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Optimizing uni-compartmental knee arthroplasty: the impact of preoperative planning and arithmetic hip-knee-ankle angle

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Abstract

Purpose The purpose of this study was to evaluate whether the combination of preoperative planning software combined with arithmetic hip-knee-ankle angle (aHKA) can help patients who underwent uni-compartmental knee arthroplasty (UKA) recover the constitutional alignment of the lower limb, obtain a better prosthetic position, and achieve better early patient-reported outcome measurements (PROMs).

Methods A total of 150 patients who underwent UKA (planning group: 50 patients using the preoperative planning software; conventional group: 100 patients using the conventional method) were included in the study. The aHKA was defined as 180° + mechanical medial proximal tibial angle (MPTA) - mechanical distal lateral femoral angle (LDFA). All patients in the planning group underwent UKA according to the planning software with the planned lower limb alignment of aHKA. All patients were divided into three groups: constitutional alignment group (postoperative HKA (post-HKA): aHKA ± 2.0°); overcorrection group (post-HKA > aHKA + 2.0°); under-correction group (post-HKA < aHKA − 2.0°). Comparisons between the planning and conventional groups were conducted: (1) the proportion of post-HKA restored to constitutional alignment group; (2) the postoperative prosthesis position parameter based on the guideline of the Oxford group; (3) the American Knee Society scores (KSS) at six months after surgery.

Results The proportion of the constitutional alignment group in the planning group was higher than that in the conventional group (86% vs. 66%) ($p = 0.033$). There was no significant difference in postoperative prosthesis position parameters between the two groups. No significant difference was found between the KSS clinical score (91.02 ± 4.20 vs. 90.61 ± 4.24) and KSS functional score (86.10 ± 7.23 vs. 84.30 ± 6.82) in six months after surgery between the planning and conventional groups.

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Conclusion Patients who underwent UKA using preoperative planning software in combination with aHKA were able to recover a higher proportion of the constitutional alignment than those with the conventional method. In addition, the planning group could achieve similar postoperative prosthesis position and short-term PROMs compared to the conventional group.

Clinical trial number Not applicable.

Keywords Preoperative planning software, Arithmetic hip-knee-ankle angle (aHKA), Uni-compartmental knee arthroplasty (UKA), Lower limb alignment, Constitutional alignment.

Introduction

Suitable postoperative lower limb alignment is critical to the success of uni-compartmental knee arthroplasty (UKA) [1–3]. The UKA's surgical target is to restore the knee to its natural state and achieve constitutional alignment (pre-arthritis alignment) [4, 5]. Hirschmann et al. introduced a novel coronal alignment classification (functional knee phenotype concept), which classified the individual coronal alignment based on an evaluation of hip-knee-ankle angle (HKA), femoral mechanical angle (FMA), and the tibial mechanical angle (TMA) [6–8]. MacDessi et al. proposed a new classification of knee joint morphology (Coronal plane alignment of the knee (CPAK) classification) based on the arithmetic hip-knee-angle (aHKA) and joint line obliquity (JLO) [9, 10]. The radiographic index (aHKA), defined as mechanical medial proximal tibial angle (MPTA) minus mechanical lateral distal femoral angle (LDFA), can be used to estimate the constitutional alignment of the lower limb with knee osteoarthritis (KOA). Its theoretical foundations include: (1) In normal populations, aHKA and HKA are approximately equal; (2) In patients with KOA, LDFA and MPTA do not change when no bone defect occur, and the value of aHKA remains constant [10].Therefore, aHKA might be used as the target angle for UKA surgery. The dilemma is that it is difficult to quantitatively assess intraoperative lower limb alignment of UKA. The surgeon often judges appropriate alignment by subjectively assessing the tension of the medial collateral ligament (MCL), which is uncertain. It has been reported that there was a certain proportion of malalignment after UKA [1, 11]. Therefore, it is particularly important to develop tools for judging intraoperative lower limb alignment of UKA.

It has been reported that robots and navigation aids could help to accurately judge the intraoperative lower limb alignment of UKA [12–14]. However, prolonged operating time, high equipment cost, and the learning curve for the surgical team limit the use of these tools [15, 16]. Therefore, we developed the simple preoperative planning software based on the full-length radiograph or the full-length computed tomography (CT) to obtain the relationship between the lower limb alignment and medial joint space width (mJSW) of the knee joint, intending to help surgeons judge the lower limb alignment through gap measurement during UKA. As is known to all, preoperative planning software with such a function has not been reported.

The purpose of this study is to evaluate whether the combination of preoperative planning software and aHKA can help patients recover the constitutional alignment of the lower limb and obtain better prosthetic positions and early PROMs compared to patients undergoing UKA with the conventional method. We hypothesis that the combination of preoperative planning software and aHKA can help patients recover the constitutional alignment of the lower limb and obtain similar prosthetic positions and early PROMs compared to patients undergoing UKA with the conventional method.

Materials and methods

Study design and patient recruitment

A total of 351 patients underwent mobile-bearing UKA in the hospital from September 2020 to June 2023 were prospectively collected. The indications for UKA surgery are as follows: (1) Anteromedial osteoarthritis (AMOA) of the knee or spontaneous osteonecrosis of the knee (SONK); (2) MCL and anterior cruciate ligament (ACL) are intact; (3) Flexion contracture < 15° and knee joint range of motion > 90°; (4) Varus deformity (HKA) < 15° and the deformity can be corrected under valgus stress [4, 17]. Inclusion Criteria: (1) Patients undergoing UKA due to AMOA combined with a bone-on-bone phenomenon in the medial compartment of the knee; (2) Patients with preoperative anterior-posterior (AP) and lateral knee radiographs, and weight-bearing full-length radiographs; (3) Patients with postoperative AP and lateral knee radiographs, and weight-bearing full-length radiographs. Exclusion criteria: (1) Patients whose radiographs are not in a standard position (such as the presence of significant rotation) and cannot be used for the study ($n = 8$); (2) Patients with a history of ipsilateral lower limb surgery ($n = 6$); (3) Patients with incomplete data (such as follow-up data) ($n = 12$). A total of 292 patients met the above inclusion and exclusion criteria, of which 50 patients used the preoperative planning software and 242 patients used the conventional surgical methods. This study was approved by the Ethics Committee of the

Table 1 Basic characteristics

Variables	Planning group ($n=50$)	Conventional group ($n=100$)	p
Age (years)	66.86 ± 6.07	66.90 ± 5.92	0.909[1]
Sex (n (%))			
Female	37 (74.0%)	74 (74.0%)	> 0.999[2]
Male	13 (26.0%)	26 (26.0%)	
Side (n (%))			> 0.999[2]
Right	26 (52.0%)	52 (52.0%)	
Left	24 (48.0%)	48 (48.0%)	
Height (cm)	159.98 ± 5.95	160.86 ± 8.11	0.957[1]
Weight (kg)	70.44 ± 8.89	71.24 ± 11.70	0.890[1]
BMI (kg/m^2)	27.49 ± 2.87	27.44 ± 3.26	0.927[3]

BMI, body mass index

[1]the Mann-Whitney U-test

[2]the chi-square test

[3]the independent-sample t-test

hospital (approval number: 2020–50-k28) and the written informed consent was obtained from all individual participants included in the study.

