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Clinical Outcomes of Medial Bicompartmental Knee Arthroplasty Versus Total Knee Arthroplasty for Bicompartmental Knee Osteoarthritis: A Propensity Score-Matched Study

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Abstract

Objective: To compare the clinical effectiveness of medial bicompartmental knee arthroplasty (M-BCA), defined as medial unicompartmental knee arthroplasty combined with patellofemoral arthroplasty, versus total knee arthroplasty (TKA) for bicompartmental knee osteoarthritis using multidimensional quantitative outcomes.

Methods: A prospective cohort study was conducted in patients with bicompartmental knee osteoarthritis undergoing arthroplasty. Propensity score matching (PSM) was performed using age, sex, body mass index (BMI), knee range of motion (ROM), American Knee Society Score (KSS), and patient blood volume (PBV) as covariates, with 1:1 nearest-neighbor matching and a caliper of 0.02. From

January 2024 to April 2026, 84 patients were included (42 per group). Perioperative hemoglobin (Hb) and hematocrit (HCT) were monitored, and total and hidden blood loss were calculated using the Nadler and Ward/Cross formulas. ROM reliability was assessed by two independent observers (ICC > 0.85). Functional outcomes were evaluated using KSS, Forgotten Joint Score-12 (FJS-12), Timed Up and Go (TUG) test, and 6-minute walk test (6MWT). D-dimer levels and lower-extremity Doppler ultrasonography were recorded to assess thrombotic events and perioperative complications.

Results: All 84 patients completed a mean follow-up of 10.81 ± 4.16 months. Baseline characteristics were well balanced after PSM ($P > 0.05$). M-BCA had a longer operative time than TKA (93.3 ± 17.9 vs. 84.3 ± 13.3 min, $P < 0.05$), but significantly less total blood loss at postoperative day 7 and a shorter hospital stay (10.81 ± 3.34 vs. 12.48 ± 3.65 days, $P < 0.05$). From 1 week postoperatively, ROM and improvement from baseline were significantly greater with M-BCA ($P < 0.05$). At 3 months, M-BCA showed greater improvements in KSS, higher FJS-12 scores, better TUG performance, and greater 6MWT distances than TKA. At follow-up beyond 1 year, 19 patients in each group were available for analysis; the M-BCA group demonstrated significantly better FJS-12 scores and TUG performance than the TKA group ($P < 0.05$). No significant between-group differences were observed in postoperative lower-extremity venous thrombosis or follow-up complications ($P > 0.05$).

Conclusion: M-BCA provides less blood loss, faster functional recovery, and shorter

hospitalization than TKA for bicompartmental knee osteoarthritis. Preservation of the cruciate ligaments and intact lateral compartment may enhance proprioception and motor function, resulting in more physiological and natural postoperative knee function.

Keywords: Medial bicompartmental knee arthroplasty; Total knee arthroplasty; Bicompartmental knee osteoarthritis; Propensity score matching.

Introduction

Knee osteoarthritis (KOA) commonly involves the medial tibiofemoral and patellofemoral compartments , with bicompartmental involvement accounting for approximately 28%–33% of patients with KOA[1-2]. Total knee arthroplasty (TKA) remains the conventional treatment for such patients and involves reconstruction of the entire knee joint). However, in patients with an intact lateral compartment and preserved anterior and posterior cruciate ligaments, TKA requires more extensive bone resection and soft-tissue disruption and may compromise native proprioception, potentially resulting in prolonged postoperative recovery. Furthermore, approximately 10%–20% of patients remain dissatisfied with their postoperative function or overall joint status[3]. Previous studies have suggested that even with cruciate-retaining implants, resection of the anterior cruciate ligament and alteration of the joint line may contribute to postoperative sensations of stiffness or an unnatural knee[4], highlighting the potential functional benefits of preserving healthy native structures.Medial bicompartmental knee arthroplasty (M-BCA), combining medial unicompartmental knee arthroplasty with patellofemoral arthroplasty, selectively

addresses the diseased compartments while preserving the intact lateral compartment and anterior and posterior cruciate ligaments.

Accordingly, M-BCA has been proposed as an “on-demand replacement” strategy [5-8]. Early bicompartmental arthroplasty was associated with relatively high failure rates, largely because monolithic implants offered limited anatomical adaptability[9]. With advances in modular and anatomically matched prosthetic designs, M-BCA has regained increasing clinical interest. Theoretically, by minimizing bone resection and preserving native ligamentous and articular structures, M-BCA may reduce surgical trauma, facilitate earlier functional recovery, and better preserve proprioception, making it an attractive option for younger and more active patients[10-11]. Nevertheless, quantitative evidence regarding early postoperative recovery and occult trauma following M-BCA remains limited.

