°)	119.42 [115.11, 123.73]	112.80 [108.70, 116.90]	+6.62	0.0287	BMI + gender

Source: Prepared by the authors based on retrospective patient data analyzed using Analysis of Covariance (ANCOVA) with BMI and sex as covariates in IBM SPSS Statistics (2025).

Remarks: The Analysis of Covariance Model (ANCOVA) is adjusted for BMI and sex covariates. Adjusted mean is calculated on the population average BMI value and the mode sex category.

The adjusted mean of the OKS of the simBTKA group was lower than that of staTKA (10.85 vs 12.21), but this difference was not statistically significant ($p = 0.322$). This suggests that after adjusting for BMI and sex, both groups had similar knee functional outcomes. The postoperative WOMAC value in the simBTKA group was significantly better than that of staTKA (22.31 vs 28.72; $p = 0.0483$). These results confirm that the simBTKA approach has the potential to produce better functional outputs after controlling for confounding factors. The simBTKA group showed a significantly wider postoperative range of motion of the knee than the staTKA group (119.42° vs 112.80°; $p = 0.0287$). These findings are consistent with the literature reporting faster functional recovery in simBTKA patients.140

StaTKA Operating Interval

In comparative studies of bilateral TKA, the time interval between the first and second surgeries in staTKA is an important variable that can play a confounding factor in clinical outcomes, complications, and functional recovery. These interval variations can affect the patient's physiological status during the second surgery, including changes in hemoglobin levels, kidney function, muscle strength, and pain perception and rehabilitation capacity. Therefore, uniform evaluation and follow-up timing are important to maintain the validity of the comparison of the simBTKA group.

Data analysis showed that the average interval between the first and second surgeries was 8.4 ± 3.2 months, with a range of 6 to 15 months. Approximately 62% of patients undergo a second surgery at an interval of 9 months <, while the rest undergo a second surgery at a 9-month ≥ period due to clinical considerations such as anemia, transient comorbidities, or patient readiness. Thus, the intervals between operations are not entirely uniform, but these variations are still within the general range reported in the international literature. To reduce bias due to differences in recovery time, the researchers set an evaluation follow-up time of at least 12 months postoperatively after the second surgery. With this approach, all patients—both SimBTKA and StaBTKA—were evaluated in the full recovery phase after bilateral foreign workers, so that the influence of the time factor could be minimized.

Studies have shown that the operating interval in staBTKA varies widely and can affect clinical outcomes. Restrepo et al. and Meehan et al. reported that the optimal interval between

the first and second surgery was in the range of 3–12 months, with comparable functional outcomes when follow-up was performed after 12 months of the second surgery. Tao et al. in Knee Surgery & Related Research found that a 6-month interval < increased the risk of minor complications, while a 6-month > interval had no significant effect on ROM final outcomes and functional scores, provided that the evaluation was performed after complete recovery after the second surgery. Huang et al. in the Journal of Orthopaedic Surgery and Research also emphasized the importance of uniformity of evaluation times; The study recommends that clinical follow-up should be calculated ≥ 12 months after the second surgery for comparisons with simBTKA to be valid.

On this basis, the determination of a follow-up of at least 12 months postoperative in this study ensures the equivalence of the bilateral recovery phase between the StaBTKA and SimBTKA groups, so that time is no longer a confounding factor for functional outcomes (ROM, OKS, WOMAC, and KSS).

Clinical Externalities

This study compared clinical outcomes between patients undergoing Simultaneous Bilateral Total Knee Arthroplasty (simBTKA) and Staged Bilateral Total Knee Arthroplasty (staTKA). Follow-up analysis using Analysis of Covariance (ANCOVA) was performed to control for differences in patients' basic characteristics (BMI and sex) so that the comparison of outcomes between groups became more statistically valid.

The results of ANCOVA's analysis showed that: Postoperative WOMAC in the simBTKA group was significantly better than in the staTKA group ($p = 0.0483$), indicating symptoms of pain, stiffness, and milder activity limitation. The OKS showed no significant difference between groups ($p = 0.3221$), suggesting that the patient's functional perception of the knee postoperatively was relatively similar. The ROM in the simBTKA group was significantly larger than that of the staTKA ($p = 0.0287$), indicating a faster and more effective recovery of range of motion.

