CLINICAL ARTICLE

Mid-Term Outcomes of Navigation-Assisted Primary Total Knee Arthroplasty Using Adjusted Mechanical Alignment

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Objective: The adjusted mechanical alignment (aMA) technique is an extension of conventional mechanical alignment (MA), which has rarely been reported. The purpose of this study was to evaluate mid-term outcomes of navigation-assisted total knee arthroplasty (TKA) using aMA.

Methods: This retrospective cohort study enrolled 63 consecutive patients (77 knees) who underwent navigation-assisted TKA using aMA between September 2017 and October 2019. Fifty-two consecutive patients (61 knees) who underwent TKA using MA during the same period were assessed as the controlled group. The demographic data and perioperative data were recorded. The parameters of resection and soft tissue balance including tibia resection angle, frontal femoral angle, axial femoral angle, joint line translation, medial and lateral gap in extension and flexion position were recorded. Radiographic parameters and functional scores including the Hospital for Special Surgery (HSS) score, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, and Forgotten Joint Score-12 (FJS-12) were evaluated. Surgery-related complications were recorded. The average follow-up was 3.5 years, with a minimum of 2.4 years.

Results: The frontal femoral angle was $2.55^\circ \pm 1.08^\circ$ in aMA group *versus* $0.26^\circ \pm 0.60^\circ$ in MA group ($p < 0.001$). The axial femoral angle was $3.07^\circ \pm 2.23^\circ$ external in aMA group *versus* $2.30^\circ \pm 1.70^\circ$ in MA group ($p = 0.027$). The lateral flexion gap was wider in the aMA group, with a mean of 0.71 mm more laxity ($p = 0.001$). Postoperative coronal alignment was $177.03^\circ \pm 1.82^\circ$ in aMA group *versus* $178.14^\circ \pm 1.69^\circ$ in MA group ($p < 0.001$). The coronal femoral component angle was $92.62^\circ \pm 2.78^\circ$ in aMA group *versus* $90.85^\circ \pm 2.01^\circ$ in MA group ($p < 0.001$). Both aMA-TKA and MA-TKA achieved satisfactory mid-term clinical outcomes. However, the HSS scores at 1 month postoperatively were significantly higher using aMA than using MA ($p < 0.001$).

Conclusion: Navigation-assisted TKA using aMA technique obtained satisfactory mid-term clinical outcomes. The aMA technique aims to produce a biomimetic wider lateral flexion-extension gap and minimize releases of soft tissues, which might be associated with better early clinical outcomes than MA technique.

Key words: Adjusted mechanical alignment; Mechanical alignment; Navigation; Soft tissue balance; Total knee arthroplasty

Introduction

In recent decades, the mechanical alignment (MA) technique, which pursues a neutrally aligned lower limb, has been considered as the gold standard for total knee arthroplasty (TKA).[1] In mechanically aligned TKA (MA-TKA), resection of the femur and tibia was referred to as neutral axis, and soft tissue release techniques, such as pie crusting and multiple needle puncturing, were frequently

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performed to compensate for insufficient osteotomy and imbalanced flexion-extension gap.[2] MA-TKA leads to successful clinical results with good long-term prosthesis survivorship.[3] However, dissatisfaction after MA-TKA met approximately one in five patients, and high rates of disappointing residual symptoms were observed despite continuous evolution in prosthesis designs or artificial intelligence devices.[4]

To enhance patient satisfaction, multiple TKA alignment techniques have been proposed to challenge conventional MA-TKA. Alternative alignment philosophies consist of: (1) anatomic alignment (AA), characterized by a physiological oblique joint line relative to the mechanical axis.[5] The tibial resection was 3° varus and femoral resection was 3° valgus in coronal plane, which allowed the joint line to be parallel to the ground during the normal-stance phase of gait; (2) kinematic alignment (KA), characterized by maintained native pre-arthritis limb alignment and knee laxity with a pure bone resection procedure.[6] Kinematic positioning was based on personalized femoral flexion axis, tibial rotational axis, and patellar flexion axis to achieve prothesis anatomically implanted; (3) restricted kinematic alignment (rKA), characterized by adjusted kinematic alignment and joint line obliquity on the tibial side to compromise deformity in a safe zone (≤3°)[7]; (4) functional alignment (FA), characterized by preserved native obliquity, restored joint line height and achieve balanced mediolateral flexion-extension gaps by manipulating bone resections and implant positioning with robot assiatance.[8] The range of targeted alignment was (0° ± 3°); and (5) adjusted mechanical alignment (aMA), characterized by a slight constitutional deformity (maximum of 3°) preservation, and adjustment was made by fine-tuning the femoral bone resections and implant positioning without ligament release as much as possible.[9] The tibial osteotomy was still performed perpendicular to the mechanical axis of the tibia in the coronal plane. Of these, several studies have investigated the clinical outcomes of TKA between the MA-TKA and AA- or KA-TKA.[10,11] However, no comparative studies have focused on the aMA technique to assess the clinical results of TKA.