To minimize heterogeneity associated with differences in surgical procedures and patterns of compartmental involvement, the present study was restricted to patients undergoing medial bicompartmental arthroplasty. Propensity score matching (PSM) was used to balance potential confounding factors between the M-BCA and TKA groups, using 1:1 nearest-neighbor matching with a caliper width of 0.02. Multidimensional quantitative outcomes were used to compare perioperative parameters and early recovery through 3 months after surgery between the two procedures (n=42 matched pairs). In addition, a nested paired subgroup (n=19 matched pairs) was prospectively evaluated to characterize the trajectory of clinical outcomes through 1 year. This study aimed to provide quantitative evidence regarding

the early clinical benefits of M-BCA and to inform procedure selection for patients with bicompartmental KOA.

Materials and Methods

General Information and Matching Strategy

A prospective surgical intervention cohort of patients with bicompartmental knee osteoarthritis was established, with a rigorous study design applied to patients scheduled to undergo arthroplasty. First, strict eligibility criteria were applied, and only patients undergoing medial bicompartmental knee arthroplasty (M-BCA) were included to minimize potential confounding from the biomechanical differences associated with lateral unicompartmental arthroplasty. Second, propensity score matching (PSM) was performed using age, sex, body mass index (BMI), knee range of motion (ROM), American Knee Society Score (KSS)[12], and preoperative patient blood volume (PBV) as covariates. A 1:1 nearest-neighbor matching algorithm with a caliper width of 0.02 was used to control and minimize potential confounding bias. From January 2024 to April 2026, a total of 84 eligible patients were included, with 42 patients in each of the M-BCA and TKA groups.

The primary outcome of this study was early postoperative recovery during the perioperative period and the first 3 months after surgery, based on the complete matched cohort of 42 pairs. To further investigate the longitudinal evolution of outcomes following M-BCA during follow-up, a nested paired subgroup (NPS) design was implemented within the aforementioned complete cohort. Nineteen matched pairs with complete 1-year follow-up data were selected to construct a “19 vs. 19” nested

subgroup. This approach enabled an extended analysis of 1-year postoperative outcomes, including joint movement coordination and preservation of proprioception, while maintaining the baseline balance achieved by propensity score matching.

Inclusion and Exclusion Criteria

Inclusion Criteria (based on the indications for TKA and M-BCA[13])

(1)A definitive diagnosis of knee osteoarthritis, with imaging confirming severe disease involving the medial tibiofemoral and patellofemoral compartments, with an Ahlbäck grade ≥2.(2)Normal function and tension of both the anterior and posterior cruciate ligaments, confirmed by preoperative physical examination and magnetic resonance imaging (MRI), and ultimately verified by direct intraoperative inspection. The cartilage of the lateral tibiofemoral compartment was intact, with an Outerbridge cartilage injury grade ≤I. (3)Varus deformity ≤15° or valgus deformity ≤10°, with the deformity passively correctable; knee flexion ≥100° and flexion contracture ≤5°.

Exclusion Criteria

(1) Concomitant rheumatoid arthritis, ankylosing spondylitis, hemophilic arthropathy, gouty arthritis, or other secondary systemic inflammatory arthropathies. (2)A history of infection or osteomyelitis involving the affected knee. (3)Severe underlying medical conditions, such as cardiac insufficiency or hepatic or renal dysfunction. (4)Laboratory evidence of coagulation abnormalities, hereditary bleeding disorders, or ongoing anticoagulant therapy that could not be appropriately bridged or substituted.(5)A history of major stress ulcer or active gastrointestinal bleeding within the previous 3 months, or a history of lower-extremity deep vein

thrombosis.(6)Severe neurological or psychiatric disorders that could impair sensory feedback or result in poor compliance.(7)Participation in or receipt of any non-standardized investigational drug or medical device clinical trial within the previous 3 months.(8)Previous surgical intervention on the affected limb.(9)Loss to follow-up or incomplete follow-up data after surgery.

Key Surgical Procedures and Perioperative Management

Surgical Techniques and Key Technical Considerations

To minimize bias arising from differences in surgeon experience, all procedures were performed by the same team of experienced joint surgeons according to a standardized surgical protocol. Both groups were placed in the supine position and underwent spinal anesthesia, with a tourniquet applied throughout the procedure. A standard anterior midline incision and medial parapatellar approach were used for surgical exposure in both groups.

(1) M-BCA

A modular bicompartmental reconstruction was performed using a medial unicompartmental knee arthroplasty (UKA) system and a patellofemoral arthroplasty (PFA) system from Zimmer Biomet (USA). For UKA, the Zimmer Biomet ZUK® fixed-bearing system was used, with dynamic balancing of the flexion–extension gaps as the guiding principle, or the Oxford® mobile-bearing system, based on the principles of “restoration of ligament tension” and “gap balancing.” For PFA, the Gender Solutions® patellofemoral system was used, and patellar resurfacing was performed in all patients.