These findings differ in part from the reports of several previous studies that used a bivariate analysis approach. For example, a 2019 meta-analysis and a retrospective study by Lee et al. concluded that there was no significant difference between simBTKA and staTKA in terms of OKS, WOMAC, or ROM, at either short- and medium-term follow-up121. Similar results were also reported by Yalın et al. who found comparable functional outcomes and complications between the two approaches122,123. However, after covariate adjustment (ANCOVA), this study showed that simBTKA resulted in better WOMAC and significantly higher ROMs, which showed functional advantages after accounting for basic differences between groups.

The increase in WOMAC and ROM outputs in simBTKA can be explained through several mechanisms, namely: 1). Simultaneous surgical implementation allows the rehabilitation and neuromuscular adaptation phases to run symmetrically so that both knees undergo a parallel recovery process and do not cause biomechanical imbalances as in staTKA. 2). One-time anesthesia exposure and an integrated physiotherapy program tend to result in faster functional recovery. In addition to biomechanical factors, psychological aspects also play an important role. In StaBTKA patients, the experience of intense pain in the first surgery can create fear ('kapok') and reduce motivation for aggressive exercises in the second knee. In

contrast, in SimBTKA, both knees undergo an identical recovery process, with no previous comparisons or traumatic experiences, so the patient is more consistent in the exercises.

In the context of Indonesian culture, where kneeling (such as in prayer) is an important functional activity, SimBTKA patients are often more motivated to achieve full flexion ROM in order to return to worship in a normal position. This religious motivation can be an additional driving factor that increases rehabilitation success.

Similar things were also reported in the study Kirschbaum et al. and Han et al. which showed improved functional recovery and faster ROM acquisition in simBTKA patients compared to the staTKA124,125 procedure. Although statistically significant, clinically the resulting ROM is relatively small.

Differences in pain control regimens between groups were not quantitatively analyzed in this study due to limitations of retrospective data. However, the three hospitals involved (RSCM, Fatmawati, St. Carolus) used similar perioperative pain management protocols, including a combination of spinal/epidural anesthesia, multimodal analgesia, and early mobilization. Thus, there is no indication that differences in analgesia regimens are the main cause of ROM differences.

Similarly, post-TKA rehabilitation programs throughout centers are relatively uniform, consisting of passive and active ROM exercises, quadriceps strengthening, and ambulatory exercises. The main difference lies in the pattern of patient participation, where SimBTKA undergoes one integrated rehabilitation curve, while StaBTKA undergoes two separate curves with a risk of decreased adherence in the second phase.

Although the results showed a statistically significant difference, clinically the difference in ROM produced was relatively small (small effect size). In addition, non-clinical factors such as differences in facilities, socioeconomics, as well as the intensity of individual rehabilitation cannot be fully controlled.

Thus, the difference in better ROMs in SimBTKA is likely to reflect the synergistic effect between simultaneous recovery, high functional motivation, and more consistent rehabilitation, rather than simply due to differences in pain control or physiotherapy protocols.

The existence of insurance bias due to differences in hospitals and facilities also cannot be ruled out, where the simBTKA group is treated in private hospitals with the majority using private insurance and the staTKA group is treated in government-owned vertical hospitals with the majority using national insurance (BPJS). Variation mitigation measures have been carried out by only including cases handled by pelvic and knee consultants or pelvic and knee trainees who have an equivalent level of relative competence. In addition, all centers use asepsis and infection prevention protocols that follow national standards (operating room sterility SOPs and the use of antibiotic prophylaxis).

Thus, the findings of this study are consistent with the literature supporting that simBTKA provides functional outputs equal to or better than staTKA, particularly in terms of range of motion and early recovery efficiency, without increasing the risk of significant complications when performed in patients with strict selection and stable systemic conditions.

Complications and Length of Stay

No complications of deep vein thrombosis were found in either group in this study. Several studies suggest that there is no difference in the incidence of venous thromboembolism in simBTKA and staTKA125,126. In contrast to the study, the study by Makaram et al showed

higher venous thromboembolic complications in simBTKA. Longer duration of a single procedure, prolonged rehabilitation, or delayed mobilization in simTKA may explain the increased incidence of deep vein thrombosis. The combination of bilateral tourniquet use and bilateral intramedullary rods theoretically increases the risk of fat embolism; because it can increase intracanal pressure and push marrow fat into the circulation127.

The amount of bleeding at the time of surgery was found to be more in the staTKA group than in the simBTKA group (median 650 cc vs 200 cc; p = <0.001). This is in line with a meta-analysis study by Ramezani et al. in 2022 where bleeding was found to be lower in the TKA procedure performed simultaneously, although the difference did not affect the need for transfusions in patients128. However, studies by Matsumura et al. and Kirschbaum et al. showed no difference in bleeding between the two groups127,129. Another study suggested simBTKA had a higher risk of bleeding compared to staTKA due to its longer duration130.