The patients in the planning group were randomly selected using envelope method by an investigator who was not involved in the planning or surgical procedure. After identifying the patients for each week's procedure, a piece of paper with the patient's name written on it was randomly selected from an opaque envelope by the investigator. The selected patient was included in the planning group; whereas, other patients in the conventional group. Each patient in the planning group was matched with patients in the conventional group in a ratio of 1:2 according to age (controlled within 3 years of age) and gender. Finally, 50 patients were included in the planning group and 100 patients in the conventional group (Figure S1). The basic characteristics of all patients were shown in Table 1.

Radiographic assessments

All patients received weight-bearing full-length radiographs, AP and lateral knee radiographs before surgery, and the same set of radiographs were taken again 3 days after surgery. The hospital's image archiving and communication system (PACS) was used to measure the preoperative and postoperative hip–knee–ankle angle (HKA), MPTA, and LDFA on the weight-bearing full-length radiograph. Referring to the study of Sappey-Marinier et al. [18], the aHKA was defined as 180° + MPTA - LDFA in the study (Fig. 1). Although the absolute values of 180° + MPTA - LDFA and MPTA - LDFA (the formula for aHKA in CPAK classification) were different, they had the same meaning [18, 19]. According to the relationship between postoperative HKA (post-HKA) and aHKA, all patients were divided into three groups:

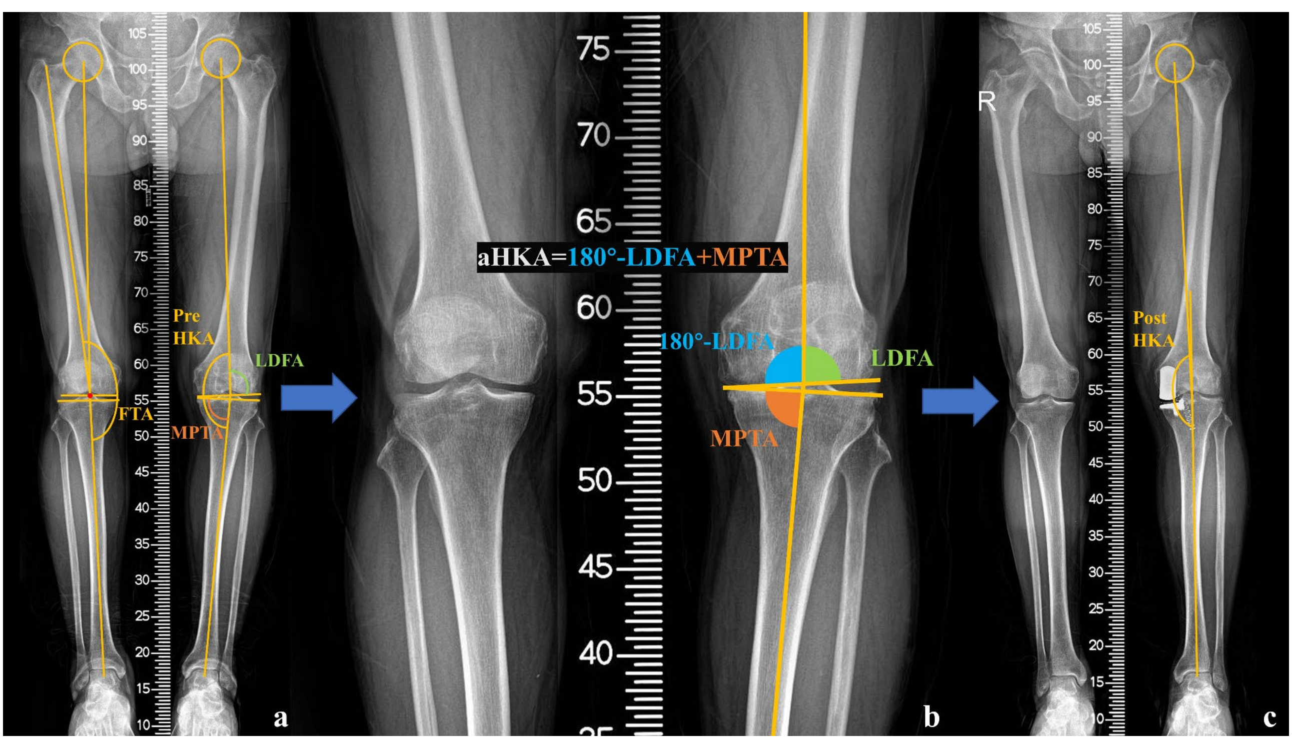

Fig. 1 Pattern diagram of radiographic parameter measurements (**a**-**c**). (**a**) The preoperative weight-bearing full-length radiograph. The preoperative hip–knee–ankle angle (pre-HKA), femoral tibial angle (FTA), mechanical lateral distal femoral angle (LDFA), and mechanical proximal tibial angle (MPTA) were measured; (**b**) Partial magnification of the preoperative weight-bearing full-length radiograph. The arithmetic hip-knee-ankle angle (aHKA) was calculated as 180° + MPTA – LDFA; (**c**) The postoperative weight-bearing full-length radiograph. The postoperative HKA (post-HKA) was measured

group A, constitutional alignment group (post-HKA: aHKA ± 2.0°); group B, overcorrection alignment group (post-HKA > aHKA + 2.0°); group C, under-correction alignment group (post-HKA < aHKA – 2.0°).

After surgery, the coronal angle of the femoral prosthesis varus/valgus (femoral angle A), sagittal angle of the femoral prosthesis flexion/extension (femoral angle B), coronal angle of the tibial prosthesis varus/valgus (tibial angle E), and posterior tibial prosthesis slope (tibial angle F) were measured on the AP and lateral knee radiograph, concerning the guideline of the Oxford group [20]. Acceptable prosthesis positions were defined as follows: femoral angle A, 10° varus to 10° valgus; tibial angle E, 5° varus to 5° valgus; femoral angle B, 15° flexion to 0° extension; tibial angle F, 2° to 12°. Angles beyond the above range indicated poor prosthesis position (Fig. 2a-b).

Preoperative planning software

The preoperative planning software based on the full-length radiograph or the full-length CT was developed to obtain the relationship between the lower limb alignment and mJSW of the knee joint preoperatively (Figs. 3 and 4). In the measurement of radiographic parameters (HKA, LDFA, MPTA, femoral tibial angle (FTA), and $mJSW_{180^\circ}$ (corresponding to the HKA of 180°)), the preoperative planning software (full-length radiograph and CT) showed good (0.75 ≤ intra-class correlation coefficient (ICC) < 0.90) or excellent (ICC ≥ 0.90) intra- and inter-observer agreement. In addition, those radiographic measurements between full-length radiographs and CTs in the same individual showed good agreement (0.75 ≤ ICC < 0.90) and negligible bias (supplementary material). Therefore, the full-length radiograph was selected for preoperative planning (the preset HKA value was aHKA), while the full-length CT scan was not performed in the study. The software automatically rotated the tibia and fibula to make the HKA reach the preset value (aHKA) and measured the mJSW under the preset HKA value (aHKA), which was denoted as d1.