That is, the aMA technique is considered an extension of the conventional MA technique. This aligned technique aims to produce a biomimetic wider lateral flexion-extension gap and minimize soft tissue releases. Therefore, the aMA might be suggested as a more rational target to treat patients with constitutional knee deformity. The purpose of the present study was: (i) to verify the mid-term clinical efficacy of navigation-assisted TKA using aMA technique compared with those treated with MA technique; (ii) to summarize the features and advantages of navigation TKA using aMA technique.

Materials and Methods

Study Design

Our study was a retrospective cohort study approved by the Institutional Review Board of the First Affiliated Hospital of Soochow University [reference number: 2020(079–1)]. In addition, the study has been registered in Chinese Clinical Trial Registry (ChiCTR2200058660). Informed consent for publication was obtained from all patients.

Patients Recruitment

From September 2017 to October 2019, data of 63 consecutive cases (77 knees) of navigation-assisted TKA using aMA were retrospectively analyzed. Fifty-two consecutive patients (61 knees) who underwent MA-TKA during the same period were assessed as the controlled group. The inclusion criteria were: (i) patients who underwent primary TKAs for end-stage osteoarthritis or rheumatoid arthritis with varus or valgus deformity (no age and angle restrictions); (ii) consecutive cases of OrthoPilot navigation-assisted TKAs using aMA or MA technique with at least 2.4 years follow-up; (iii) all operations were performed by one single experienced orthopaedic surgeon. Patients were excluded if they had the following: (i) severe cardiopulmonary diseases achieved the criteria of New York Heart Association (NYHA) classification IV and American Society of Anesthesiologists (ASA) classification IV; (ii) history of previous knee surgery; (iii) a neuromuscular or neurosensory deficiency with muscle atrophy. The average follow-up was 3.5 years, with a minimum of 2.4 years.

Operative Techniques

All operations were performed using general anesthesia. A medial parapatellar capsular approach through a midline skin incision was used. All TKAs were performed using a cemented, fixed-bearing implant (Columbus UC, B. Braun Aesculap, Germany) with the assistance of the OrthoPilot navigation system (version 5.1; B. Braun Aesculap, Germany). Tibial preparation was performed first, and no patellar resurfacing was performed for all patients.

Briefly, the purpose of the aMA technique is to correct the constitutional coronal limb deformity into a safe zone (≤3°).[12] Unlike the MA technique, which required alignment correct to the neutral axis, the aMA technique allowed us to preserve slight constitutional frontal deformity due to the protection of soft tissue. Only severe coronal limb alignment deviation was adjusted to a safe zone. In addition, the adjustment of prosthesis positioning was fine-tuned on the femoral side while keeping the tibial side aligned the same as the MA.

In the aMA group, tibial and femoral transmitters were first positioned accordingly to capture the infrared for registration. After the approval of bony anatomical landmarks, the system automatically calculated the mechanical axis. Osteophytes were then removed. After that, the tibial cutting guide was positioned perpendicular to the mechanical tibial axis in coronal plane. The tibial component slope was set at 0°–3° posterior tilt. Then, tibial resection and verification were performed. Next, alignment on the femoral side was adjusted following the feedback of navigation. Distal resection of the femur was approximate varus or valgus to the line perpendicular to the femoral mechanical axis, aiming to restore joint line height and achieve balanced mediolateral