Both procedures followed a standardized surgical protocol, with UKA performed before PFA. During UKA, the superior margin of the femoral component was kept below the entry point of the intramedullary canal to avoid an oversized component and potential overlap with the PFA component. A bone bridge of at least 2–3 mm was preserved to facilitate appropriate integration between the two components. The UKA trial component was left in situ during PFA to facilitate 3°–5° of external rotation of the femoral cut. Milling depth was carefully controlled to avoid component overlap or the formation of a step-off between the components. After trial component placement, patellar tracking was carefully assessed to ensure smooth tracking without catching, tilting, or subluxation.

(2) TKA

Standard surface replacement was performed using the AK Medical A3® posterior-stabilized (PS) total knee system (Beijing AK Medical Co., Ltd.). Mechanical alignment and measured resection techniques were used. The tibia was positioned using an extramedullary guide with 3°–5° of posterior slope, while the femur was positioned using an intramedullary guide with 5°–7° of valgus and 3° of external rotation. Lower-limb alignment correction and soft-tissue balancing were performed according to standard TKA protocols.

Enhanced Recovery After Surgery (ERAS) Perioperative Management Protocol

Both groups underwent a standardized multidisciplinary enhanced recovery after surgery (ERAS) perioperative care pathway developed based on existing clinical guidelines and consensus recommendations[14].

(1) Hemostasis and Blood Loss Control

Hemostatic management: Previous meta-analyses and clinical guidelines have supported the use of tranexamic acid (TXA) to reduce perioperative blood loss and transfusion requirements in TKA, without an overall increase in the risk of thromboembolic events[15-16]. In the present study, a combined regimen of intra-articular topical infiltration and sequential intravenous administration of TXA was adopted, consisting of intraoperative intra-articular administration followed by intravenous infusion for 3 consecutive postoperative days.

Drainage management: A drain-free strategy was adopted in both groups. Hemoglobin and hematocrit levels were closely and dynamically monitored throughout the perioperative period.

(2) Multimodal Analgesia

Intraoperatively,the surgeon performed peri-incisional local infiltration analgesia using a “cocktail” consisting of ropivacaine and lidocaine. Postoperatively, patient-controlled intravenous analgesia was maintained for 48 hours and combined with nonsteroidal anti-inflammatory drugs and the weak opioid tramadol to provide multimodal, stepwise analgesia.

(3) Thrombosis and Infection Prophylaxis

Short-course antibiotic prophylaxis: A second-generation cephalosporin was administered prophylactically 30 minutes before skin incision; clindamycin was used in patients with cephalosporin allergy. Antibiotics were routinely discontinued after 24 hours postoperatively.

Two-stage thromboprophylaxis:Low-molecular-weight heparin was administered subcutaneously 12 hours after surgery, followed by oral rivaroxaban from the next day through postoperative day 14 for venous thromboembolism prophylaxis.

(4) Functional Rehabilitation and Discharge Criteria

Functional rehabilitation: Bedside rehabilitation was initiated on postoperative day 1 under the guidance of a rehabilitation therapist, including ankle-pump exercises and isometric muscle-strengthening exercises. On postoperative day 2, continuous passive motion (CPM) and active and passive range-of-motion (ROM) exercises were progressively introduced.

Discharge criteria: Discharge was based on objective functional criteria, including independent bedside and level-ground ambulation, achievement of the predefined knee ROM target, a dry and well-healed incision, and absence of systemic signs of infection.

Outcome Measures

(1) Time-Related Measures

Operative time: Defined as the time from skin incision to completion of wound closure, recorded in minutes (min).

Length of hospital stay: Defined as the number of days from the day of surgery to discharge after meeting predefined clinical criteria, recorded in days (d).

(2) Blood Loss Assessment

Hemoglobin (Hb) and hematocrit (HCT) levels were dynamically monitored preoperatively and on postoperative days 1, 4, and 7. Blood loss following joint

arthroplasty includes not only visible intraoperative blood loss and drain output but also hidden blood loss into the tissue compartments; therefore, reliance solely on estimated intraoperative blood loss may substantially underestimate the actual perioperative blood loss[17]. To accurately quantify this occult surgical trauma, the patient's blood volume (PBV) was calculated using the Nadler equation, and the Ward and Cross linear equations were subsequently applied to rigorously estimate hidden blood loss and total blood loss.

(3) Objective ROM Assessment and Reliability Testing

To ensure the objectivity of the measurements, ROM was assessed independently by two observers under blinded conditions. Interobserver reliability was evaluated using the intraclass correlation coefficient (ICC), with an ICC > 0.85 considered indicative of good agreement. The mean of the two measurements was used for the final statistical analysis. The specific assessment procedure was as follows:

Range of motion (ROM): ROM was assessed preoperatively and at 1 week, 2 weeks, 3 months, and 1 year postoperatively, with the maximum knee flexion angle recorded at each time point.

(4) Multidimensional Clinical Scale Assessment

To systematically evaluate postoperative functional recovery and sensorimotor performance, the following clinical scales and functional tests were used for longitudinal assessment:

American Knee Society Score (KSS): Assessed preoperatively and at 3 months, and 1 year postoperatively. Knee function was evaluated across multiple domains, including

pain, knee function, range of motion, muscle strength, knee stability, and flexion deformity, with a total score of 100 points.

