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Preoperative valgus-corrected hip-knee-ankle angle and medial meniscal extrusion are useful for evaluating postoperative alignment in mobile-bearing UKA

Changquan Liu [a,b,1], Juncheng Ge [c,1], Yankun Jiang [c,1], Weiguo Wang [a,b], Qidong Zhang [a,b,**], Wanshou Guo [a,b,*]

[a] China-Japan Friendship Hospital (Institute of Clinical Medical Sciences), Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing, China
[b] Department of Orthopaedic Surgery, China-Japan Friendship Hospital, Beijing, China
[c] Department of Orthopaedic Surgery, Peking University China-Japan Friendship School of Clinical Medicine, Beijing, China

A R T I C L E I N F O

Keywords:
Knee magnetic resonance imaging (MRI)
Medial meniscal extrusion (MME)
Valgus stress radiograph (VSR)
Valgus-corrected hip-knee-ankle angle (vcHKA)
Mobile-bearing unicompartmental knee arthroplasty (UKA)
Postoperative alignment

A B S T R A C T

Purpose: The purposes of the study were to analyze the correlation between preoperative variables (valgus corrected hip-knee-ankle angle (vcHKA), medial osteophyte areas of the tibia and femur, and medial meniscus extrusion (MME)) and the postoperative alignment in mobile-bearing unicompartmental knee arthroplasty (UKA).

Methods: This study enrolled 109 patients (118 knees) who underwent mobile-bearing UKA between January 1, 2019 and January 1, 2023, retrospectively. Radiographic parameters, including the HKA, hip-knee-shaft angle (HKS), and valgus-corrected femorotibial angle (vcFTA), were measured using preoperative radiographs. The vcHKA was calculated as vcFTA – HKS. The medial osteophyte areas of the tibia and femur and MME were measured using knee magnetic resonance imaging (MRI). Simple and multiple linear regression analyses, univariate and multivariate logistic regression analyses, and receiver operating characteristic (ROC) curves were performed.

Results: In total, 109 patients (118 knees) were enrolled in this study. In the multiple linear regression analysis, vcHKA ($\beta = 0.732$, 95 % confidence interval (95%CI) = 0.582 to 0.881; $p < 0.001$) and MME ($\beta = 0.203$, 95%CI = 0.001 to 0.405; $p = 0.049$) were positively correlated with postoperative HKA, and postoperative HKA was modeled according to the following equation: $45.420 + (0.732^\circ * \text{vcHKA}) + (0.203\ \text{mm} \times \text{MME})$. In the multivariate logistic regression analysis, vcHKA (odds ratio (OR) = 2.007, 95 % CI = 1.433 to 2.810, $p < 0.001$) was associated with postoperative valgus malalignment independently. In the ROC curve, vcHKA (cutoff value: 180°) was predictive of postoperative valgus malalignment, with an accuracy (95%CI) of 0.862 (0.780–0.944).

* Corresponding author. China-Japan Friendship Hospital (Institute of Clinical Medical Sciences), Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing, China.
** Corresponding author. China-Japan Friendship Hospital (Institute of Clinical Medical Sciences), Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing, China.
E-mail addresses: liuchangquan1995@163.com (C. Liu), gejuncheng@pku.edu.cn (J. Ge), jyk930364018@163.com (Y. Jiang), jointwwg@163.com (W. Wang), zhangqidong1982@sina.com (Q. Zhang), wanshou_guo@outlook.com (W. Guo).

[1] These authors have contributed equally to this work.

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Conclusion: Overcorrection of a varus knee under valgus stress radiograph (VSR) and excessive MME on preoperative MRI increase the possibility of overcorrection of postoperative alignment in mobile-bearing UKA.

1. Introduction

Knee osteoarthritis (OA) is a prevalent orthopedic disease, and unicompartmental knee arthroplasty (UKA) serves as a dependable and successful treatment for anteromedial osteoarthritis (AMOA) [1–3]. With the increase in the number of UKA, an increasing number of studies have reported long-term survival rates and satisfactory patient-reported outcome measurements (PROMs) [4–6]. However, failure still occurs in patients who undergo UKA. Undercorrection or overcorrection of postoperative alignment is a common cause of UKA revision. Overcorrection can cause progression of lateral compartment osteoarthritis, and severe undercorrection can lead to wear of the bearing and loosening of the tibial prosthesis [7–10]. Therefore, appropriate postoperative alignment is critical for successful UKA surgery.

The valgus stress radiograph (VSR) can evaluate the cartilage thickness of the lateral compartment and the correctability of preoperative varus deformity of the knee while reflecting the coronal alignment at the maximum correction as quantified by the valgus corrected hip-knee ankle angle (vcHKA) before UKA [11,12]. However, few research has investigated the correlation between preoperative VSR and postoperative alignment of UKA, and the relationship needs to be clarified, especially in mobile-bearing UKA [13–15].

Medial meniscal extrusion (MME) and medial osteophytes of the tibia and femur are often correlated with knee OA progression [16–18]. The medial osteophyte and meniscus removal during UKA may affect postoperative alignment. Ishibashi et al. [13] reported that preoperative MME was correlated with postoperative alignment, whereas excessive MME increased the risk of postoperative valgus malalignment in fixed-bearing UKA. Mullaji et al. [19] investigated that osteophyte removal was a useful step in achieving varus deformity correction and gap balance while influencing the postoperative alignment in patients undergoing TKA. However, as far as we know, no studies have reported a relationship between the MME, medial osteophytes of the tibia and femur, and postoperative alignment in mobile-bearing UKA.