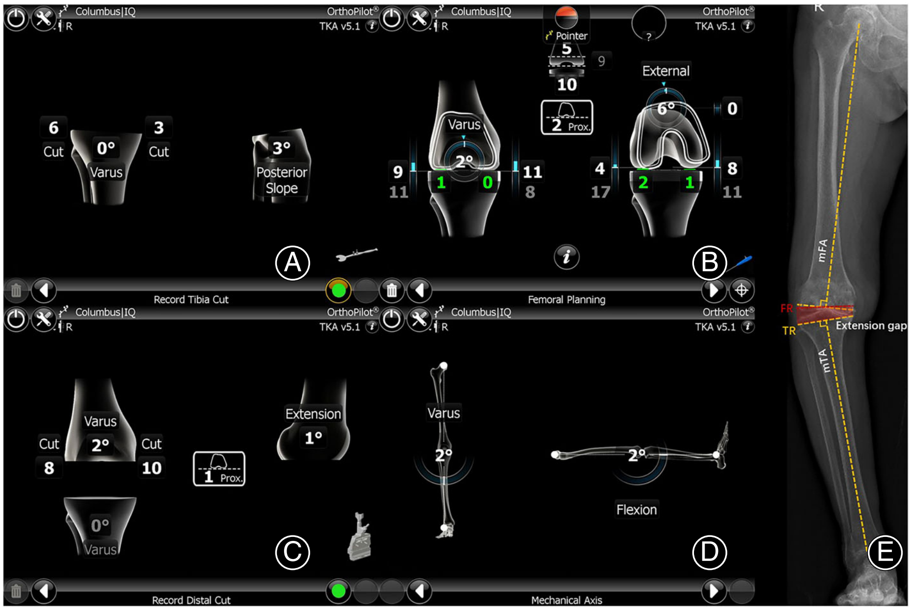

Fig. 1 Operation using the aMA technique assisted by the navigation system. (A) Tibial resection was perpendicular to the mechanical axis of the tibia. (B) A slight varus deformity was preserved on the femoral side with a biomimetic wider lateral flexion gap. (C) Record after resection of tibia and femur. (D) Final coronal alignment after cementation of the definitive prosthesis. (E) Illustration of aMA in a varus knee. Femoral resection (red) was more varus using aMA than MA (orange). mFA mechanical femoral axis; mTA mechanical tibial axis; FR femoral resection; TR tibial resection

extension gap without ligament releases. Moreover, the over-resection of distal femur was not allowed to avoid proximal translation of the joint line >3 mm and to maintain the stability of the knee during flexion. Then, an approximate rectangular flexion gap was obtained using the gap balancing technique by externally or internally rotating the femoral component. Notably, the aim of balance in aMA-TKA was not the routinely rectangular gap, but a balanced gap simulated with a physiological medial pivoting human knee. The lateral gap laxity was wider than the medial gap in extension and flexion with 1–2 mm more laxity. Femur resection was then performed in accordance with the cutting plan. Finally, trial prostheses were implanted, and a final set of checks, including stability, range of motion, and patellar tracking, were performed before cementation of the definitive prosthesis *in situ* (Fig. 1).

In the MA group, the basic surgical procedures were the same as described in the aMA technique. However, the goal of the MA technique was to achieve an overall neutral mechanical axis. Navigation was used to position both tibial and femoral cutting blocks at 90° to the mechanical axis of each bone. Moreover, the aim of balancing MA-TKA was to pursue a symmetrical rectangular gap. Ligament and soft tissue releases, such as pie crusting and multiple needle

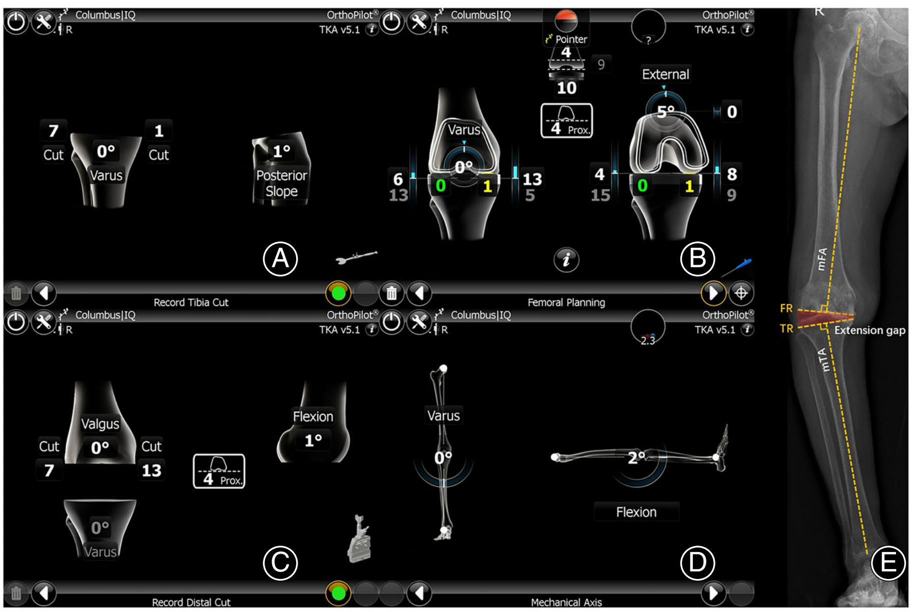

Fig. 2 Operation using the MA technique assisted by the navigation system. (A) Tibial resection was performed at 90° to the mechanical axis of the tibia. (B) Femoral resection was perpendicular to the mechanical axis of the femur. (C) Record after resection of tibia and femur. (D) Final coronal alignment after cementation of the definitive prosthesis. (E) Illustration of MA in a common knee described in aMA. An extreme asymmetrical trapezoidal gap was typically produced, and soft tissue release was frequently performed to restore the balance of the flexion-extension gap

puncturing techniques, were commonly performed to achieve balanced flexion and extension gaps (Fig. 2).