Forgotten Joint Score-12 (FJS-12): Assessed at 3 months, and 1 year postoperatively. Scores range from 0 to 100 and reflect the patient's ability to “forget” the presence of the artificial joint during daily activities, thereby providing an assessment of higher-order recovery of proprioception.

Timed Up and Go (TUG) Test: Performed at 3 months and 1 year postoperatively. Without an assistive device, patients were instructed to rise from a standard armchair (seat height, 46 cm), walk 3 m at a safe and comfortable pace, turn around, and return to the chair and sit down. Patients were permitted to stop or rest during the test if necessary because of pain or other reasons. The completion time was recorded in seconds (s), with a shorter time indicating better lower-extremity functional mobility. Patients were allowed 1–2 practice trials to familiarize themselves with and understand the procedure, followed by a 10-minute rest before the next test.

6-Minute Walk Test (6MWT): Performed at 3 months and 1 year postoperatively. Without an assistive device, patients were instructed to walk for 6 minutes at a safe and comfortable pace. They were permitted to stop or rest during the test if necessary because of pain or other reasons. The total walking distance was recorded in meters (m), with a longer distance indicating better lower-extremity walking capacity. Patients were allowed 1–2 practice trials to familiarize themselves with and understand the procedure.

(5) Thrombotic Risk and Adverse Events

D-dimer levels were dynamically monitored throughout the perioperative period. Color Doppler ultrasonography of the bilateral lower-extremity arteries and veins was routinely performed at 1 week postoperatively, and the risk of deep vein thrombosis (DVT) was assessed based on the comprehensive findings. The incidence of adverse events was recorded during the 3-month and 1-year follow-up periods, including delayed local DVT, pulmonary embolism (PE), perioperative incisional edge ischemia with delayed wound healing, early aseptic prosthetic loosening, and acute superficial or deep periprosthetic infection.

Statistical Analysis

Data were analyzed using SPSS version 29.0. Normally distributed continuous variables were expressed as mean ± standard deviation ($\bar{x}\pm s$) and compared using the independent-samples t test. Non-normally distributed continuous variables were analyzed using nonparametric tests. Categorical variables were compared using the chi-square test. For longitudinal data measured at multiple time points, repeated-measures analysis of variance (RM-ANOVA) was used to assess the effects of time and group. A P value < 0.05 was considered statistically significant.

Results

Baseline Characteristics

After propensity score matching (PSM)(Figure 1), the two groups (42 matched pairs) were well balanced in terms of age, sex, BMI, KSS score, preoperative ROM, and preoperative blood volume, with no statistically significant between-group differences (all $P > 0.05$), indicating good baseline comparability (Table 1).