Therefore, the objectives of this study were to analyze the correlation between preoperative variables (vcHKA, MME, and medial osteophyte area of the tibia and femur) and the postoperative alignment to determine the predictors of postoperative alignment and identify the risk factors for postoperative valgus malalignment in mobile-bearing UKA.

2. Material and methods

This study retrospectively enrolled patients who underwent mobile-bearing UKA in the hospital between January 1, 2019 and January 1, 2023. Indications for medial UKA: (1) AMOA; (2) Preserved knee range of motion more than 90° and fixed flexion deformity

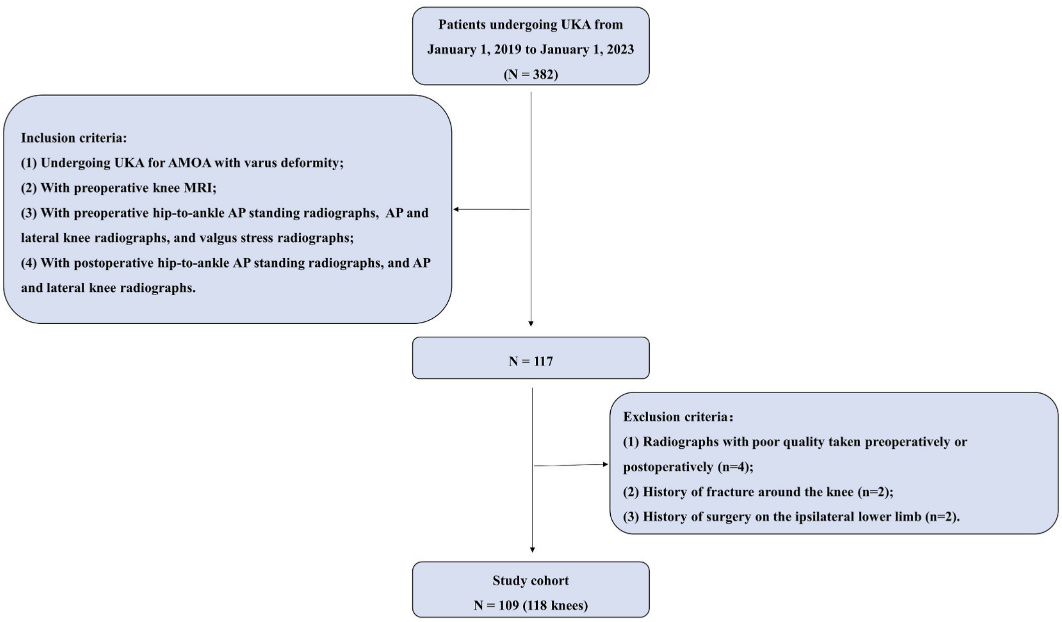

Fig. 1. Flowchart.

less than 15°; (3) Intact medial collateral ligament (MCL) and anterior cruciate ligament (ACL); (4) Correctable varus deformity less than 15° [20,21]. Inclusion criteria: (1) Undergoing UKA for AMOA with varus deformity; (2) With preoperative knee magnetic resonance imaging (MRI); (3)With preoperative hip-to-ankle anterior-posterior (AP) standing radiographs, AP and lateral knee radiographs, and VSRs; (4) With postoperative hip-to-ankle AP standing radiographs, and AP and lateral knee radiographs. Exclusion criteria: (1) Radiographs with poor quality taken preoperatively or postoperatively (n = 4); (2) History of fracture around the knee (n = 2); (3) History of surgery on the ipsilateral lower limb (n = 2). The study involved 109 patients (118 knees), as shown in Fig. 1. The hospital's institutional review board approved this study (approval number: 2020-50-k28), and informed consent was obtained from the patients for the publication of their images.

2.1. Surgical procedures

A skilled surgeon conducted all UKA procedures with mobile-bearing Oxford medial UKA prostheses (Oxford Unicompartmental Knee; Zimmer Biomet, Bridgend, UK) using the novel extramedullary technique proposed by our team in 2020 [22]. A small incision was made to expose the knee joint. An osteotome was used to remove all medial osteophytes (tibial and femoral sides). Tibial osteotomy was performed according to the Oxford UKA guidelines, whereas the femoral side procedure was performed using the extramedullary technique. During the femoral-side procedure, the distal femur condyle was ground using a femoral spherical mill to balance the flexion and extension gaps. The tibial and femoral prostheses were prepared and fixed with bone cement after the gap balance. The ligament balance was based on the thicknesses of the polyethylene inserts. No intraoperative medial release to balance the ligaments or realignment was conducted.

2.2. Radiographic measurements

Before surgery, all patients underwent hip-to-ankle AP standing radiographs, AP and lateral knee radiographs, and VSRs. To obtain a VSR, the patient needs to be in a supine position with the knee joint flexed at 20°. At the same time, a junior doctor manually applies a firm valgus force to the target knee joint without anesthesia [13,23]. During the process, parallelism between the radiograph beam and tibial plateau and neutral rotation were maintained. The junior doctors were experienced and applied valgus stress uniformly every time. In accordance with the method proposed by Paley et al. [24], hip-to-ankle AP standing radiographs were obtained. A standard hip-to-ankle AP standing radiograph showed: (1) the shapes of the lesser trochanters on both sides were similar; (2) the patella was located at the center of the knee joint and pointed vertically forward; (3) the fibular head overlapped the tibia by about one-third [25]. The same series of radiographs (except for the VSR) was obtained again three days after surgery,.