Surgical procedures

Conventional group

All UKA surgeries were performed by an experienced surgeon using the novel extramedullary technique proposed by our team [21, 22]. The patient was in the supine position with a medial parapatellar arc incision (5–8 cm in length) in the knee and an osteotome was used to remove the medial osteophytes. The tibial osteotomy was performed with the extramedullary technique according to the Oxford UKA operating guidelines, the femoral

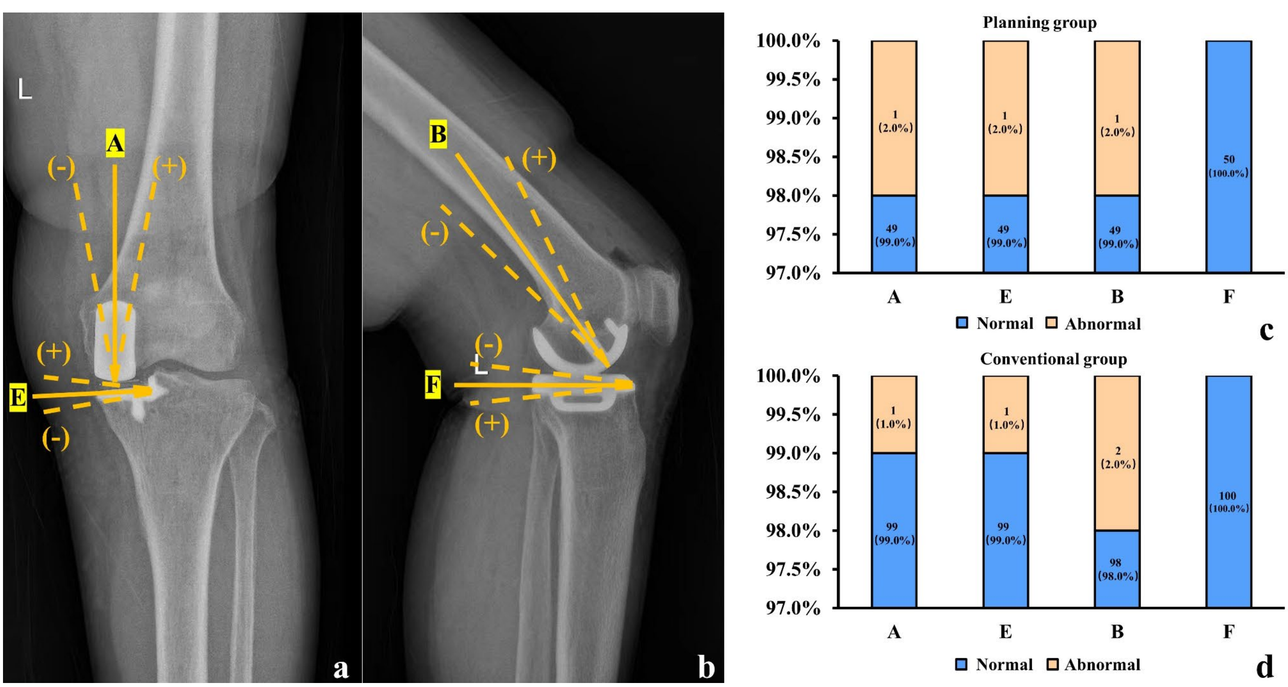

Fig. 2 Pattern diagram of postoperative prosthetic parameter measurements (**a**-**b**). (**a**) The postoperative anterior-posterior (AP) knee radiograph. The coronal angle of the femoral prosthesis varus/valgus (femoral angle A) and the coronal angle of the tibial prosthesis varus/valgus (tibial angle E) were measured; (**b**) The postoperative lateral knee radiograph. The sagittal angle of the femoral prosthesis flexion/extension (femoral angle B) and posterior tibial prosthesis slope (tibial angle F) were measured; (**c**) Distribution of postoperative prosthesis position in the planning group. 47 (94%) patients achieved acceptable prosthesis position while 3 (6%) patients were in poor prosthesis position, including 1 (2%) patient with an angle A greater than 10°, 1 (2%) patient with an angle E greater than 5°, and 1 (2%) patient with an angle B greater than 15°; (**d**) Distribution of postoperative prosthesis position in the conventional group. 96 (96%) patients achieved acceptable prosthesis position while 4 (4%) patients were in poor prosthesis position, including 1(1%) patient with an angle A greater than 10°, 1 (1%) patient with an angle E greater than 5°, and 2 (2%) patient with an angle B greater than 15°