Postoperative Protocol

The concept of enhanced recovery after surgery (ERAS) was applied to assist patients to recover faster and better.[13] The drainage tube was removed 24–48 h postoperatively. Intravenous analgesics were used for pain management after surgery and subsequently discharged with oral analgesics for 1–3 months. Routine antibiotics were administered for 1–2 days to prevent infection. Anticoagulant therapy was subcutaneously administrated and continued oral anticoagulation after being discharged for at least 2 weeks. Rehabilitation was started on the same day after operation with quadriceps exercise and passive motion of the knee under the guidance of a physical therapist. Patients then started sitting, standing and walking with aids at least three times daily in order to achieve at least 60 m walking with correct gait, knee flexion over 100°, and extension <5° before being discharged.

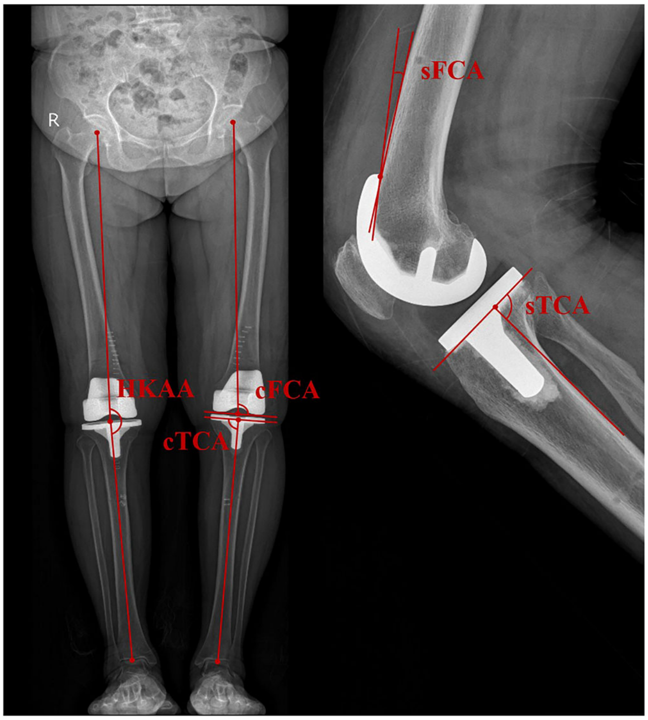

Fig. 3 Illustration of radiographic evaluation. Hip-knee-ankle angle (HKAA) is the inner angle formed by the mechanical line of the femur and the tibia; coronal femoral component angle (cFCA) is the outer angle formed by femoral mechanical axis and the tangent to the most distal part of the medial and lateral condyles of the femoral component in coronal plane; coronal tibial component angle (cTCA) is the inner angle formed by the tibial mechanical axis and the tangent to the plateau of tibial component in coronal plane; sagittal femoral component angle (sFCA) is the angle formed by the frontal femoral cortex and the inner frontal part of the femoral component in sagittal plane; sagittal tibial component angle (sTCA) is the posterior angle formed by the posterior tibial cortex and the tangent to the plateau of the tibial component in sagittal plane

Clinical and Radiographic Evaluation

Functional outcomes were evaluated by the Hospital for Special Surgery (HSS) score, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, and Forgotten Joint Score-12 (FJS-12). The evaluation was performed preoperatively and at 1, 6, 12 months and every other year after surgery. Additionally, perioperative data were recorded, including duration of operation, length of incision, volume and duration of drainage, hemoglobin change and hospital stay. In addition, the parameters of resection and soft tissues balance were measured, including the tibial resection angle, frontal femoral angle, axial femoral angle, medial and lateral gaps in the extension and flexion positions, and joint line translation. The standing full-lower limb, anteroposterior and lateral views of radiographs were taken by EOS® biplanar X-ray imaging. The radiographic evaluation consisted of the hip-knee-ankle angle (HKAA), coronal femoral component angle (cFCA), coronal tibial component angle (cTCA), sagittal femoral component angle (sFCA), sagittal tibial component angle (sTCA), and femoral notching (Fig. 3). Radiographic parameters were assessed by two residents separately. Assessors and patients were blinded to the alignment technique performed in TKA.