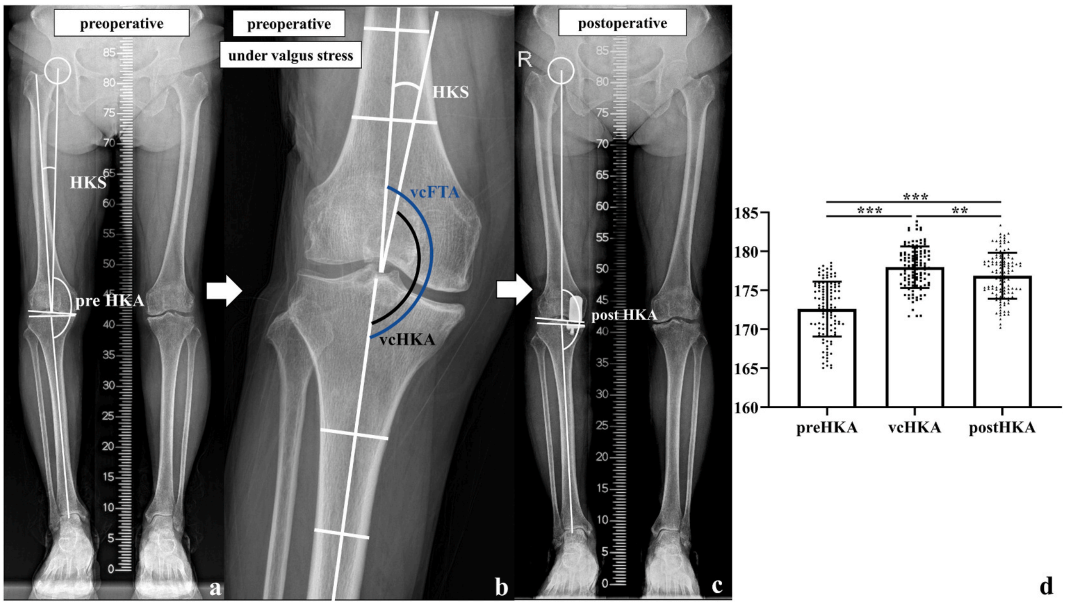

Fig. 2. Measurement of different radiographic parameters on the radiograph **(a–d)**. **(a)** The preoperative hip-to-ankle anterior-posterior (AP) standing radiograph, with preoperative hip-knee-ankle angle (pre-HKA) and hip-knee-shaft angle (HKS) measurements. **(b)** The valgus stress radiograph, with valgus-corrected femorotibial angle (vcFTA) measurements and the valgus-corrected HKA (vcHKA) calculated as vcFTA – HKS. **(c)** The postoperative hip-to-ankle AP standing radiograph with postoperative HKA (post-HKA) measurements. **(d)** Charts showing pre-HKA, vcHKA, and post-HKA. The means ± standard deviations (SD) of pre-HKA, vcHKA, and post-HKA are 172.59 ± 3.53°, 177.97 ± 2.65°, and 176.87 ± 2.94°. Significant differences between preoperative HKA and vcHKA ($p < 0.001$), preoperative HKA and postoperative HKA ($p < 0.001$), and vcHKA and postoperative HKA ($p = 0.033$) are shown.

The picture archiving and communication system (PACS) in the hospital was used to measure all radiographic parameters. Preoperative and postoperative HKA and preoperative hip-knee-shaft angle (HKS) were measured on hip-to-ankle AP standing radiographs. The angle between the femoral and tibial mechanical axes was defined as HKA, and the angle between the anatomical and mechanical axes of the femur was defined as HKS [26,27]. Patients included in the study were divided into two groups in accordance with postoperative HKA: non-valgus group (postoperative HKA $\leq 180^{\circ}$) and valgus group (postoperative HKA $>180^{\circ}$). The valgus-corrected femorotibial angle (vcFTA), which was measured on the preoperative VSR, was the angle between the anatomical axes of the tibial and femur. The vcHKA was the angle between the femoral and tibial mechanical axes and was calculated as vcFTA – HKS on the VSR [12] (Fig. 2a–c).

2.3. MRI measurements

All patients underwent preoperative knee MRI using a GE Signa 1.5 T magnetic resonance imaging system (GE Company, USA) before surgery. During the examination, the patient was placed in the supine position with the knee flexed at 20°–30°. A special coil was used to perform routine serial scanning of the sagittal plane, cross-section, and coronal plane of the knee joint. The scan parameters were FSE-T2WI (TR = 4500 m, TE = 39.8 m, 5 mm, FOV 17 × 17) and SE-T1WI (TR = 540 m, TE = 13 m, 5 mm, FOV17 × 17). The MME was measured in accordance with the method described by Costa et al. [28] using the hospital's PACS imaging system. MME was defined as the distance between the tangential line of the medial edge of the medial meniscus and the medial tibial plateau in the coronal plane (i.e., the plane with the largest medial spinous process on the tibia) on MRI [18]. Using ImageJ software, the preoperative tibial and femoral osteophyte areas in the coronal plane (i.e., the plane with the largest osteophyte area on MRI imaging) were measured (Fig. 3a and b).

Two orthopedic surgeons conducted the measurements utilizing both the hospital's PACS imaging system and ImageJ software. The intra-observer reliability of radiographic measurements was assessed by an orthopedic surgeon (CQL) after performing measurements on 30 knees at random and repeating them a week later. The inter-observer reliability was assessed using radiographic measurements on the same 30 knees by a second orthopedic surgeon (JCG). The orthopedic surgeon (CQL) conducted all measurements on a total of 118 knees. These radiographic measurements (preoperative HKA, HKS, vcFTA, postoperative HKA, MME, femoral osteophyte area, and tibial osteophyte area) showed excellent intra- and inter-observer reliabilities, with intra-class correlation coefficients (ICCs) ranging from 0.857 to 0.950 for intra-observer reliabilities and from 0.875 to 0.936 for inter-observer reliabilities.