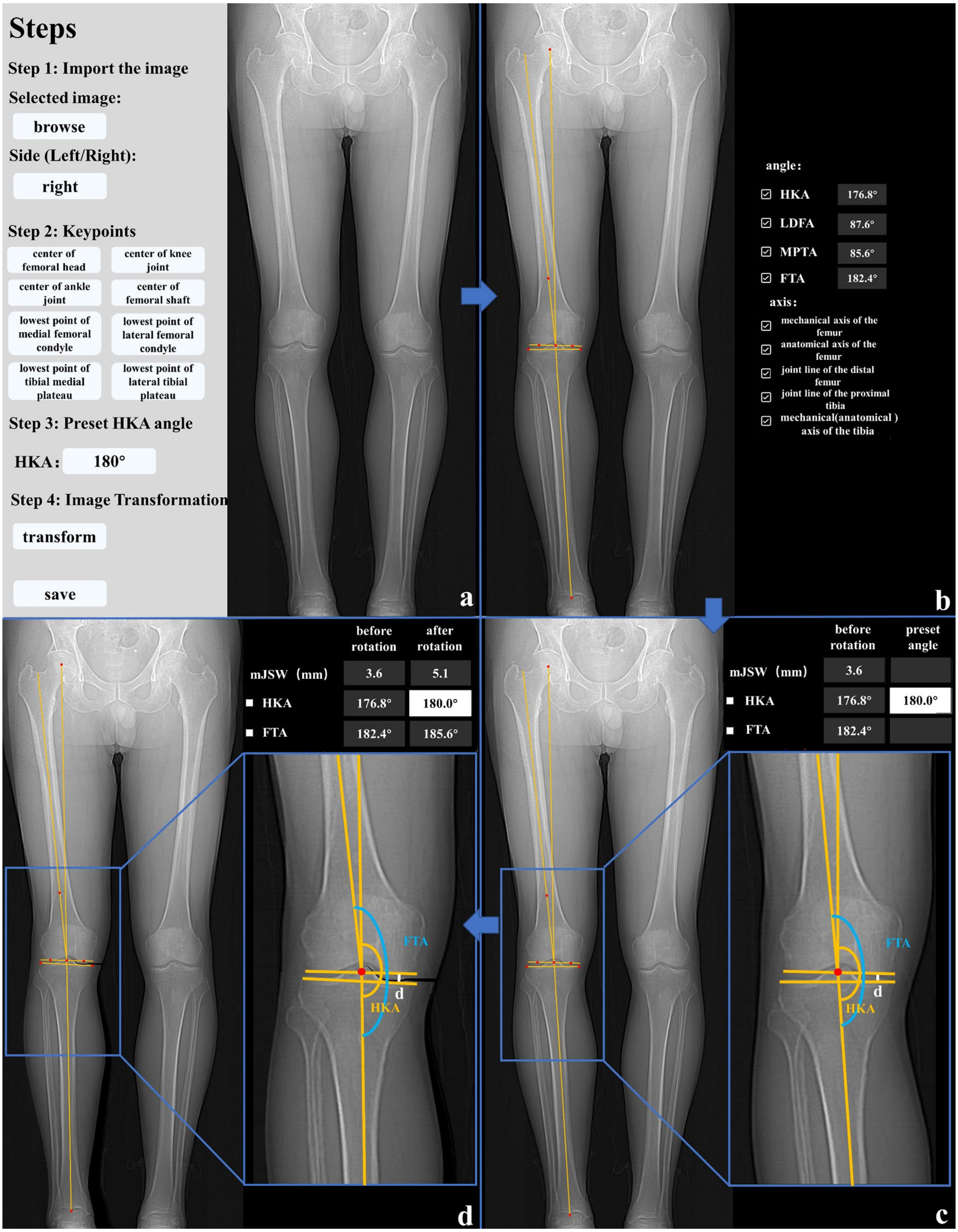

Fig. 3 Usage steps of the full-length radiograph software (**a**-**d**). (**a**) Step 1, import the full-length radiograph; (**b**) Step 2, manually mark the key points, automatically connect the axes and calculate the angles; (**c**) Step 3, manually preset the angle of hip–knee–ankle angle (HKA), and automatically display the original HKA, femoral tibial angle (FTA) and medial joint space width (mJSW); (**d**) Step 4, recognize and segment the tibia and fibula, automatically rotate the tibia and fibula to the preset HKA, and display HKA, FTA, and mJSW after rotation

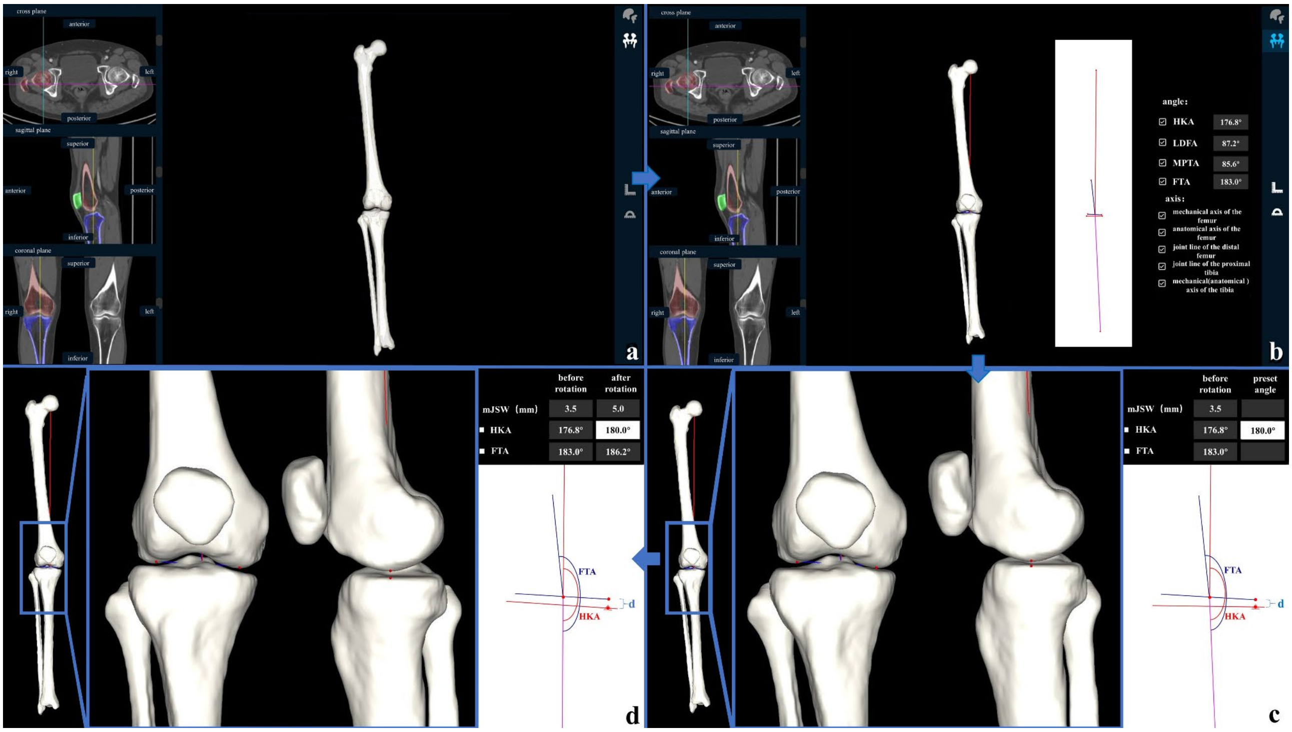

Fig. 4 Usage steps of the full-length computed tomography (CT) software (**a**-**d**). (**a**) Step 1, import the full-length CT and segment the full-length CT of the target side by artificial intelligence method; (**b**) Step 2, manually mark the key points, automatically connect the axes and calculate the angles; (**c**) Step 3, manually preset the angle of hip–knee–ankle angle (HKA), and automatically display the original HKA, femoral tibial angle (FTA) and medial joint space width (mJSW); (**d**) Step 4, automatically rotate the tibia and fibula to the preset HKA and display HKA, FTA, and mJSW after rotation

osteotomy was performed concerning the extramedullary technique, and the posterior femoral condyle osteotomy was followed by a cylindrical grinder for distal femur grinding to balance the flexion and extension gap. The prosthesis was installed after the balance of the flexion and extension gap. All patients were treated with the mobile-bearing Oxford medial UKA prostheses (Oxford unicompartmental knee, Biomet, Bridgend, UK).

Planning group

The surgical method was the same as that of the conventional group, and all the surgeries in the planning group were performed by the same experienced surgeon. Differences from the conventional group: All patients were planned using the preoperative planning software of weight-bearing full-length radiographs. The preoperative planning mJSW was recorded as d1 (corresponding to the planning lower limb alignment (HKA) of aHKA), the intraoperative femoral grinding depth was recorded as d2, and the thickness of tibial osteotomy was recorded as d3 (d3 = tibial osteotomy block thickness + blade thickness (1.2 mm)) (Fig. 5). The thickness of the tibial prosthesis was recorded as d4 (3 mm), the thickness of the distal femoral prosthesis was recorded as d5 (3 mm), and the thickness of the polyethylene bearing was d6. During the operation, the thickness of the polyethylene bearing (d6) was adjusted to meet the requirement of d1 + d2 + d3 = (d4 + d5 + d6) ± 1 mm (Fig. 6a-c). If the medial joint space of the knee joint was too loose or too tight after inserting the planned polyethylene bearing during the operation, the appropriate polyethylene bearing should be selected according to the operator's experience. At the same time, the patient was included in the conventional group.

Postoperative follow-up

Patients will be followed up at 1, 3, 6, and 12 months postoperatively, followed by an annual follow-up. The follow-up includes the Knee Society Score (KSS), knee range of motion (ROM), and complications. The evaluation of complications includes poor wound healing, periprosthetic infection, progression of osteoarthritis in the lateral compartment of the knee joint, deep vein thrombosis in the lower limb, fractures, and loosening of the prosthesis [23].