Statistical Analysis

Statistical analysis was performed using the software package SPSS (Version 25.0, SPSS Inc., USA). The results are presented as the means ± standard deviation for continuous variables. Frequencies and percentages were calculated for categorical and ranked variables. Comparisons of continuous variables between groups were conducted using independent sample t tests. Chi-square tests were performed to compare categorical variables. Mann–Whitney U tests were used to compare ranked variables. Values of two side's $p < 0.05$ were considered to be significantly different.

Results

Demographic Data

There were 51 female and 12 male patients with an average age of 68.13 ± 8.78 years (range, 46–86) in the aMA group. In the MA group, there were 46 female and six male patients with an average age of 68.30 ± 6.34 years (range, 56–83). The mean body mass index (BMI) was 26.13 ± 4.07 and 25.52 ± 3.52 kg/m^2, respectively. No statistically significant differences in operation side, diagnosis, and K-L grade were observed between the two groups (Table 1). A mean follow-up of 3.5 years was achieved in all patients (range, 29–54 months). The baseline data were comparable between the aMA and MA groups.

TABLE 1 Demographic data

Parameters	aMA Group	MA Group	Statistic value	*p* value
Age (years)	68.13 ± 8.78	68.30 ± 6.34	$t = -0.124$	0.902
Sex ($n = 115$)				
Female	51 (80.95%)	46 (88.46%)	$\chi^2 = 1.217$	0.270
Male	12 (19.05%)	6 (11.54%)		
Height (cm)	1.58 ± 0.07	1.57 ± 0.69	$t = 0.617$	0.538
Weight (kg)	65.23 ± 11.40	62.94 ± 8.95	$t = 1.287$	0.200
Body mass index (kg/m^2)	26.13 ± 4.07	25.52 ± 3.52	$t = 0.925$	0.357
Side ($n = 138$)				
Left	37 (48.05%)	24 (39.24%)	$\chi^2 = 1.046$	0.306
Right	40 (51.95%)	37 (60.66%)		
Etiology ($n = 138$)				
Osteoarthritis	69 (89.61%)	51 (83.61%)	$\chi^2 = 1.082$	0.298
Rheumatoid arthritis	8 (10.39%)	10 (16.39%)		
K-L Grade ($n = 120$)				
III	42 (60.87%)	30 (58.82%)	Z = 0.225	0.822
IV	27 (39.13%)	21 (41.18%)		
Duration of follow-up (months)	41.52 ± 7.55	43.80 ± 7.49	$t = -1.772$	0.079

Abbreviation: K-L grade, Kellgren and Lawrence Grade.

Perioperative Results

No statistically significant differences in the duration of the operation, length of incision, volume and duration of drainage, hemoglobin change, or hospital stay were observed between the aMA and MA groups (Table 2).

Resection and Soft Tissue Balance

The frontal femoral angle was 2.55° ± 1.08° in aMA group *versus* 0.26° ± 0.60° in MA group ($p < 0.001$, Table 3). The axial femoral angle was 3.07° ± 2.23° external in aMA group *versus* 2.30° ± 1.70° in MA group ($p = 0.027$). The medial extension gap was significantly tighter in the MA group ($p = 0.019$). The lateral flexion gap was wider in the aMA group, with a mean of 0.71 mm more laxity ($p = 0.001$). Additionally, the difference in mediolateral flexion laxity was significantly wider using aMA than using MA ($p < 0.001$). There was no statistically significant difference in the tibial resection angle, lateral extension gap, medial flexion gap, or joint line translation between the two groups.

Radiographic Evaluation

Postoperative coronal alignment was 177.03° ± 1.82° in aMA group *versus* 178.14° ± 1.69° in MA group ($p < 0.001$, Table 4). The cFCA was 92.62° ± 2.78° in aMA group *versus* 90.85° ± 2.01° in MA group ($p < 0.001$). No statistically significant difference in the sFCA, cTCA, sTCA, or femoral notching were observed between the groups (Fig. 4).

Clinical Evaluation

Both aMA-TKA and MA-TKA achieved satisfactory functional outcomes. However, the HSS score at 1 month postoperatively was significantly higher in the aMA group ($p < 0.001$, Table 5). There was no statistically significant difference in HSS, WOMAC, or FJS-12 scores in the other periods of follow-up between groups.

Complications

Seven (9.09%) patients in the aMA group and six (9.84%) in the MA group had lower limb deep vein thrombosis (DVT), most of which were intermuscular vein thrombosis beneath the level of the knee. All DVTs were successfully treated with routine anticoagulant therapy. There was no knee infection, prosthesis loosening, patellofemoral problem, pin site fracture, dislocation, or neurovascular injury during the follow-up.