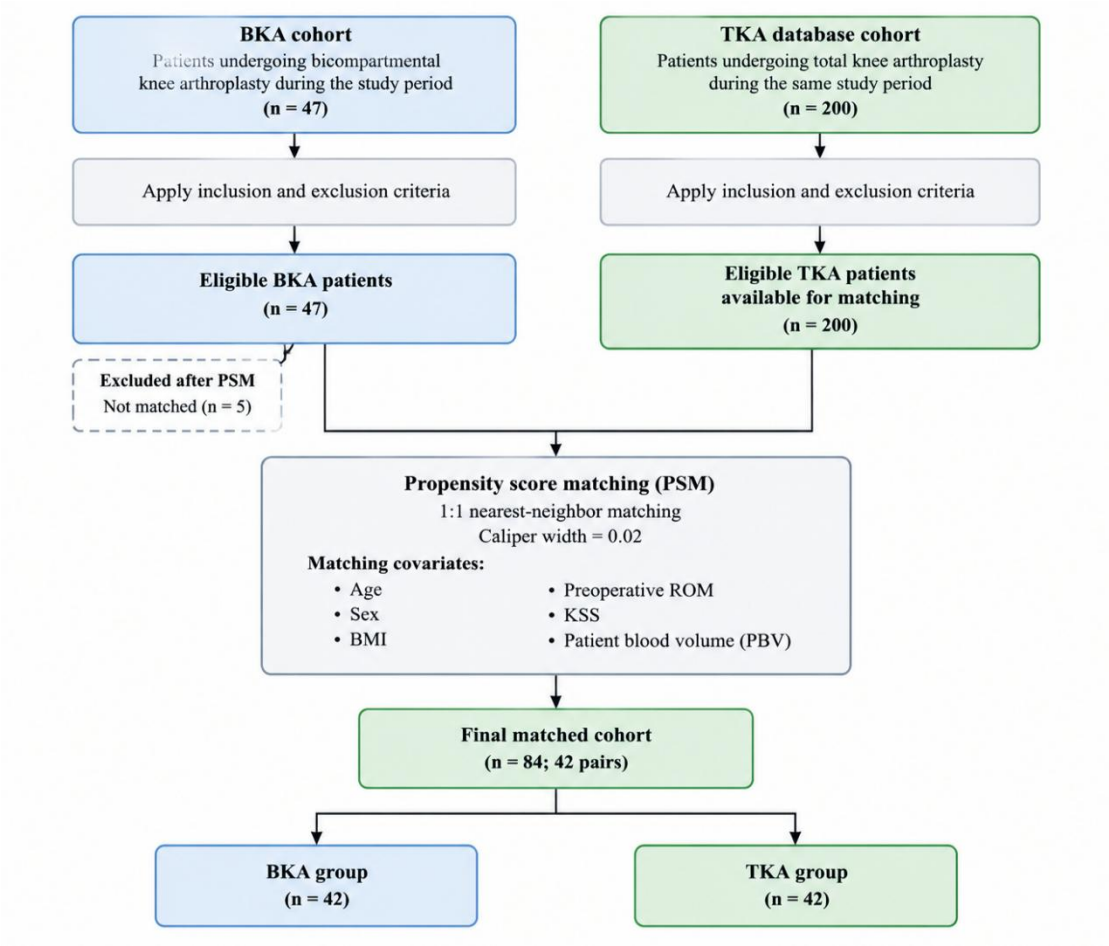


Figure 1. Flow diagram of patient selection and propensity score matching process.

Table 1. Comparison of Baseline Characteristics Between the Two Groups After Propensity Score Matching (mean ± SD)

Variable	M-BCA Group (n=42)	TKA Group (n=42)	Test statistic (t/χ^2)	*P*
Sex (male/female)	4/38	3/39	0.156	0.693
Age (years)	65.02 ± 4.13	65.48 ± 3.56	-0.538	0.592
BMI (kg/m²)	27.14 ± 3.59	28.05 ± 5.75	-0.870	0.387
Preoperative ROM (°)	106.21 ± 2.38	106.59 ± 2.15	-0.122	0.903
Preoperative KSS score (points)	56.26 ± 4.99	55.62 ± 4.85	0.599	0.551

Preoperative blood volume (mL)	4034.04 ± 567.18	4177.08±502.16	-1.246	0.2162

Comparison of Perioperative Total Blood Loss, Operative Time, and Length of Hospital Stay

Regarding blood loss, the M-BCA group had less perioperative total blood loss than the TKA group, with a statistically significant difference. The mean operative time was 93.3 ± 17.9 min in the M-BCA group, longer than the 84.3 ± 13.3 min in the TKA group ($P < 0.05$). Regarding length of hospital stay, patients in the M-BCA group reached the discharge criteria earlier, with a mean hospital stay of 10.81 ± 3.34 days, shorter than the 12.48 ± 3.65 days in the TKA group ($P < 0.05$) (Table 2).

Table 2. Comparison of Perioperative Total Blood Loss, Operative Time, and Length of Hospital Stay Between the Two Groups(mean ± SD)

Variable	M-BCA Group (n=42)	TKA Group (n=42)	t	P
Total blood loss (mL)	478.96 ± 416.28	679.09 ± 518.91	-1.982	0.0409
Operative time (min)	93.3 ± 17.9	84.3 ± 13.3	2.658	0.0095
Length of hospital stay (d)	10.81 ± 3.34	12.48 ± 3.65	-2.184	0.032

Multidimensional Assessment of Knee FunctionRegarding knee range of motion (ROM), the intraclass correlation coefficient (ICC) for ROM measurements was 0.93, indicating excellent interobserver agreement. The measured ROM was better in the M-BCA group than in the TKA group at 1 week, 2 weeks, and 3 months postoperatively ($P < 0.05$). Compared with preoperative ROM, the degree of

improvement in ROM was greater in the M-BCA group than in the TKA group ($P < 0.05$). A total of 38 patients (19 in each group) completed the 1-year follow-up. At 1 year postoperatively, ROM was slightly higher in the M-BCA group than in the TKA group, but the difference was not statistically significant(Table 3).

Table 3. Comparison of ROM Between the Two Groups Before and After Surgery（°，mean ± SD）

Time point	M-BCA Group	TKA Group	t	P
1week postoperatively(n=42)	101.50 ± 7.14	94.83 ± 6.28	4.543	0.000019
2weeks postoperatively(n=42)	112.64 ± 8.68	108.38 ± 6.26	2.581	0.012
3months postoperatively(n=42)	122.50 ± 5.85	116.06 ± 10.32	-3.517	0.001
1year postoperatively (n=19)	124.26 ± 5.02	123.32 ± 6.15	-0.52	0.606

Note: Compared with the preoperative values, the changes in ROM at 1 week, 2 weeks, and 3 months postoperatively showed a more favorable trend in the M-BCA group than in the TKA group (1 week: $t = 3.583$, $P = 0.001$; 2 weeks: $t = 2.201$, $P = 0.031$; 3 months: $t = -3.185$, $P = 0.002$).

