Influence of hindfoot alignment on postoperative lower limb alignment in medial opening wedge high tibial osteotomy

Abstract

Introduction: We have experienced unexpected undercorrection after medial opening wedge high tibial osteotomy (MOWHTO). Although the tibia was corrected accurately, the postoperative mechanical axis (MA) was less than 57%. The purpose of this study was to evaluate the relationship between hindfoot alignment and postoperative lower limb alignment, and to reveal whether hindfoot alignment affects lower limb alignment after MOWHTO. Our hypothesis was that hindfoot alignment influences the postoperative MA in MOWHTO.

Materials and Methods: This study was a retrospective comparative study. The study cohort comprised 43 knees in 43 patients who underwent MOWHTO and had standing long-leg anteroposterior view and hindfoot alignment view radiographs taken preoperatively and at 3 months postoperatively. To evaluate the hindfoot alignment, the absolute value of the ankle joint line orientation relative to the ground was added to the absolute value of the hindfoot angle. We defined a postoperative MA of 57–67% as acceptable correction (A-group) and a MA of < 56% as undercorrection (U-group). The two groups were analyzed to identify factors that affected postoperative limb alignment.

Results: The preoperative hindfoot alignment angle was significantly larger in the U-group than the A-group. The preoperative hindfoot alignment angle was a significant predictive factor of the postoperative MA, and the cut-off value that distinguished undercorrection from acceptable correction was 15.9 degrees.

Conclusions: Abnormal hindfoot alignment is one of the causes of undercorrection after MOWHTO. Attention should be paid to the preoperative ankle joint line orientation relative to the ground and hindfoot angle. If the preoperative hindfoot alignment angle is ≥ 15.9 degrees, surgeons should reconsider the operative procedure and correction angle.

Level of Evidence: Therapeutic level III, retrospective study

Keywords: medial opening wedge high tibial osteotomy, hindfoot, alignment, undercorrection

Introduction

Reproduction of the preoperatively planned lower limb alignment is important for the attainment of good results after medial opening wedge high tibial osteotomy (MOWHTO). The target coronal alignment is generally the mechanical axis (MA) that passes through the Fujisawa point [1] located at 62.5% of the tibial plateau from the medial edge, because this alignment achieves good clinical outcomes [2-5]. However, we have experienced cases in which MOWHTO did not achieve the preoperatively planned lower limb alignment, despite the surgical correction being performed as preoperatively planned. The factors that affect the under- or overcorrection of postoperative lower limb alignment are varus contracture (tightness of the medial collateral ligament and looseness of the lateral collateral ligament), an inaccurate preoperative plan, and inaccurate alignment evaluation intraoperatively [6-9,10-13]. To obtain the preoperatively planned lower limb alignment after MOWHTO in patients with varus contracture, it is important to consider the preoperative instability of the knee soft tissue [9]. However, even with an accurate preoperative plan and procedure, there are cases in which the postoperative lower limb alignment cannot be achieved as planned.

In a varus osteoarthritic lower leg, the varus inclination of the talus and the valgus inclination of the calcaneus is compensated for by the hindfoot [14]. MOWHTO improves the hindfoot alignment along with the improvement of the knee alignment [14-20]. Therefore, the improvement of the hindfoot alignment after MOWHTO was presumed to be due to hindfoot mobility. Lee et al. [21] reported that the talar inclination at 1 year after MOWHTO showed larger varus alignment in the undercorrection group than in the acceptable correction group, which suggests an association between the postoperative alignment of the lower limb and the hindfoot. Previous studies have reported that a change in ankle joint alignment affects knee joint alignment and function [19, 22, 23]. Therefore, we consider that the hindfoot alignment would affect the lower limb alignment after MOWHTO.

In our institution, we have noted that the cases with a large ankle joint line orientation relative to the ground (AJLO) were undercorrected after MOWHTO, despite accurate preoperative planning, intraoperative evaluation, and performance of the procedure. We hypothesized that the reason that the ideal hindfoot alignment was not obtained after MOWHTO was due to abnormal hindfoot alignment, even though the tibia was corrected as preoperatively planned. This suggests that hindfoot alignment affects postoperative lower limb alignment.

The purpose of this study was to evaluate the relationship between hindfoot alignment and lower limb alignment pre- and postoperatively, and to reveal whether hindfoot alignment affects the lower limb alignment after MOWHTO. Our hypothesis was that hindfoot alignment influences the postoperative MA in MOWHTO.

Materials and methods

This study was approved by our Institutional Review Board (approval no. U19-07-017), and informed consent was obtained from all patients. This study was a retrospective, nonrandomized, and sequential review study.