TABLE 2 Perioperative data

Parameters	aMA Group ($n = 77$)	MA Group ($n = 61$)	*t* value	*p* value
Operative duration (min)	75.97 ± 11.98	80.02 ± 13.47	−1.864	0.065
Length of incision (cm)	14.41 ± 1.47	14.62 ± 1.44	−0.867	0.387
Drainage volume (ml)	170.81 ± 138.78	175.08 ± 138.32	−0.180	0.857
Drainage duration (days)	1.46 ± 0.47	1.51 ± 0.50	−0.568	0.571
Hemoglobin change (g/L)	16.45 ± 7.93	15.82 ± 9.48	0.428	0.669
Hospital stay (days)	5.94 ± 2.16	6.13 ± 1.86	−0.563	0.574

TABLE 3 Resection and soft tissue balance data

Parameters	aMA Group (n = 77)	MA Group (n = 61)	t value	p value
Tibial resection (°)	0.42 ± 0.52	0.33 ± 0.57	0.942	0.348
Extension				
Frontal femoral angle (°)	2.55 ± 1.08	0.26 ± 0.60	14.751	<0.001
Medial gap (mm)	0.01 ± 0.77[a]	−0.44 ± 1.44[b]	2.377	0.019
Lateral gap (mm)	0.68 ± 0.94	0.48 ± 1.67	0.889	0.376
Difference of M-L extension laxity (mm)	0.66 ± 1.06	0.92 ± 2.10	−0.930	0.354
Flexion				
Axial femoral angle (°)	3.07 ± 2.23	2.30 ± 1.70	2.231	0.027
Medial gap (mm)	0.13 ± 0.83	0.15 ± 1.28	−0.098	0.922
Lateral gap (mm)	0.92 ± 0.87	0.21 ± 1.50	3.483	0.001
Difference of M-L flexion laxity (mm)	0.79 ± 1.04	0.07 ± 0.79	4.505	<0.001
Joint line translation (mm)	1.35 ± 1.60[c]	1.34 ± 1.60	0.023	0.981

Abbreviation: M-L, medial-lateral; [a] Positive signifies laxity of the soft tissue; [b] Negative signifies distension of the soft tissue; [c] Positive signifies proximal translation.

Discussion

Main Findings of Study

The aMA technique is considered an extension of the conventional MA technique in TKA, aiming to correct the coronal lower limb deformity within a safe zone by fine tuning the position of the femoral component. aMA-TKA was reported to provide good clinical outcomes for varus and valgus knees.[14] However, to the best of our knowledge, no comparative study between the aMA and MA techniques in TKA has been previously performed, which is possibly due to the limited choices of alignment techniques under conventional instruments. Therefore, in this retrospective cohort study, we compared the aMA and MA techniques in navigation-assisted TKA at a mean of 3.5 years of follow-up. The major finding of this study was that the aMA technique aims to produce a biomimetic wider lateral flexion-extension gap and minimize soft tissue releases, which might be associated with better early clinical outcomes than MA technique.

Feasibility of aMA Technique

Restoration of the neutrally aligned lower limb has been considered the gold standard for TKA by most knee surgeons for decades, aiming to reduce the wear of prostheses by creating a biomechanically friendly artificial knee. Ritter *et al.* indicated that malalignment of the component could increase the risk of implant failure.[15] In addition, the preservation of tibial varus deformity with a BMI of >33.7 kg/m^2 represented contributors to failure of TKA.[16] Comparable results are highlighted in other publications.[17,18] However, some new views have been proposed by other scholars. Distinct populations have different proportions of physiological varus knees. Bellemans *et al.* reported that 32% of males and 17% of females had constitutional varus knees with a mechanical coronal alignment of >3° varus in a European population.[19] The clinical outcomes may not be satisfactory and desirable in these cases if the alignment is restored to neutral. This step might lead to over-resection of the distal lateral femoral condyle and thus cause patellofemoral problems and altered tightness

TABLE 4 Radiographic data

Parameters	aMA Group (n = 77)	MA Group (n = 61)	Statistic value	p value
HKAA				
Preop. (°)	169.05 ± 6.12	170.78 ± 6.01	t = −1.664	0.098
Deformity of <10°	33 (48.05%)	31 (50.82%)	χ^2 = 0.959	0.619
Deformity of 10–20°	37 (48.05%)	26 (42.62%)		
Deformity of >20°	7 (9.09%)	4 (6.56%)		
Postop. (°)	177.03 ± 1.82	178.14 ± 1.69	t = −3.677	<0.001
Femoral angle				
Coronal plane (°)	92.62 ± 2.78	90.85 ± 2.01	t = 4.183	<0.001
Sagittal plane (°)	1.86 ± 0.87	1.75 ± 0.77	t = 0.791	0.430
Tibial angle				
Coronal plane (°)	90.42 ± 1.47	90.36 ± 1.17	t = 0.250	0.803
Sagittal plane (°)	90.12 ± 1.57	89.97 ± 1.47	t = 0.559	0.577
Femoral Notching	6 (7.79%)	5 (8.20%)	χ^2 = 0.008	0.931