In this study, there were no cases in either group that had the infection. Studies in Japan show no difference between the two groups in complications of infection127. Another study suggested a higher risk of infection in the staTKA group. This increased risk of infection may be explained by increased exposure to microorganisms with two separate measures accompanied by an increase in total hospitalization128,129. Differences in patient demographics, surgical techniques, and perioperative management may explain the differences in these studies.

In a comparative study of non-randomized bilateral foreign workers, infection risk assessment requires an analytical approach that considers the fundamental differences between simultaneous and staged strategies. Horizon-based risk evaluation was used to ensure equivalence of physiological exposure and perioperative burden between the two groups. In simBTKA, both knees are performed in one surgery session and one anesthesia, so that the duration of perioperative exposure comes from only one episode of action. In contrast, in staBTKA, the patient undergoes two separate surgeries; So that the evaluation of the risk of infection is carried out based on the second operation, which is the point of completion of the bilateral intervention as a whole. With this approach, the risk horizon becomes commensurate between simBTKA and staBTKA.

The results of statistical analysis showed a very significant difference in the duration of surgery between the two groups. In simBTKA, the average duration of surgery was recorded at 65.77 ± 9.86 minutes, while the second operation in the staBTKA group took 211.15 ± 44.70 minutes. The abnormal distribution necessitated the use of the non-parametric Mann–Whitney U assay, which yielded a p< value of 0.001 with an effect size of 1.00—indicating a clinically significant difference.

Table 5. Comparison of Duration of Operation

Variabel	**SimBTKA group (n = 31)**	**StaTKA Group (n = 31)**
Average ± elementary school (minutes)	65.77 ± 9.86	211.15 ± 44.70
Median (IQR) (minutes)	68.0 (58.5 – 73.5)	210.0 (181.2 – 238.0)
Statistical tests used	Mann–Whitney U test (non-parametrik)	
p-value	< 0.001 (4.58×10^{-12})	

Variabel	SimBTKA group (n = 31)	StaTKA Group (n = 31)
Effect size (rank-biserial correlation)	1.00 (very big effect)	

Source: Prepared by the authors based on retrospective operative data from RSCM, St. Carolus Hospital, and Fatmawati General Hospital, analyzed using the Mann–Whitney U test in IBM SPSS Statistics (2025).

This difference in the duration of the operation has important physiological implications. Longer surgical durations are known to increase the risk of wound space contamination, prolong tissue exposure to the operating environment, and increase the patient's inflammatory and metabolic load. Therefore, the operation of both staBTKA conceptually has a higher risk of infection than simBTKA, despite uniform techniques and operators.

However, the findings of two cases of infection in the staBTKA group and zero in simBTKA in this study are only descriptive, not inferentially analyzed, and cannot be used as a basis for concluding that simBTKA is safer than staBTKA. The findings were strongly influenced by host variability, hospital contexts, and different procedure characteristics between service centers.

Physiologically, staBTKA patients enter a second operation in a major postoperative condition with the potential for decreased hemoglobin, altered renal function, metabolic stress, and decreased immunological reserves. In addition to host factors, the clinical characteristics and comorbidities of patients also make significant contributions.

Variation in intervals between operations is also an important determinant. The mean interval of 8.4 ± 3.2 months reflects substantial heterogeneity. Surgery performed too quickly (<6 months) may overlap with the residual inflammatory phase, while excessively long intervals (>12 months) may increase tissue fibrosis, thus prolonging the duration of surgery.

No incidence of heart complications was found in this study. Several studies showed no difference in the incidence of heart complications in the simBTKA and staTKA130,131 groups. However, other studies showed an increased risk of heart complications in the simBTKA132 group. Systematic review studies showed differences in the risk of heart complications were found only in studies with unequal demographic characteristics. In studies with the same demographic characteristics, there was no difference in the incidence of heart complications133.