Data analyses

The study's continuous variables were summarized as mean ± standard deviation (SD), while categorical variables were expressed as frequency and percentage (%). The Shapiro-Wilk test was utilized to assess the normality of continuous variables. Comparisons of

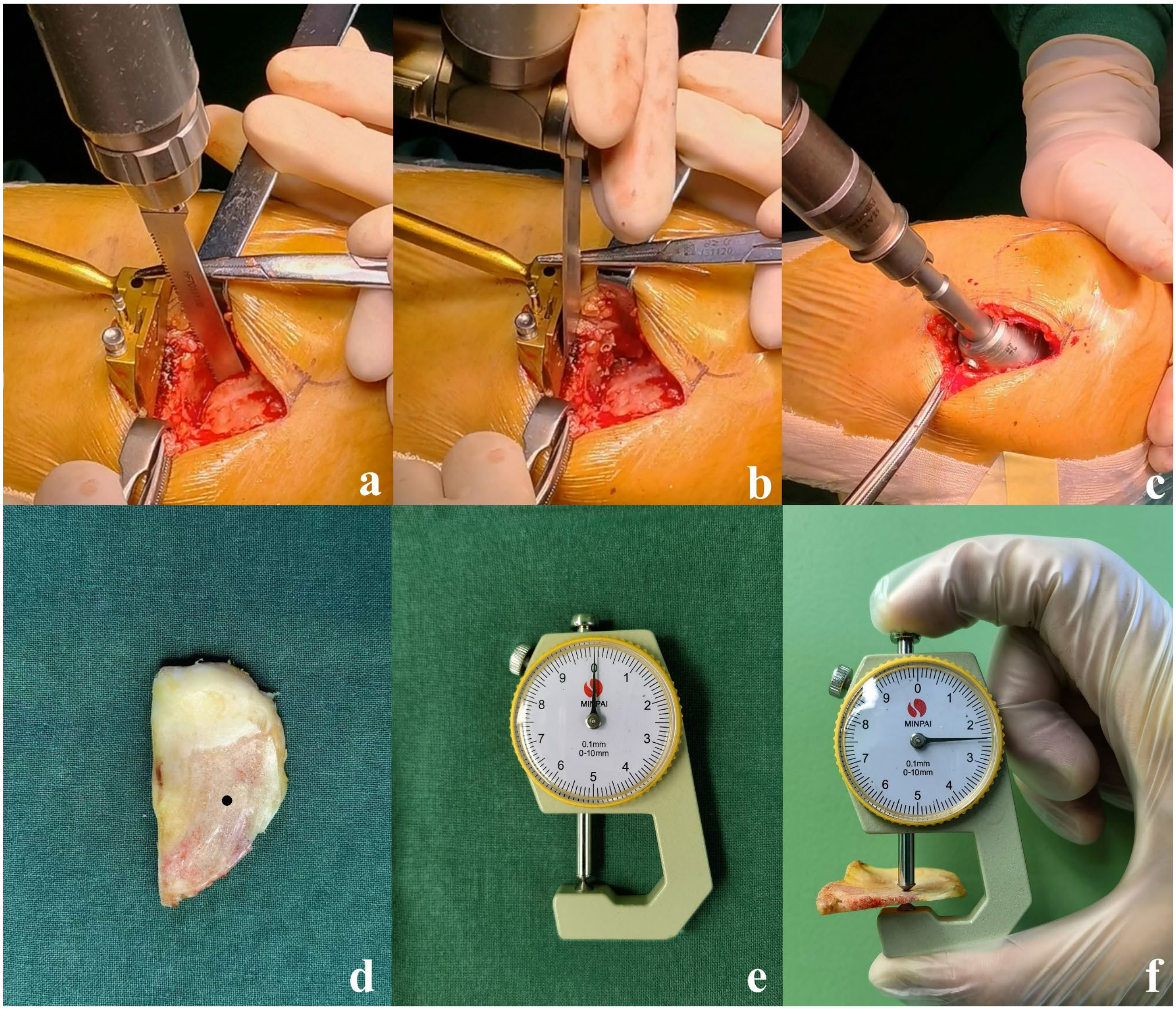

Fig. 5 Measurement of intraoperative femoral grinding depth (d2) and tibial osteotomy thickness (d3) (**a**-**f**). (**a**) Tibial longitudinal osteotomy process; (**b**) Tibial horizontal osteotomy process; (**c**) Femoral grinding process. The depth of femur grinding is recorded as d2; (**d**) Tibial osteotomy block. The marked point is the lowest point of tibial wear; (**e**) Measuring instrument. The range is 0–10 mm, with an accuracy of 0.1 mm; (**f**) Using the measuring instrument to measure the thickness of the tibial osteotomy block (the thickness at the lowest point of tibial wear). The thickness of tibial osteotomy (d3) = tibial osteotomy block thickness + blade thickness (1.2 mm)

continuous variables between the planning group and the conventional group were conducted using either the independent sample t-test or the Mann-Whitney U-test, depending on normality. Categorical variables were compared using the chi-square test or Fisher's exact test. Additionally, Spearman correlation analysis was performed to evaluate the relationship between aHKA and post-HKA. Changes in KSS scores and knee ROM before and six months after surgery were analyzed using the Wilcoxon test.

In alignment with previous research, a mean difference of 1.5° or less between radiographic measurements was deemed approximately equivalent, with the SD of paired differences assumed to be 2.5° [24]. With an alpha of 0.05, a power of 90%, and a 1:2 experimental-to-control group ratio, a minimum sample size of 45 was calculated for the experimental group to detect differences in radiographic measurements. In this study, 50 patients were included in the planning group (experimental group) to satisfy the sample size requirement.

Statistical analyses were performed using SPSS 24.0 software (IBM, USA), while Excel 2019 software (Microsoft, USA) and GraphPad Prism 9.0 software (GraphPad Software, USA) were employed for graph presentation. A p-value of less than 0.05 was considered statistically significant.