2.4. Statistical analysis

Continuous variables are presented as means and standard deviations (SD), while categorical variables are presented as frequencies and percentages (%).

The normality of continuous variables was examined using the Shapiro-Wilk test. The Student's t-test or Mann-Whitney *U* test was used to compare the differences among preoperative HKA, vcHKA, and postoperative HKA, as well as to compare the differences in

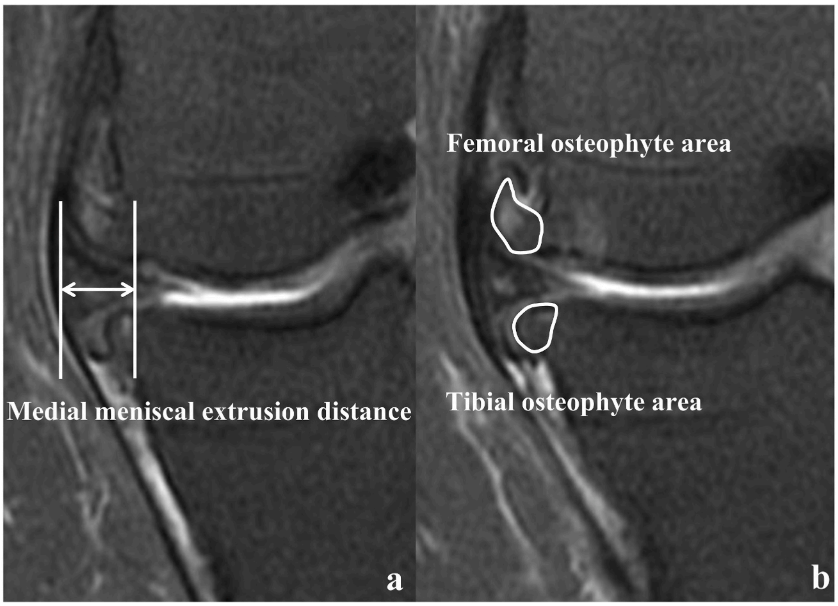

Fig. 3. Measurement of different radiographic parameters on magnetic resonance imaging (MRI) **(a–b)**. **(a)** The medial meniscal extrusion (MME) distance is measured as the distance between the tangent line of the medial tibial plateau and the medial edge of the medial meniscus in the coronal plane of the MRI. **(b)** The femoral and tibial osteophyte areas are measured in the coronal plane of the MRI.

radiological measurements between the valgus and non-valgus groups. Pearson or Spearman correlation analysis was performed between radiographic variables (vcHKA, MME, femoral osteophyte area, and tibial osteophyte area) and postoperative HKA, and the Bland Altman plot was used to evaluate the consistency between vcHKA and postoperative HKA. Simple linear regression analysis was conducted between independent variables (age, sex, side, body mass index [BMI], vcHKA, MME, femoral osteophyte area, and tibial osteophyte area) and the dependent variable (postoperative HKA); multiple linear regression analysis was further used in variables with p-values <0.1 in the simple linear regression analysis. Univariate and multivariate logistic regression analyses (variables with p-values <0.1 in univariate logistic regression analysis) were performed to assess the risk factors for postoperative valgus malalignment. The cutoff values and diagnostic accuracy of the radiographic measurements for postoperative valgus malalignment were determined by using the receiver operating characteristic (ROC) curve and area under the curve (AUC).

SPSS24.0 (IBM, New York, USA) was used for all analyses, and a two-sided p-value <0.05 was deemed statistically significant.

3. Results

3.1. Subject characteristics

In total, 109 patients (118 knees) participated in this study. The mean ± SD of age, height, weight, and BMI were 67.55 ± 7.54 years, 160.70 ± 7.86 cm, 71.59 ± 12.90 kg, and 27.65 ± 4.01 kg/m^2, respectively. Overall, 95 patients were female, and 23 were male; 60 underwent left knee surgery, while 58 underwent right knee surgery. Table 1 presents the frequencies (%) of the prosthesis parameters, including the sizes of the tibial component, femoral component, and polyethylene bearing.

3.2. Comparison analyses

The mean ± SDs of preoperative HKA, vcHKA, and postoperative HKA were 172.59 ± 3.53°, 177.97 ± 2.65°, and 176.87 ± 2.94°, respectively. Significant differences were found between the preoperative HKA and vcHKA ($p < 0.001$), preoperative HKA and postoperative HKA ($p < 0.001$), and vcHKA and postoperative HKA ($p = 0.033$) (Fig. 2d). The mean ± SD of the radiological parameters, including HKS, vcFTA, vcHKA, preoperative HKA, postoperative HKA, MME, femoral osteophyte area, and tibial osteophyte area, are presented in Table 2. There were significant differences in the vcFTA ($p < 0.001$), vcHKA ($p < 0.001$), preoperative HKA ($p < 0.001$), postoperative HKA ($p < 0.001$), and MME ($p = 0.033$), whereas no significant differences were observed in the other radiological parameters between the valgus and non-valgus groups (Table 2).

Table 1
Basic characteristics.