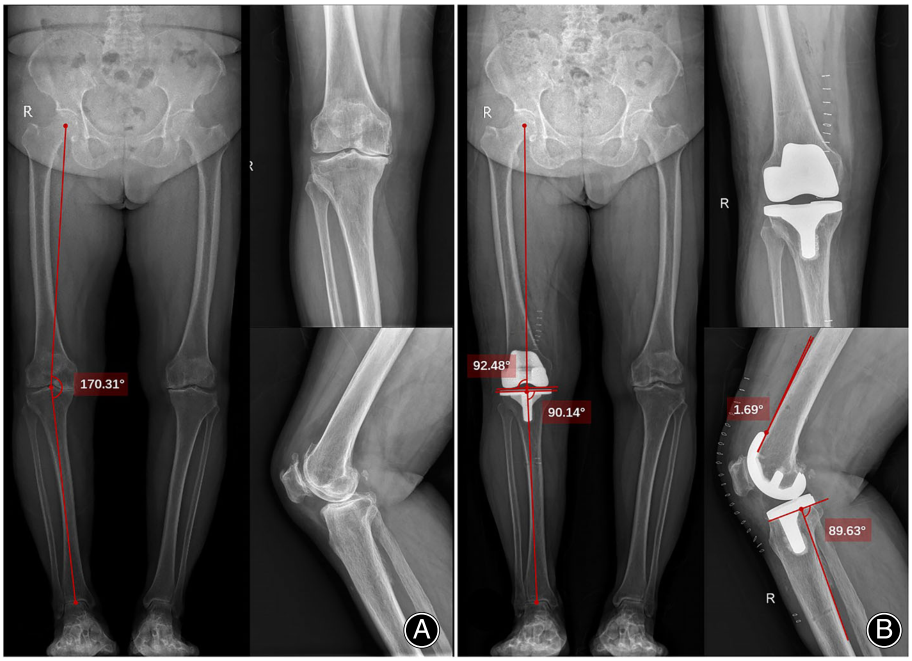

Fig. 4 Radiographs of a 64-year-old female patient who underwent navigation-assisted TKA using the aMA technique. (A) Preoperative standing full-leg X-ray (EOS) showed an osteoarthritis right knee with 170.31° varus. (B) EOS at 1 week postoperatively showed a restored knee with an angle of 2.53° varus. The cFCA was 92.48°, the cTCA was 90.14°, the sFCA was 1.69°, and the sTCA was 89.63°.

in deep flexion.[20] Moreover, patients with slight undercorrection deformity following TKA even led to better functional outcomes in varus knees with a mean of 7.2 years of follow-up.[9] In our study, we found similar tibial resection angles in the aMA and MA groups. However, the frontal femoral angle was 2.55° ± 1.08° in aMA group *versus* 0.26° ± 0.60° in MA group, which is consistent with the findings of Winnock *et al.*, who adjusted the femoral component to preserve mild constitutional deformity with the aMA technique.[14] These findings also match the stated concept of the kinematic alignment technique to reverse the alignment of the pre-arthritis native knee.[21] In addition, the fault tolerance of the artificial joint prosthesis increased following the modification of prosthetic design and materials. Therefore, aMA might be suggested as a more rational target to treat patients with constitutional knee deformity. This aligned technique aims to preserve mild varus for varus knees and some valgus for valgus knees to avoid extensive and multiple soft tissue releases.

TABLE 5 Clinical data

Parameters	aMA Group (n = 77)	MA Group (n = 61)	t value	p value
Preop.				
Range of motion (°)	111.36 ± 8.98	111.87 ± 8.90	0.909	0.742
HSS score (points)	47.44 ± 7.58	48.71 ± 7.79	−0.960	0.339
WOMAC score (points)	66.16 ± 8.54	65.49 ± 8.77	0.448	0.655
Postop.				
Range of motion (°)	123.71 ± 5.68	122.98 ± 6.07	0.729	0.467
1 month postop.				
HSS score (points)	72.16 ± 3.10	69.28 ± 2.51	5.874	<0.001
WOMAC score (points)	24.13 ± 1.81	24.34 ± 2.00	−0.660	0.510
1 year postop.				
HSS score (points)	91.88 ± 1.37	91.98 ± 2.30	−0.269	0.788
WOMAC score (points)	15.05 ± 1.73	14.79 ± 1.88	0.860	0.391
FJS-12 score (points)	25.16 ± 3.98	25.25 ± 5.60	−0.102	0.919
Last follow-up				
HSS score (points)	94.86 ± 1.97	94.25 ± 2.66	1.551	0.123
WOMAC score (points)	12.82 ± 2.10	12.62 ± 2.32	0.519	0.605
FJS-12 score (points)	41.59 ± 4.93	42.09 ± 8.28	−0.440	0.661