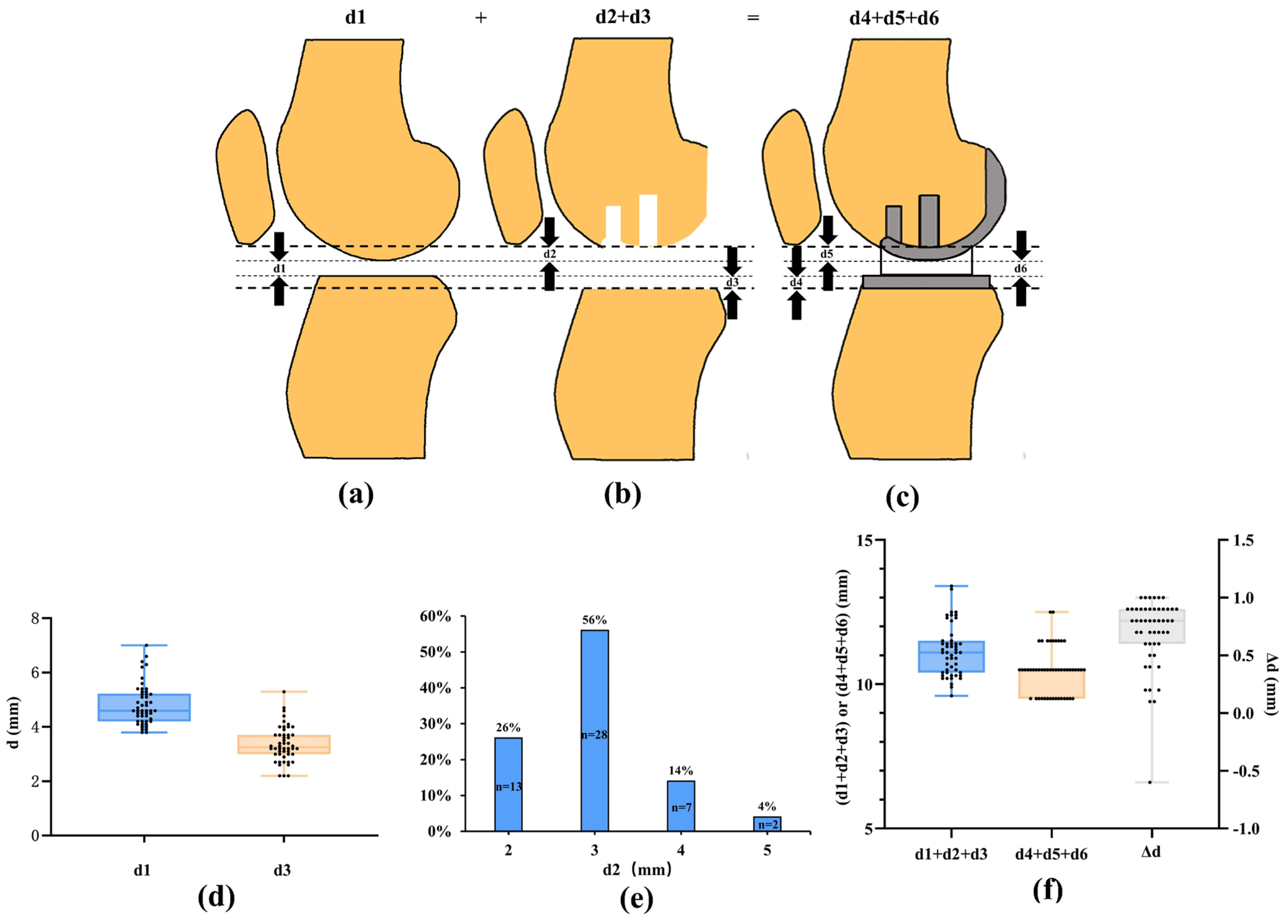

Fig. 6 Surgical pattern diagram of the planning group (**a**-**c**). (**a**) Preoperative pattern diagram. The preoperative planned medial joint space width is d1 (corresponding to the planned alignment of arithmetic hip-knee-ankle angle (aHKA)); (**b**) Intraoperative pattern diagram. The depth of femoral grinding during surgery is d2, and the tibial osteotomy thickness is d3; (**c**) Postoperative pattern diagram. The thickness of the tibial prosthesis is d4, the thickness of the distal femoral prosthesis is d5, and the thickness of the polyethylene bearing is d6. During the operation, the d6 is adjusted to meet the requirement of d1 + d2 + d3 = (d4 + d5 + d6) ± 1 mm; (**d**) The planned medial joint space width (d1) and tibial osteotomy thickness (d3). The mean ± standard deviation (SD) of d1 and d3 were 4.82 ± 0.75 mm and 3.37 ± 0.64 mm; (**e**) Femoral grinding depth (d2). The number of patients with d2 of 2/3/4/5 mm is 13 (26.0%)/28 (56.0%)/7 (14.0%)/2 (4.0%), respectively; (**f**) The total space width (d1 + d2 + d3 or d4 + d5 + d6) and space width difference (Δd= (d1 + d2 + d3) - (d4 + d5 + d5)). d1 + d2 + d3 = 11.15 ± 0.87 mm, d4 + d5 + d6 = 10.46 ± 0.80 mm, and Δd is 0.69 ± 0.31 mm

Results

Radiological and prosthetic parameters were shown in Table 2. There were significant differences in postoperative HKA classification ($p = 0.033$) and polyethylene bearing size ($p = 0.012$) between the planning group and the conventional group, but no significant differences were found in other parameters between the two groups (Table 2). The planned mJSW and intraoperative parameters in the planning group were shown in Fig. 6.

The relationship between post-HKA and aHKA

The proportion of the constitutional alignment group in the planning group was higher than that in the conventional group (86% vs. 66%), the proportion of the under-correction alignment group (10% vs. 23%) and the overcorrection alignment group (4% vs. 11%) was lower than that in the conventional group, and the difference was statistically significant (**p = 0.033**) (Fig. 7a). A positive correlation was found between post-HKA and aHKA in the planning group (**r = 0.757, p < 0.001**) and the conventional group (**r = 0.673, p < 0.001**). The correlation between post-HKA and aHKA in the planning group was stronger than that in the conventional group (Fig. 7b-c).

Postoperative prosthesis position

There was no significant difference in postoperative prosthesis position parameters between the planning group and the conventional group (Table 2). Distribution of postoperative prosthesis position in the planning and conventional group were shown in Fig. 2c-d.

Postoperative follow-up

There were no significant differences in preoperative and postoperative KSS clinical and functional scores

Table 2 Radiological and prosthesis parameters

Variables	Planning group ($n=50$)	Conventional group ($n=100$)	*p*
Radiological parameters			
LDFA (°)	88.21 ± 1.61	88.30 ± 1.64	0.752[1]
MPTA (°)	86.09 ± 1.68	86.13 ± 2.03	0.517[2]
aHKA (°)	177.88 ± 1.63	177.82 ± 2.32	0.882[1]
FTA (°)	178.61 ± 2.90	178.19 ± 3.11	0.419[1]
Pre-HKA (°)	172.36 ± 2.89	172.03 ± 3.31	0.559[1]
Post-HKA (°)	177.51 ± 1.81	177.07 ± 2.62	0.292[1]
Post-HKA classification			0.033[3]
< aHKA − 2°	5 (10.0%)	23 (23.0%)	
aHKA ± 2°	43 (86.0%)	66 (66.0%)	
> aHKA + 2°	2 (4.0%)	11 (11.0%)	
Femoral angle A (°)	1.17 ± 4.51	1.53 ± 3.96	0.622[1]
Tibial angle E (°)	-1.20 ± 2.03	-0.93 ± 2.09	0.472[2]
Femoral angle B (°)	5.34 ± 3.37	5.13 ± 3.32	0.751[2]
Tibial angle F (°)	7.08 ± 2.31	6.85 ± 2.21	0.550[1]
Prosthesis parameters			
Size of femoral prosthesis (n (%))			0.370[3]
Extra small	1 (2.0%)	7 (7.0%)	
Small	36 (72.0%)	65 (65.0%)	
Medium	13 (26.0%)	24 (24.0%)	
Large	0 (0.0%)	4 (4.0%)	
Size of tibial prosthesis (n (%))			0.228[3]
AA (smallest)	1 (2.0%)	11 (11.0%)	
A	19 (38.0%)	33 (33.0%)	
B	14 (28.0%)	31 (31.0%)	
C	15 (30.0%)	21 (21.0%)	
D	1 (2.0%)	1 (1.0%)	
E (largest)	0 (0.0%)	3 (3.0%)	
Size of polyethylene bearing (n (%))			0.012[3]
3 (thinnest)	15 (30.0%)	57 (57.0%)	
4	24 (48.0%)	31 (31.0%)	
5	9 (18.0%)	10 (10.0%)	
6 (thickest)	2 (4.0%)	2 (2.0%)	

LDFA, mechanical lateral distal femoral angle; MPTA, mechanical proximal tibial angle; aHKA, arithmetic hip-knee-ankle angle; FTA, femorotibial angle; Pre-HKA, preoperative hip-knee-ankle angle; Post-HKA, postoperative hip-knee-ankle angle

[1]the independent-sample t-test

[2]the Mann-Whitney U-test

[3] the Fisher's exact test

between the planning and conventional groups. Both groups showed significant improvement in KSS scores six months post-surgery ($p<0.001$) (Fig. 8). Preoperative ROM was 114.10 ± 9.67° for the planning group and 115.40 ± 9.18° for the conventional group, with postoperative ROM at six months being 122.20 ± 6.16° and 121.40 ± 5.69°, respectively; no significant difference was found between groups. Both groups had a significant increase in postoperative ROM compared to preoperative ROM ($p<0.001$). At the final follow-up, only one patient in the conventional group reported persistent knee pain, with no other complications noted.