Regarding the KSS, there was no significant difference in KSS scores between the M-BCA and TKA groups at 3 months postoperatively. However, compared with preoperative scores, the magnitude of improvement in knee function was greater in the M-BCA group than in the TKA group. At 1 year postoperatively, there was no significant difference in KSS scores between the two groups ($P > 0.05$) (Table 4).

Table 4. Comparison of KSS Scores Between the Two Groups Before and After

Surgery（mean ± SD）

Time point	M-BCA Group	TKA Group	*t*	*P*
3 months postoperatively (n=42)	83.05 ± 4.29	81.19 ± 4.29	-1.983	0.051
1 year postoperatively (n=19)	87.32 ± 3.96	85.47 ± 4.03	-1.421	0.164

Note: Compared with preoperative values, the magnitude of change in KSS scores at 3 months postoperatively was greater in the M-BCA group than in the TKA group ($t = -4.73$, $P = 0.00001$).

Regarding the FJS-12, the degree of joint forgetting was better in the M-BCA group than in the TKA group at both 3 months and 1 year postoperatively, with statistically significant differences ($P < 0.05$).

Regarding the Timed Up and Go (TUG) test, the M-BCA group performed better than the TKA group at 3 months postoperatively, and the M-BCA group continued to demonstrate an advantage in motor function at 1 year ($P < 0.05$).

Regarding the 6-minute walk test (6MWT), the M-BCA group performed better than the TKA group at 3 months postoperatively. At 1 year postoperatively, there was essentially no difference between the two groups P=0.236 (Table 5).

Table 5. Comparison of Postoperative FJS-12 Scores, Timed Up and Go Test, and

6-Minute Walk Test Between the Two Groups（mean ± SD）

Outcome measure	Time point	M-BCA Group	TKA Group	t	P
FJS-12	3 months postoperatively(n=42)	47.42 ± 6.02	43.58 ± 4.22	2.278	0.029
	1 year postoperatively (n=19)	69.84 ± 5.71	59.53 ± 4.21	6.341	<0.001
Timed Up and Go test (s)	3 months postoperatively(n=42)	14.31 ± 1.45	16.77 ± 1.48	-5.189	0.000009
	1 year postoperatively (n=19)	11.27 ± 1.37	12.56 ± 1.04	-3.275	0.002
6-Minute Walk Test (m)	3 months postoperatively(n=42)	382.47 ± 5.72	370.63 ± 8.92	4.871	0.000022
	1 year postoperatively (n=19)	427.47 ± 9.18	423.74 ± 9.90	1.206	0.236

Comparison of Perioperative Thrombotic Event Rates

Safety screening showed that postoperative bilateral lower-extremity ultrasonography detected intermuscular venous thrombosis in 9 patients (21.43%) in the M-BCA group and 15 patients (35.71%) in the TKA group. There was no statistically significant difference in the incidence between the two groups P=0.147. No patients in either group developed deep vein thrombosis (DVT), pulmonary embolism (PE), early prosthetic loosening, or joint infection(Table 6).

Table 6. Comparison of Intermuscular Venous Thrombosis Between the Two Groups at 1 Weeks Postoperatively

Outcome	M-BCA Group	TKA Group	χ^2	P
Incidence of intermuscular venous thrombosis	9/42	15/42	2.100	0.147

Discussion

Synergistic Effects of Trauma Control and Enhanced Recovery

In the clinical decision-making for bicompartmental knee osteoarthritis, a key objective of modern joint surgery is to achieve adequate pain relief while minimizing iatrogenic trauma. The present study demonstrated that M-BCA had clear advantages over conventional TKA in controlling perioperative total blood loss and shortening hospital stay, without increasing the risk of perioperative complications such as deep vein thrombosis (DVT). These findings are consistent with several previous clinical studies. As early as 2014, Heekin and Fokin et al[1].reported that nearly one-third of patients scheduled for TKA had bicompartmental degeneration essentially confined to the medial and patellofemoral compartments, suggesting that routine TKA may be relatively aggressive from a trauma perspective. A comparative clinical study by Yeo et al[18].likewise demonstrated that M-BCA could reduce perioperative blood loss by nearly one-third and shorten the mean hospital stay by approximately 1.5 days. Biazzo et al[19].further reported that this “need-based” and targeted replacement strategy reduced the systemic stress response while maintaining safety comparable to conventional TKA.Taken together, the present findings and previous evidence suggest that the “need-based replacement” concept of M-BCA avoids extensive bone resection associated with TKA while preserving the anterior and posterior cruciate ligaments and the intact lateral compartment[20]. This less invasive surgical approach is consistent with the principles of enhanced recovery after surgery (ERAS), potentially creating favorable physiological conditions for early postoperative mobilization and pain-free rehabilitation.