Variables	Total (n = 118)
Age (years)	67.55 ± 7.54
Sex (n (%))	
Female	95 (80.5 %)
Male	23 (19.5 %)
Side (n (%))	
Right	58 (49.2 %)
Left	60 (50.8 %)
Height (cm)	160.70 ± 7.86
Weight (kg)	71.59 ± 12.90
BMI (kg/m^2)	27.65 ± 4.01
Prosthesis parameters	
Size of femoral component (n (%))	
Extra small	9 (7.6 %)
Small	82 (69.5 %)
Medium	22 (18.6 %)
Large	5 (4.2 %)
Size of tibial component (n (%))	
AA (smallest)	12 (12.2 %)
A	42 (35.6 %)
B	38 (32.2 %)
C	22 (18.6 %)
D	1 (0.8 %)
E (largest)	3 (2.5 %)
Size of polyethylene bearing (n (%))	
3 (thinnest)	70 (59.3 %)
4	40 (33.9 %)
5	5 (4.2 %)
6 (thickest)	3 (2.5 %)

BMI, body mass index.

3.3. Correlation and consistency analyses

In the correlation analysis, vcHKA ($r = 0.692$, $p < 0.001$) and MME ($r = 0.289$, $p = 0.002$) were positively correlated with the postoperative HKA, whereas no significant correlation was found in the femoral osteophyte area ($r = 0.091$, $p = 0.327$) and tibial osteophyte area ($r = 0.040$, $p = 0.668$) (Fig. 4a, c-d). In the Bland-Altman plot, 109 (92.4 %) of the 118 values were within the 95 % limit of agreement (LOA) range for vcHKA and postoperative HKA, showing good agreement between the two measurements (Fig. 4b).

3.4. Simple and multiple linear regression analyses

The vcHKA ($\beta = 0.766$, 95 % confidence interval (95 % CI) = 0.619 to 0.914; $p < 0.001$) and MME ($\beta = 0.432$, 95%CI = 0.169 to 0.696; $p = 0.002$) were significantly related with postoperative HKA in simple linear regression analysis, while no significant correlation was found with other variables. Variables (vcHKA and MME) with p-values <0.1 in the simple linear regression analysis were taken into account in multiple linear regression analysis. The vcHKA ($\beta = 0.732$, 95%CI = 0.582 to 0.881; $p < 0.001$) and MME ($\beta = 0.203$, 95%CI = 0.001 to 0.405; $p = 0.049$) showed a significant relationship with the postoperative HKA. A predictive model (adjusted $r^2 = 0.487$) was constructed using the two variables: postoperative HKA = 45.420 + (0.732° * vcHKA) + (0.203 mm × MME) (Table 3).

3.5. Univariate and multivariate logistic regression analyses

The vcHKA (odds ratio [OR] = 2.047, 95%CI = 1.462 to 2.864, $p < 0.001$) was significantly related with postoperative valgus malalignment in univariate logistic regression analysis, while the other variables showed no significant correlation with postoperative valgus malalignment. Variables (vcHKA and MME) with p-values <0.1 in the univariate logistic regression analysis were subsequently assessed in multivariate logistic regression analysis. According to the multivariate analysis, vcHKA (OR = 2.007, 95 % CI = 1.433 to 2.810; $p < 0.001$) was independently associated with postoperative valgus malalignment (Table 4).

3.5. The ROC curve

In the ROC curve, vcHKA (with 180° as the cutoff value) could predict the postoperative valgus malalignment after UKA (AUC [95 % CI] = 0.862 [0.780 to 0.944]; sensitivity: 72.2 %; specificity: 89.0 %; $p < 0.001$). Other variables, including the MME, femoral osteophyte area, and tibial osteophyte area, could not predict postoperative valgus malalignment (Fig. 5).

4. Discussion

The important results of the study are as follows: (1) vcHKA and MME were positively associated with the postoperative HKA, and the postoperative HKA could be calculated as 45.420 + (0.732° * vcHKA) + (0.203 mm × MME) (Table 3); (2) the vcHKA was an independent risk factor for postoperative valgus malalignment (Table 4), and vcHKA (with 180° as the cutoff value) could be used to predict postoperative valgus malalignment after UKA with an accuracy of 0.862 (95 % CI, 0.780 to 0.944) (Fig. 5). Thus, overcorrection of a varus knee under VSR along with excessive MME on preoperative MRI were related with overcorrection of postoperative alignment. Caution should be required when implementing mobile-bearing UKA in these patients, particularly those with a preoperative vcHKA >180°.

The appropriate alignment of the lower limbs after surgery is important for the success of medial UKA. The progression of lateral compartment OA is often caused by overcorrection of postoperative alignment, and severe undercorrection can lead to wear of the bearing and loosening of the tibial prosthesis [7–10,29]. Mild varus has been reported as the ideal postoperative alignment for medial UKA. Zuiderbaan et al. [30] followed 104 patients with medial UKA for an average of 2.3 years and found that patients with a postoperative HKA of 1°–4° varus had higher Western Ontario and McMaster Universities Osteoarthritis Index scores (WOMAC) than other patients with a postoperative HKA ≤1° or ≥ 4° varus. Vasso et al. [31] reported that patients with a postoperative HKA of 2°–4°

Table 2
Radiological measurements between the valgus group and the non-valgus groups.