The average LOS in the simBTKA group was 4.90 ± 1.80 days, while in the staBTKA group it was 3.16 ± 0.55 days. Thus in this study, when compared per episode of hospitalization, the simBTKA group showed a slightly longer LOS. These findings are in line with a number of international publications reporting that, when calculated per single period of hospitalization, simBTKA patients tend to have the same or slightly longer LOS compared to the average LOS in staBTKA. Makaram et al. (2021) in the Journal of Arthroplasty reported that the LOS per episode in simBTKA was slightly higher than the average LOS staBTKA, which was associated with the need for simultaneous observation and recovery of both knees in a single anesthesia session. Fu et al. (2013) also confirmed a similar pattern, in which simBTKA had a relatively longer LOS per episode due to bilateral surgical burden and more intensive postoperative monitoring134,135. Research by Kirschbaum et al. (2024) found that the average LOS simBTKA reached 7.8 ± 2.1 days, slightly longer than the 7.4 ± 1.7 days on average staBTKA,

with a statistically insignificant difference. This phenomenon is reinforced by the report Yalin et al. (2024) which explains that the elongation of LOS per episode in simBTKA is a logical consequence of the double surgical load136,137. The results of this study showed that the LOS per episode of simBTKA hospitalization was slightly longer compared to the average LOS staBTKA due to :(1) the burden of bilateral surgery in a single anesthetic, (2) the need for slightly more intensive postoperative monitoring, and (3) the tendency of clinicians to hold patients one or two days longer on simBTKA episodes to ensure stability of both knees before discharge138.

The need for revision was found to be more in the staTKA group than in the simBTKA (2 vs 0) although it was not statistically significant ($p = 0.649$). The study by Fu et al. showed a lower risk of revision needs in the simBTKA group. This study explains that this is related to the decreased risk of infection in the simBTKA72 group. However, more recent meta-analysis studies show no difference in the need for revision in the two groups139.

CONCLUSION

Based on the comparative analysis between simBTKA and staTKA after adjustment for covariates (BMI and sex) using analysis of covariance (ANCOVA), several important conclusions can be drawn regarding the clinical outcomes and safety profiles of these two surgical strategies in patients with severe bilateral knee osteoarthritis.

After covariate adjustment, the postoperative WOMAC score in the simBTKA group was significantly better than that in the staTKA group (adjusted mean 22.31 vs. 28.72, $p = 0.0483$), indicating that patients undergoing simBTKA experienced less pain, stiffness, and functional limitation. Similarly, postoperative range of motion (ROM) was significantly greater in the simBTKA group than in the staTKA group (adjusted mean 119.42° vs. 112.80°, $p = 0.0287$), suggesting more effective recovery of knee mobility. However, no significant difference was observed in the Oxford Knee Score (OKS) between the two groups (adjusted mean 10.85 vs. 12.21, $p = 0.3221$), indicating that patients' overall perceptions of knee function were comparable regardless of the surgical strategy. Regarding safety outcomes, intraoperative blood loss was significantly higher in the staTKA group than in the simBTKA group (median 650 cc vs. 200 cc, $p < 0.001$). No major complications, including deep vein thrombosis (DVT), cardiac events, or infections, were observed in either group, although two infection cases were descriptively identified in the staTKA group. The length of hospital stay per admission episode was significantly longer in the simBTKA group than in the staTKA group (4.90 vs. 3.16 days, $p < 0.001$), reflecting the greater perioperative burden associated with simultaneous bilateral surgery. These findings suggest that simBTKA was not inferior to staTKA in terms of postoperative safety and, when performed in appropriately selected patients, may provide superior functional outcomes based on WOMAC scores and ROM without increasing the risk of major complications. Additionally, simBTKA was associated with lower intraoperative blood loss compared with staTKA.

For future research, several recommendations are proposed to further advance understanding of the optimal surgical strategies for bilateral knee OA. First, prospective randomized controlled trials with larger sample sizes and standardized perioperative protocols are needed to validate these findings and minimize selection bias associated with retrospective study designs. Second, future studies should include longer follow-up periods beyond 36

months to assess the durability of functional outcomes, long-term revision rates, and implant survival in both simBTKA and staTKA groups. Third, comprehensive cost-effectiveness analyses incorporating direct medical costs, indirect costs, and quality-adjusted life years (QALYs) are warranted to support healthcare policy decisions, particularly in resource-limited settings. Fourth, future research should investigate patient-specific risk stratification models to identify subgroups that may derive greater benefits from each surgical strategy, thereby facilitating personalized surgical decision-making. Fifth, studies evaluating the influence of cultural factors, such as kneeling and squatting activities in daily life and religious practices, on functional outcomes and patient satisfaction would provide valuable insights, particularly among Southeast Asian populations. Finally, multicenter collaborative studies using standardized data collection methods, consistent outcome measures, and uniform follow-up protocols are recommended to improve the generalizability of findings and strengthen the evidence base for clinical guidelines regarding bilateral total knee arthroplasty (TKA).

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