Kinematic Mechanisms and Trajectory Remodeling of Postoperative Knee Range of Motion

Data analysis showed that the ROM and the degree of improvement from preoperative values at 1 week, 2 weeks, and 3 months postoperatively were significantly greater in the M-BCA group than in the TKA group. The biomechanical basis of this early advantage may lie in the precise preservation of the anterior and posterior cruciate ligaments and the entire lateral compartment in M-BCA, thereby maintaining more physiological knee kinematics. This structural preservation not only provides stability during knee motion but may also contribute to improved postoperative joint control, facilitating earlier and safer participation in active functional rehabilitation.

At 1 year postoperatively, both groups achieved favorable ROM, and the between-group difference was no longer statistically significant $P = 0.606$. This finding objectively suggests that although TKA may be associated with a relatively longer rehabilitation period because of greater surgical trauma and impaired proprioception, structured rehabilitation can ultimately lead to satisfactory terminal ROM. As Heyse et al[21-22]. Reported in their medium- to long-term follow-up of M-BCA, the principal value of partial replacement lies in its “rapid early rehabilitation trajectory” rather than in achieving a greater absolute terminal flexion angle.

The findings of the present study are consistent with this observation. The primary clinical value of M-BCA in terms of ROM lies more in shortening the rehabilitation period and facilitating rapid early postoperative functional recovery.

Multidimensional Assessment of Subjective Naturalness and Objective Agility

In the present study, although there were no significant between-group differences in KSS scores at 3 months or 1 year postoperatively, the magnitude of improvement in KSS scores at 3 months was significantly greater in the M-BCA group than in the TKA group. More importantly, in terms of the Forgotten Joint Score-12 (FJS-12), which reflects proprioception and the perceived naturalness of the joint[23], the M-BCA group demonstrated a sustained and significant advantage over the TKA group at both 3 months and 1 year postoperatively ($P < 0.05$).

This difference in subjective satisfaction is highly consistent with the concept of the "forgotten joint" in joint arthroplasty. A large-scale survey by DeFrance et al.[3] demonstrated that although conventional TKA provides well-established clinical outcomes, approximately 10%–20% of patients remain dissatisfied with their functional performance because of joint stiffness or impaired proprioception. Parratte et al.[24]further provided a mechanistic explanation: preservation of the cruciate ligaments and physiological compartments also preserves the abundant neural mechanoreceptors within these structures, allowing continuous transmission of precise joint-position information to the central nervous system. Consequently, patients undergoing M-BCA may be more likely to achieve a "forgotten joint state," in which the presence of the prosthesis is barely perceived during daily activities, compared with patients undergoing TKA.

The FJS-12 findings in the present study support this theoretical framework, suggesting that preservation of anatomical and neural structural integrity with M-BCA

may provide patients with a subjective experience more closely resembling that of the native knee, making it easier to “forget” the presence of the artificial joint.

Additionally, the Timed Up and Go (TUG) test, as a simple and reproducible measure of functional mobility, provides a comprehensive assessment of overall mobility during a sequence of tasks involving sit-to-stand transfer, walking, turning, and returning to a seated position[25]. The 6-minute walk test (6MWT) was performed according to a standardized protocol to evaluate patients’ walking capacity and overall exercise endurance over a specified period[26]. Together, these two tests provided objective quantitative measures of patients’ dynamic functional performance. At 3 months postoperatively, the M-BCA group performed better on both tests. At 1 year postoperatively, the two groups showed comparable performance in long-distance lower-extremity endurance $P = 0.236$; however, the M-BCA group still required significantly less time to complete the TUG test, which involves agile postural transitions.

This finding can be explained from both biomechanical and neuromuscular control perspectives. Studies have shown that preservation of the ACL and PCL in BCA may enhance joint stability, reduce shear forces at the implant–bone interface compared with TKA, and maintain more physiological tibiofemoral kinematics while preserving rotational and translational motion, thereby allowing postoperative knee motion to more closely approximate normal patterns. Although BCA may exhibit a slight reduction in the extension moment between 70° and 90° of flexion, extension efficiency remains largely unaffected within the range of flexion required for daily

activities[27].

Gait analysis studies by Parratte and Garner et al.[24,28]have demonstrated that M-BCA, by preserving physiological structures, can maintain more physiological patellar and ligamentous moment arms and enable patients to achieve knee extensor moments closer to those of healthy individuals. In contrast, following conventional TKA, the knee adduction moment is reduced, while both the knee flexion moment during early stance and the knee extension moment during late stance are increased. At lower degrees of knee flexion, however, the extension moment is substantially reduced, resulting in a 12%–43% decrease in extensor efficiency within the range of motion required for daily activities.

Garner et al.[2]reported that cruciate-retaining M-BCA can better preserve near-physiological knee kinematics and extensor efficiency, thereby improving functional performance during dynamic tasks such as sit-to-stand transitions and changes of direction. The objective measurements in the present study further demonstrate that, for agile movements requiring postural transitions, dynamic balance, and coordinated neuromuscular control, M-BCA may provide more sustained functional benefits. This finding provides clinically relevant evidence for patients seeking to regain a high quality of life and high levels of physical activity after surgery.