Variables	Total (n = 118)	Valgus group (n = 18)	Non-valgus group (n = 100)	p
HKS (°)	5.96 ± 0.87	5.69 ± 0.93	6.01 ± 0.85	0.155[a]
vcFTA (°)	183.93 ± 2.46	186.49 ± 1.66	183.47 ± 2.30	< 0.001[a]
vcHKA (°)	177.97 ± 2.65	180.80 ± 1.74	177.46 ± 2.47	< 0.001[a]
preHKA (°)	172.59 ± 3.53	175.35 ± 1.44	172.10 ± 3.57	< 0.001[b]
postHKA (°)	176.87 ± 2.94	181.33 ± 0.86	176.07 ± 2.41	< 0.001[b]
MME (mm)	6.16 ± 1.96	6.92 ± 1.46	6.02 ± 2.02	0.033[a]
Femoral osteophyte area (mm^2)	21.31 ± 12.54	21.86 ± 13.81	21.21 ± 12.37	0.917[b]
Tibial osteophyte area (mm^2)	18.16 ± 11.46	17.23 ± 10.42	18.33 ± 11.68	0.884[b]

HKS, hip-knee-shaft angle; vcFTA, valgus-corrected femorotibial angle; vcHKA, valgus-corrected hip-knee-ankle angle; preHKA, preoperative hip-knee-ankle angle; postHKA, postoperative hip-knee-ankle angle; MME, medial meniscal extrusion.

[a] The Student's t-test.

[b] The Mann–Whitney *U* test.

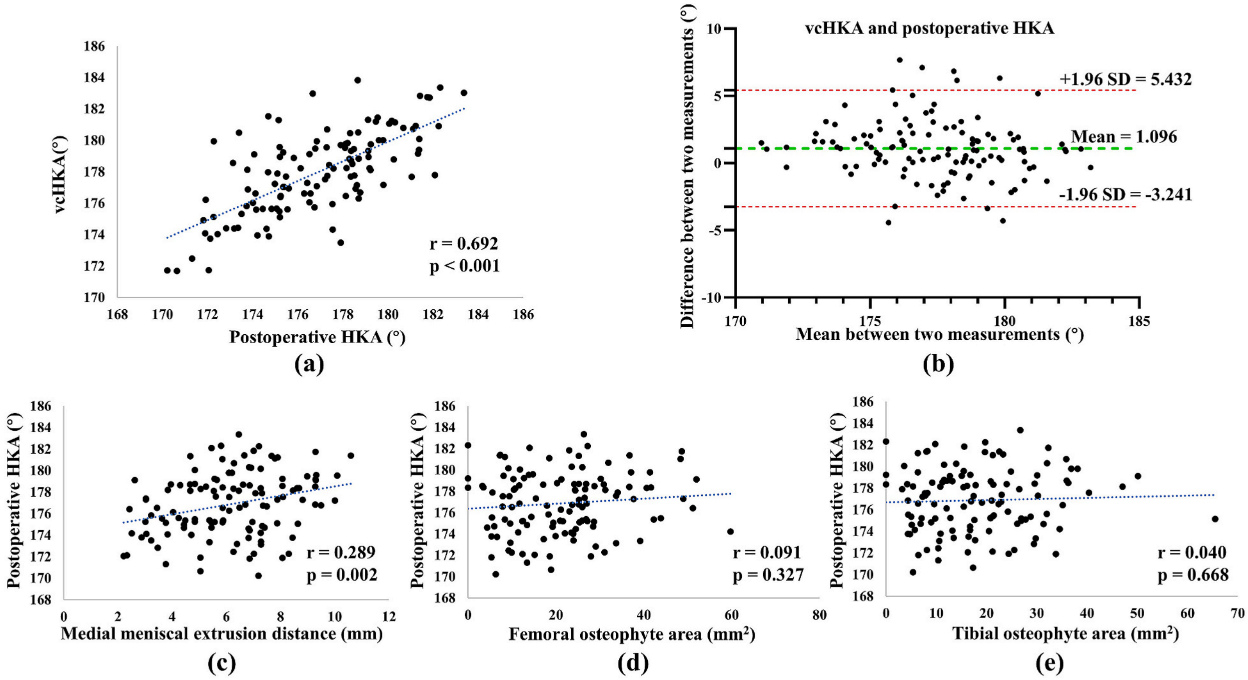

Fig. 4. Correlation and consistency analysis. **(a)** The valgus-corrected hip-knee-ankle angle (vcHKA) is positively correlated with postoperative HKA ($r = 0.692$, $p < 0.001$). **(b)** In the Bland-Altman plot, 109 (92.4 %) of the 118 values are within the 95 % limits of agreement (LOA) range for vcHKA and postoperative HKA, showing good agreement. **(c)** The medial meniscal extrusion distance is positively correlated with postoperative HKA ($r = 0.289$, $p = 0.002$). **(d)** The femoral osteophyte area is not significantly correlated with postoperative HKA ($r = 0.091$, $p = 0.327$). **(e)** The tibial osteophyte area is not significantly correlated with postoperative HKA ($r = 0.040$, $p = 0.668$).

Table 3
Simple and multiple linear regression analysis of postoperative HKA.

Variables	Simple linear regression			Multiple linear regression		
	β	95 % CI	p	β	95 % CI	p
Age (years)	0.017	−0.054 to 0.089	0.634			
Sex	−0.721	−2.074 to 0.632	0.293			
Side	0.549	−0.524 to 1.621	0.313			
BMI (kg/m^2)	−0.033	−0.167 to 0.102	0.633			
vcHKA (°)	0.766	0.619 to 0.914	<0.001	0.732	0.582 to 0.881	<0.001
MME (mm)	0.432	0.169 to 0.696	0.002	0.203	0.001 to 0.405	0.049
Femoral osteophyte area (mm^2)	0.024	−0.019 to 0.067	0.278			
Tibial osteophyte area (mm^2)	0.011	−0.037 to 0.058	0.659			

CI, confidence interval; BMI, body mass index; vcHKA, valgus-corrected hip-knee-ankle angle; MME, medial meniscal extrusion. Sex: male = 0, female = 1; Side: left = 0, right = 1.
Multiple linear regression model: postoperative HKA = 45.420 + (0.732° * vcHKA) + (0.203 mm × MME).