Discussion

The main findings of the study were as follows: (1) The proportion of the constitutional alignment group in the preoperative planning group was higher than that in the conventional group (86% vs. 66%) (Fig. 7a); (2) There was no significant difference in postoperative prosthesis position parameters (including angle A, angle E, angle B, and angle F) between the two groups (Table 2); (3) There was no significant difference in the KSS clinical and functional score in six months after surgery between the two groups (Fig. 8). Such results suggested that the planning software combined with aHKA could help patients to better recover constitutional alignment of the lower limb while obtaining postoperative prosthesis position and short-term PROMs similar to that of the conventional group.

The planning group had a higher proportion of patients achieving constitutional alignment (86%) compared to the conventional group (66%), while the under-correction (10% vs. 23%) and overcorrection groups (4% vs. 11%) were lower, with a statistically significant difference ($p=0.033$) (Fig. 7a). This indicated that the preoperative planning software enhanced recovery to constitutional alignment after UKA. In addition, in the planning group, 86% of patients were in the conventional alignment group and the correlation between postoperative HKA and aHKA was 0.757 ($p<0.001$) (Fig. 7), which was similar to the results of Bayoumi et al. [13] and Foissey et al. [14]. Bayoumi et al. [13] reported that 91% of patients in robotic-assisted UKA were within the conventional alignment range (aHKA ± 3°). Foissey et al. [14] reported that 67% of patients undergoing robot-assisted UKA had postoperative alignment within the normal range (175°≤ HKA ≤ 180°). This suggested that our preoperative planning software, used with aHKA, could achieve results similar to robotic-assisted UKA. Notably, our software could utilize full-length radiographs, which were commonly used in routine UKA assessments, offering advantages of lower radiation, cost, and ease of implementation compared to CT planning.

There was no significant difference between the femoral prosthesis size and the tibial prosthesis size between the two groups. However, the proportion of polyethylene bearing size (4/5/6) in the planning group was higher than that in the conventional group, and the proportion of polyethylene bearing size (3) was lower than that in the conventional group, with statistical significance ($p=0.012$) (Table 2). This was consistent with the measurements of lower limb alignment in this study. The post-HKA in the planning group (post-HKA = 177.51 ± 1.81) was larger than that of the

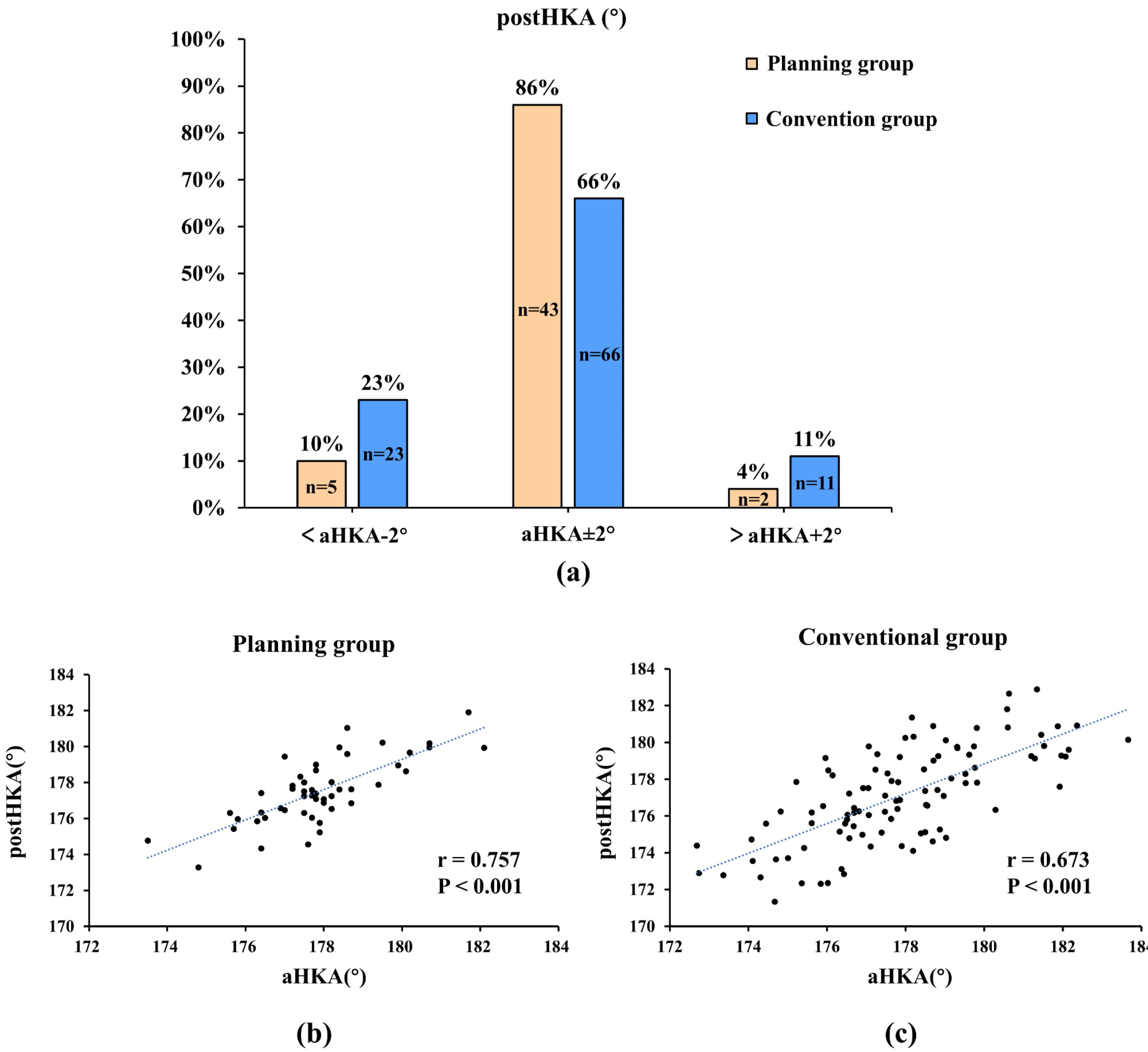

Fig. 7 The relationship between postoperative hip–knee–ankle angle (post-HKA) and arithmetic hip-knee-ankle angle (aHKA) in the planning group and the conventional group. (**a**) The postoperative alignment grouping. Constitutional alignment group (post-HKA: aHKA ± 2.0°), overcorrection alignment group (post-HKA > aHKA + 2.0°), under-correction alignment group (post-HKA < aHKA – 2.0°); (**b**) Correlation analysis in the planning group; (**c**) Correlation analysis in the conventional group

conventional group (post-HKA = 177.07 ± 2.62), and the proportion of patients achieving under-correction alignment in the in the planning group (10%) was lower than that of the conventional group (23%) (Table 2). These results suggested that patients in the conventional surgery group were more likely to had under-correction than those in the preoperative planning group, which might be related to the previous perception that patients with a slight varus after UKA had a better prognosis [11, 25]. On the other hand, the results also suggested that the preoperative planning software could help surgeons reduce the proportion of under-correction and enhanced recovery to constitutional alignment after UKA.