Evidence-Based Evaluation of Long-Term Implant Survival and Revision Strategies

When evaluating the feasibility of M-BCA, long-term implant survival and the potential risk of revision are key clinical considerations. Holz et al[29].reported in a

retrospective study published in 2026 that the 6-year implant survival rate after BCA remained stable at 97.8% among 47 patients.

Parratte et al[30].investigated the long-term functional outcomes of BCA and retrospectively analyzed the clinical and radiographic outcomes of 84 patients with bicompartmental UKA (100 knees) and 71 patients with BCA (77 knees). The maximum follow-up period was 23 years, and the 17-year implant survival rate in the BCA group was 54%. However, these patients underwent surgery between April 1972 and December 2000. Considering that the 20-year survival rates of UKA and PFA implants during the same period were 80.2% and 69%, respectively, the relatively high revision rate of BCA may have been associated with limitations in early implant design and material-related factors.

A 10-year comparative study by Goh JKM et al.[31]showed no significant differences in 10-year implant survival or functional scores between BCA and TKA. Baba R et al.[32]reported that excessive filling of the patellofemoral joint should be avoided during PFA. In BCA, compared with TKA, patellofemoral overstuffing may have a greater impact on early postoperative knee function, placing higher technical demands on the surgeon.

Study Limitations

Although the present study demonstrated the clinical advantages of M-BCA through rigorous propensity score matching (PSM) and multidimensional outcome assessment, several limitations should be acknowledged. First, the single-center study design limits the generalizability of the findings, and the application of PSM cannot

completely eliminate bias arising from unmeasured confounding factors. Second, although the complete cohort (42 matched pairs) provided evidence supporting early accelerated recovery, the 1-year outcomes were based only on 19 matched pairs in the nested subgroup, limiting the representativeness of the findings. Therefore, the present study cannot yet adequately assess the long-term incidence of aseptic implant loosening, progression of lateral compartment degeneration, or revision rates following M-BCA. Finally, given the anatomical differences between the medial and lateral compartments, the findings of this study are applicable only to medial bicompartmental knee arthroplasty and should not be directly extrapolated to lateral unicompartmental knee arthroplasty. Future multicenter, large-scale, long-term prospective cohort studies are warranted to systematically characterize the treatment trajectory and long-term implant survival of this surgical strategy over its full clinical course.

Conclusion

In the clinical management of bicompartmental knee osteoarthritis, compared with conventional TKA, M-BCA, as a precise “need-based replacement” strategy, demonstrated favorable early clinical outcomes. By minimizing intramedullary canal violation and bone resection while preserving as much uninvolved tissue as possible, M-BCA reduced perioperative total blood loss and shortened hospital stay. In terms of functional reconstruction, M-BCA facilitated earlier recovery of knee range of motion (ROM) and functional performance. Furthermore, preservation of the anterior and posterior cruciate ligaments and the intact lateral compartment may contribute to

improved proprioception and motor agility, while its perioperative safety profile was comparable to that of conventional TKA.

Overall, M-BCA offers the potential advantages of less surgical trauma, faster recovery, better proprioception, and superior dynamic functional performance, and may represent a safe and reliable stepwise surgical option for appropriately selected patients with bicompartmental knee osteoarthritis. Further large-scale, long-term follow-up studies are warranted to provide more comprehensive evidence regarding the long-term implant survival and durability of this surgical strategy.

List of abbreviations

BMI Body mass index

CT Computed tomography

FJS-12 Forgotten Joint Score-12

HKA Hip-knee-ankle

ICC Intraclass correlation coefficient

KSS Knee Society Score

MCID Minimal clinically important difference

OKS Oxford Knee Score

PCL Posterior cruciate ligament

PS Posterior stabilized

PSM Propensity score matching

PROMs Patient-reported outcome measures

PTS Posterior tibial slope

RATKA Robot-assisted total knee arthroplasty

ROM Range of motion

SD Standard deviation

SMD Standardized mean difference

TKA Total knee arthroplasty

VAS Visual analogue scale

WOMAC Western Ontario and McMaster Universities Osteoarthritis Index

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Wangjing Hospital, China Academy of Chinese Medical Sciences on October 10, 2026 (approval number: WJEC-KT-2021-035-P006). Written informed consent was obtained from all participants before enrollment.

Consent for publication

Written informed consent for publication was obtained from each patient.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Qi Yan: Conceptualization, methodology, formal analysis, data curation, writing—original draft, writing—review & editing.

Boyi Chen, Siye Liu, Ximing Yu,Qianyu He,Xiaoqin Wang: Investigation, Data curation, Validation.

Lin Jing, Hongmei Zhang: Supervision, Project administration, Writing—review & editing.

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