Table 4
Univariate and multivariate logistic regression analysis of risk factors for valgus malalignment.

Variables	Univariate logistic regression			Multivariate logistic regression		
	OR	95 % CI	p	OR	95 % CI	p
Age (years)	1.031	0.964 to 1.102	0.375			
Sex (female vs male)	1.752	0.554 to 5.537	0.339			
Side (right vs left)	0.961	0.352 to 2.621	0.938			
BMI (kg/m^2)	0.940	0.816 to 1.084	0.396			
vcHKA (°)	2.047	1.462 to 2.864	<0.001	2.007	1.433 to 2.810	<0.001
MME (mm)	1.275	0.972 to 1.673	0.080	1.124	0.816 to 1.547	0.475
Femoral osteophyte area (mm^2)	1.004	0.965 to 1.045	0.841			
Tibial osteophyte area (mm^2)	0.991	0.947 to 1.038	0.708			

OR, odds ratio; CI, confidence interval; BMI, body mass index; vcHKA, valgus-corrected hip-knee-ankle angle; MME, medial meniscal extrusion.

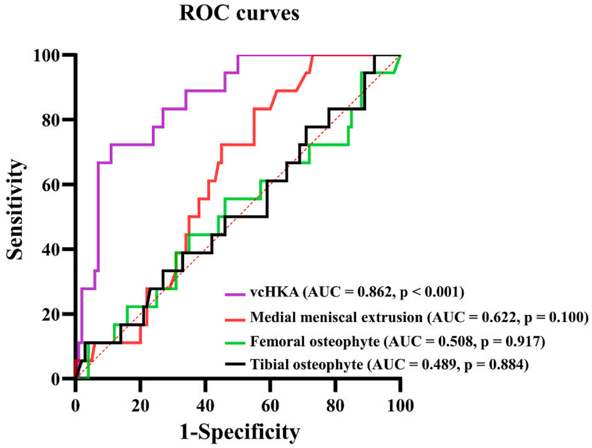

Fig. 5. The receiver operating characteristic (ROC) curve for the valgus-corrected hip-knee-ankle angle (vcHKA), medial meniscal extrusion distance, femoral osteophyte area, and tibial osteophyte area. The area under the curve (AUC) is 0.862 (95 % confidence interval [95%CI], 0.780 to 0.944) for vcHKA.

and 5°–7° varus had a better Knee Society Score (KSS) than those with a postoperative HKA of −2°–1° varus in a cohort of 125 patients undergoing medial UKA with an average follow-up of 7.6 years. Slaven et al. [9] followed 3351 patients with medial UKA for at least 10 years and found that patients with a postoperative HKA of approximately 4° varus showed good functional outcomes. Therefore, it is important to perform a preoperative assessment of the correctability of knee varus deformities as well as identify the predictors of postoperative alignment in medial UKA. It should be noted that in the study, the average postoperative HKA was 176.87° ± 2.94°, and 68 % of patients recovered the postoperative HKA to the 177° ± 3° range, which was in line with the concept that the ideal UKA postoperative alignment was mild varus.

The use of preoperative VSR to predict the postoperative alignment in patients undergoing UKA remains controversial [11,15]. Zhang et al. [32] evaluated 79 patients who underwent Oxford UKA and reported that changes in HKA before and after surgery were closely related to changes in the femorotibial facet angle (FTFA) on preoperative AP knee radiographs and VSRs. Tashiro et al. [14] reported a significant correlation between postoperative HKA and vcHKA on full-length VSRs taken prior to UKA. However, Kreitz et al. [15] found that VSRs exaggerated the correctable extent of the varus deformity in patients undergoing UKA and could determine the correction of the varus deformity only after osteophyte removal. Ishibashi et al. [13] found that the postoperative HKA of patients undergoing fixed-bearing UKA was not only related to vcHKA on preoperative VSRs but was also affected by the MME distance. Similar to the results of Ishibashi et al. [13], the study investigated that preoperative VSRs could predict the postoperative HKA in mobile-bearing UKA. Moreover, the addition of MME to the linear regression model (adjusted $r^2 = 0.487$ [vcHKA + MME] vs. adjusted $r^2 = 0.474$ [vcHKA]) could improve the prediction accuracy (Table 3). It should be noted that the study also demonstrated that postoperative HKA was slightly less corrected than vcHKA on VSRs (postoperative HKA vs. vcHKA, 176.87° ± 2.94° vs. 177.97° ± 2.65°) (Fig. 2d), which was similar to the finding of Tashiro et al. [14]. One possible explanation for this outcome is that the FTA increases by 1° when the knee is flexed by 10°, and the VSR was taken with the knee flexed at 20°; therefore, the value of vcHKA (i.e., vcFTA-HKS) would theoretically increase by 2° [33]. However, the vcHKA was only 1.1° (not 2°) larger than the postoperative HKA in this study, which may be related to the influence of the MME and medial osteophytes.