Previous studies indicated that patients who regained constitutional alignment after UKA tended to have better PROMs [26–29]. For example, Plancher et al. [27] followed 150 UKA patients for an average of 10 years and found those within constitutional alignment (aHKA ± 3.0°) had superior PROMs compared to those outside this range. Bayoumi et al. [26] tracked 537 UKA patients for an average of 4.4 ± 1.6 years and observed that both the constitutional alignment group (aHKA ± 2.0°) and the overcorrection group (> aHKA + 2.0°) showed

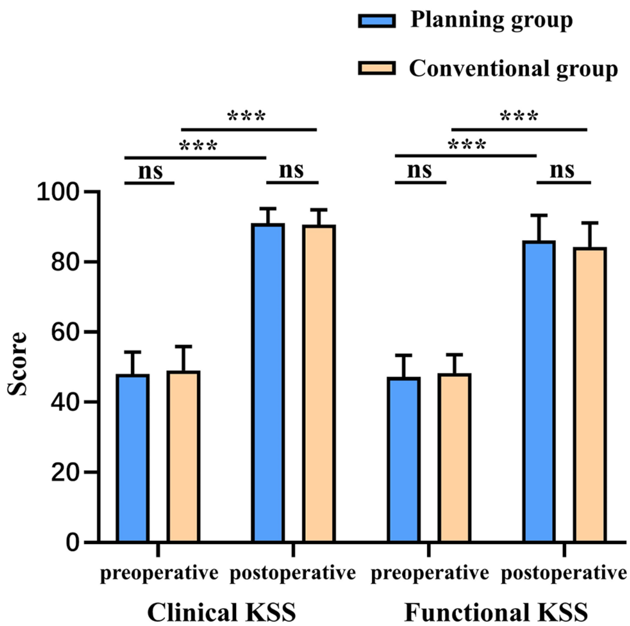

Fig. 8 The American Knee Society scores (KSS) before and six months after surgery in the preoperative planning group and the conventional group. There was no significant difference in the preoperative KSS clinical score (48.08 ± 6.25 vs. 49.04 ± 6.87), postoperative KSS clinical score (91.02 ± 4.20 vs. 90.61 ± 4.24), preoperative KSS functional score (47.20 ± 6.16 vs. 48.30 ± 5.23), and postoperative KSS functional score (86.10 ± 7.23 vs. 84.30 ± 6.82) between the two groups. Both groups showed significant improvement in KSS scores six months post-surgery

better PROMs than the under-corrected group (< aHKA − 2.0°). Kwon et al. [29] compared the differences between conventional UKA and robotic-assisted UKA postoperative recovery of constitutional alignment and early PROMs, robotic-assisted UKA was found to be effective in restoring constitutional alignment while achieving better PROMs at 1-year follow-up. In our study, a higher proportion of patients in the planning group regained constitutional alignment compared to the conventional group (86% vs. 66%) (Fig. 7a). Theoretically, this would suggest better PROMs for the planning group; however, no significant difference was found between the groups in postoperative KSS clinical scores (planning: 91.02 ± 4.20 vs. conventional: 90.61 ± 4.24) or KSS functional scores (planning: 86.10 ± 7.23 vs. conventional: 84.30 ± 6.82) (Fig. 8). One possible explanation for this discrepancy was the shorter average follow-up period of six months in our study, compared with 4.4 ± 1.6 years in the study of Bayoumi et al. [26], 10 years of Plancher et al. [27] and 1 year of Kwon et al. [29]. The length of follow-up time may have an impact on the PROMs. Nonetheless, the lack of difference in PROMs at six months post-surgery indicated that UKA performed with preoperative planning could achieve short-term PROMs comparable to the conventional approach, highlighting the software's effectiveness; however, long-term PROMs required further investigation.

For patients undergoing UKA, the tension of the MCL was a key consideration during surgery. Typically, orthopedic surgeons assessed MCL tension using the valgus stress test preoperatively and adjusted lower limb alignment by restoring MCL tension intraoperatively. In cases of MCL contracture or other conditions meeting UKA criteria, total knee arthroplasty was often preferred. Preoperative planning software allowed surgeons to understand the relationship between lower limb alignment and mJSW before surgery, enabling them to measure mJSW during the operation and reducing reliance solely on MCL tension. In cases of MCL contracture, surgeons may release the MCL to achieve the planned mJSW, aligning with the intended lower limb alignment during the UKA procedure. Thus, utilizing this software could enhance UKA outcomes for more OA patients, particularly those with MCL contracture. However, this remained a theoretical proposition that required clinical validation.

This study had limitations

Firstly, the preoperative planning software did not account for cartilage thickness, which could lead to discrepancies between planned and actual values during surgery. However, participants had typical AMOA with a bone-on-bone phenomenon in the medial knee compartment, rendering cartilage effects on mJSW measurements negligible. Secondly, the software only assessed the relationship between mJSW and lower limb alignment, lacking prosthesis size planning capabilities, indicating a need for future development. There were also issues with incomplete segmentation of images when segmenting the tibia and fibula, although image transformation and calculations were based on manually annotated keys, minimizing segmentation impact. Thirdly, only KSS score was used in the study and KSS was not an optimal outcome score for personalized UKA [30]. The optimal outcome score for UKA will be used in future studies. Fourthly, only the constitutional alignment index-aHKA was considered in the study. However, when preoperative and postoperative CPAK typing changes were considered, different results might be present [31]. In the future, the types of CPAK classification should be compared before and after UKA. Fifthly, the relationship between aHKA and mJSW could be obtained only through the software measurements, and we could not evaluate the arithmetic relationship between aHKA and mJSW to help simplify preoperative planning. Further work will be carried out to address this issue. Lastly, the follow-up period was short (only 6 months), highlighting the need for longer-term outcomes.

Conclusion

Patients who underwent UKA using preoperative planning software in combination with aHKA were able to recover a higher proportion of the constitutional alignment than those with the conventional method. In addition, the planning group could achieve similar postoperative prosthesis position and short-term PROMs compared to the conventional group.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-025-08512-3.

Supplementary Material 1

Author contributions

W.S., W.G. and W.W. designed the study. C.L., C.H. and Y.Z. did the data collection. C.L., C.H. and Q.Z. did the data analysis. C.L., C.H. and X.S. wrote the article. W.S., W.G. and W.W. revised the article. C.L., C.H. and X.S. contributed equally to this work. All authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the institutional review board of the China-Japan Friendship Hospital (approval number 2020–50-k28). The written informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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