Abbreviations: FJS-12, Forgotten Joint Score-12; HSS, Hospital for Special Surgery; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Advantages of aMA Technique

The strength of aMA technique is mainly reflected in the soft tissue protection compared to MA technique. In MA-TKA, the resection of the tibia and femur was perpendicular to the mechanical axis of each bone. As a result, an imbalanced trapezoidal gap was frequently produced. To pursue balanced flexion and extension gaps, multiple additional bony resection and soft tissue release techniques are required. Repeat multiple bone resection or soft tissue release may easily create more imbalance and subsequent instable knee. However, in aMA-TKA, balanced flexion-extension gap and equal mediolateral soft tissue tension could be achieved by manipulating femoral resections and fine-tuning implant positioning. Traditional ligament releases may be required if there are fixed deformities, but the extent and frequency of such releases is smaller compared to MA technique.

In addition, the aim of gap balance in aMA-TKA was not the routinely rectangular gap, but a biomimetic flexion-extension gap simulated with a physiological human knee. Studies on cadaveric knees have shown that the flexion gap is typically larger than the extension gap, while lateral flexion laxity tends to be wider than medial flexion laxity if the anterior and posterior cruciate ligaments are intact.[22] Moreover, the physiological human knee is characterized by medial-pivot motion with a much more stable medial compartment.[23] In our study, we obtained a satisfactory balance of the flexion-extension gap by adjusting the position of the femoral component to minimize ligament releases in the aMA group, which meets the view of Howell *et al.*, who advocated restoration of native knee alignment to avoid unnecessary releases of collateral ligaments. Moreover, the lateral gap laxity was wider than the medial gap and a wider flexion gap laxity was produced, which is consistent with the normal knee joints.[24] In addition, the lateral flexion gap was significantly wider in the aMA group, with a mean of 0.71 mm more laxity than in the MA group, which matches the results of McEwen *et al.*, who revealed that a wider lateral flexion gap laxity was associated with better clinical and functional outcomes.[25] As a result, we found that the HSS scores at 1 month postoperatively were significantly higher in the aMA group. Preservation of mild constitutional frontal deformity with less ligament releases and a biomimetic flexion-extension gap may be the causes of the superior functional scores in the aMA group. After 6 months, the healing of soft tissues tended to make the function of the knee equivalent in both groups.

Complications

There were no statistically significant differences in the rate of complications between the aMA and MA groups. Boldt *et al.* reported that the increased rotation and varus/valgus of the femoral component is possibly correlated with an adverse effect on patellofemoral tracking.[26] However, no increase in the incidence of patellofemoral problem was observed in the aMA group, which is similar to previous studies about the kinematic alignment technique in TKA.[27]

Strengths and Limitations

This study is a retrospective cohort study that compared the mid-term outcomes of two alignment techniques, which has been registered in Chinese Clinical Trial Registry. There are also several limitations of the current study that should be mentioned. First, this was a retrospective cohort study, which may increase selection bias and recall bias. A prospective randomized controlled trial is needed to further investigate the outcomes between the aMA and MA techniques. Second, the sample size was relatively small, and the mean period of follow-up was only 3.5 years, which is inadequate to systematically evaluate the complications affected by the alignment technique. Outcomes with a larger sample size and longer-term follow-up are still needed to be confirmed. Finally, this was a single center study performed by one experienced surgeon, further multicenter clinical studies may be required to assess our findings.

Conclusions

Comprehensively, our study suggested that navigation-assisted TKA using aMA technique obtained satisfactory clinical outcomes. Notably, aMA-TKA granted superior functional scores at the 1 month postoperatively, which may be due to the preservation of mild constitutional frontal deformity with less soft tissues release and a biomimetic wider lateral flexion-extension gap.

Author Contribution

Kai Zheng and Houyi Sun wrote the draft of the manuscript and were major contributors to study design and data collection. Weicheng Zhang and Feng Zhu were involved in manuscript editing and statistical analysis. Jun Zhou, Rongqun Li, and Dechun Geng critically reviewed and revised the manuscript. Yaozeng Xu was responsible for patients' treatment and final approvement of submission. All authors read and approved the manuscript.

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Ethics statement

This study was approved by the local Ethics Committee of the First Affiliated Hospital of Soochow University.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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