Recently, some researchers have proposed that appropriate resection of the bone, meniscus and osteophytes (without the release of medial soft tissue) can restore good postoperative alignment in TKA [19,34,35]. After measuring the joint space of each procedure during TKA surgery, Yagishita et al. [36] found that resecting medial osteophytes led to an increase of 1.9 ± 2.5 mm in the medial space in the extension position and 1.7 ± 1.6 mm in the flexion position, which in turn affected the postoperative alignment. Limited research has been conducted on the relationship between medial osteophytes, meniscal removal, and postoperative alignment in UKA. Ishibashi et al. [13] found that the postoperative alignment was significantly correlated with the MME in fixed-bearing UKA. Kreitz et al. [15] found that vcHKA under VSR could be further corrected by 1.8° after removing the medial osteophytes in patients undergoing UKA. A significant correlation between the postoperative HKA and preoperative MME was observed in this study (Table 3 and Fig. 4c), suggesting that medial meniscus resection affects the postoperative alignment of mobile-bearing UKA, which is consistent with the findings of Ishibashi et al. [13]. However, no significant association was found between medial osteophytes (including tibial and femoral osteophytes) and postoperative HKA (Table 3 and Fig. 4d and e), possibly because knee OA develops earlier in patients undergoing UKA, as compared to patients undergoing TKA.

Postoperative alignment is critical for the success of UKA procedures, and OA progression in the lateral compartment may be induced by postoperative valgus malalignment [8–10]. Therefore, avoiding postoperative valgus malalignment is necessary. However, despite the extensive experience of the surgeon performing UKA at our center, 15 % of the patients in this study (18 valgus vs. 100 non-valgus patients) still suffered from postoperative valgus malalignment. Therefore, identifying predictors of postoperative valgus malalignment in patients undergoing UKA is important. Although the role of preoperative VSR in predicting the postoperative alignment of UKA remains a subject of debate, the correctability of varus deformity under preoperative VSR was an important indicator of postoperative alignment in UKA, as was discovered by Ahn et al. [37], Ishibashi et al. [13], and Tashiro et al. [14]. Our results also showed that vcHKA (OR = 2.007, 95%CI = 1.433–2.810; $p < 0.001$) was associated with postoperative valgus malalignment independently, and a vcHKA cutoff value of 180° could be used to predict postoperative valgus malalignment after UKA, with an accuracy (95 % CI) of 0.862 (0.780–0.944) (Table 4 and Fig. 5). Therefore, overcorrection is ought to be prevented in patients with a preoperative vcHKA >180°. For these patients, three approaches might be helpful in avoiding postoperative valgus malalignment: (1) The flexion and extension gap can be in a slightly loose state to avoid overfilling during surgery. However, the quantitative assessment of the relationship between the intraoperative gap pressure and lower limb alignment is still unsolved. (2) The intraoperative removal of medial osteophytes should be reduced, although such patients tend to have small varus deformities and relatively small osteophytes. (3) Medial UKA is not recommended for patients with a preoperative vcHKA >183°. In addition, according to the formula for postoperative HKA of 45.420 + (0.732° * vcHKA) +(0.203 mm × MME) (Table 3), patients with a preoperative vcHKA greater than 180° and large MME are more likely to suffer from postoperative valgus malalignment, and the surgeon needs to be more cautious when performing UKA in these patients.

Our study had some limitations. First, although the radiographic examination of each patient adopted the same protocol, radiographic measurements, including the HKA, HKS, and vcFTA, were still influenced by osteophytes and lower-limb rotation. Thus, the use of computer tomography (CT) for measurement and evaluation could be a better solution. Second, this retrospective study only involved one prosthesis (i.e., mobile-bearing UKA). As such, the outcomes of this study are specifically applicable to mobile-bearing UKA. To broaden the applicability of these findings, prospective studies involving various prosthesis types, including fixed-bearing UKA, are needed. Third, the magnitude of valgus stress in the VSR was not quantified by a quantitative machine. However, the physician who examined the VSR had extensive experience and applied valgus stress uniformly, whereas patients with VSRs of poor quality were excluded from the study. Fourth, the VSR in this study was obtained with the knee flexed at 20°, and vcHKA was calculated as vcFTA-HKS. This had a certain measurement error compared with vcHKA values obtained from full-length VSRs. However, VSRs with the knee flexed at 20° are routinely used in clinical practice. Fifth, the predictors of postoperative alignment and risk factors for postoperative valgus malalignment in UKA were analyzed in this study; however, the correlation between long-term PROMs and postoperative alignment has not been studied. Therefore, further follow-up is needed to explore the correlation between long-term PROMs and postoperative alignment.

5. Conclusion

In conclusion, vcHKA under VSR and MME on preoperative MRI were positively related with postoperative alignment in mobile-bearing UKA; overcorrection of a varus knee under valgus stress and excessive MME increased the possibility of overcorrection of postoperative alignment. In addition, a vcHKA cutoff value of 180° can be used to predict postoperative valgus malalignment. Therefore, caution should be required when implementing mobile-bearing UKA in these patients, particularly those with a preoperative vcHKA >180°

Ethics statement

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 reviewed and approved by the institutional review board of the China-Japan Friendship Hospital, with the approval number: 2020–50-k28. All participants provided informed consent to participate in the study.

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CRediT authorship contribution statement

Changquan Liu: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Juncheng Ge:** Writing – original draft, Formal analysis, Data curation. **Yankun Jiang:** Methodology, Formal analysis, Data curation. **Weiguo Wang:** Formal analysis, Data curation. **Qidong Zhang:** Writing – review & editing, Formal analysis, Conceptualization. **Wanshou Guo:** Writing – review & editing, Resources, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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