Our patient database was searched to identify patients who underwent MOWHTO performed by three senior surgeons for medial osteoarthritis of the knee at our institution between June 2017 and May 2020. The surgical indications for MOWHTO were (1) primary degenerative osteoarthritis (not inflammatory arthritis), (2) radiographic evidence of isolated medial compartment osteoarthritis (Kellgren-Lawrence grade II–IV) in the knee, (3) concurrent varus deformity of the lower limb, (4) failure of conservative treatments, (5) active patients who complied well with the postoperative rehabilitation program. This search identified 83 knees in 81 patients. The exclusion criteria were a lack of radiographs in the standing long-leg anteroposterior view and hindfoot angle view [24] preoperatively and at 3 months postoperatively (22 knees in 20 patients), a history of lower extremity injuries (two knees in two patients), ankle osteoarthritis (two knees in two patients) because the talar tilt may be affected by ankle osteoarthritis, the mechanical medial proximal tibial angle (mMPTA) was not reproduced as preoperatively planned (seven knees in seven patients), and postoperative overcorrection of alignment (seven knees in seven patients). A total of 43 knees in 43 patients were eligible for analysis (Fig. 1). No patients were lost to follow-up. The patient characteristics are summarized in Table 1.

Surgical procedures and postoperative rehabilitation

In preoperative planning, the target weightbearing line was the Fujisawa point (62.5% of the tibial plateau from the medial edge) [1] on the standing long-leg anteroposterior view radiograph. The correction angle was measured using Miniaci's method [25]. Additionally, the definitive correction was decided in accordance with Ogawa's method [9]; if the joint line convergence angle (JLCA) under varus stress was ≥ 6 degrees, the correction angle was reduced by 0.3 degrees per 1 degree of the JLCA, considering the soft tissue correction.

Before osteotomy, arthroscopy was conducted to evaluate the cartilage and meniscus. Microfracture or drilling was performed for degraded cartilage lesions (International

Cartilage Research Society grade ≥ 3) to trigger cartilage regeneration. Partial meniscectomy or meniscal repair was performed for meniscal tears. Bi-planar MOWHTO was performed. At this point, it was important to check that the intraoperative mMPTA image before osteotomy was consistent with the mMPTA image on the anteroposterior view of the standing long-leg radiograph that was used for planning (Fig. 2a, 2b). The osteotomy site was opened using an opener until the preoperatively planned mMPTA was reproduced; the mMPTA was checked using an angle meter made of a permeable acrylic plate that reached from the knee to the ankle (Fig. 2c). The gap between the most posteromedial cortexes was measured. β-tricalcium phosphate particles with a porosity rate of 75% (Osferion®, Olympus Terumo Biomaterials, Tokyo, Japan) were inserted into the gap on the cancellous side. Two β-tricalcium phosphate wedges with a porosity rate of 60% (Osferion60®, Olympus Terumo Biomaterials) were inserted into the gap on the cortex side. The medial osteotomy site was rigidly fixed using a locking compression plate (Tris plate®; Olympus Terumo Biomaterials) after the pes anserinus was repaired.

Isometric quadriceps exercises, active ankle exercises, straight leg raises, and continuous passive motion with no limitation were started on postoperative day 3. Patients were allowed to begin 1/2 partial weightbearing exercise at 2 weeks postoperatively, and were allowed to begin full weightbearing exercise at 4 weeks postoperatively. Patients with microfracture were allowed to begin 1/2 partial weightbearing exercise at 3 weeks postoperatively, and were allowed to begin full weightbearing exercise at 5 weeks postoperatively.

Radiographic measurements

Radiographs were taken preoperatively and at 3 months after MOWHTO. The MA, mMPTA, mechanical lateral distal femoral angle (mLDFA), mechanical lateral distal tibial angle (mLDTA), talar tilt, JLCA, knee joint line obliquity relative to the ground (KJLO; a negative value indicated valgus deviation of the proximal knee joint line [18]) and AJLO (a negative value indicated valgus deviation of the talus surface [18]) were measured on anteroposterior weight-bearing whole-leg radiographs with the knee joint in extension and the patella facing directly anterior. The hindfoot angle (normally inclined 2–6 degrees [26, 27]) was measured on a hindfoot angle view radiograph [24] (Fig. 3).

Some previous studies reported that MOWHTO resulted in a change in the hindfoot angle due to compensation of the subtalar joint [15, 17, 19], although these studies did not report which methods were used to directly evaluate the compensation of the subtalar joint on radiographs. We defined the angle that the absolute value of the AJLO added to the absolute value of the hindfoot angle as the hindfoot alignment angle, and used this as an indicator of hindfoot alignment. We then indirectly evaluated the compensation of the subtalar joint as the pre- versus post-MOWHTO difference in the hindfoot alignment angle.

Statistical analysis

A paired *t* test was used to evaluate pre- and postoperative differences in all measured parameters. Cases in which the weightbearing line passed between points at 57–67% of the tibial plateau width were considered to have acceptable correction, while cases in which the weightbearing line passed through a point medial to < 57% of the tibial plateau width were considered to have undercorrection [28]. The Mann-Whitney U test was used for comparisons of radiographic parameters between the undercorrection group (U-group) and the acceptable correction group (A-group). Univariate regression was performed under the assumption of a linear relationship between the independent variables (preoperative radiographic parameters, age, sex, and BMI) and the dependent variable of postoperative MA. Multivariate regression was then performed based on the results of univariate regression. The estimated area, sensitivity, and specificity of the receiver operating characteristic (ROC) curve were analyzed to determine the cut-off value of each parameter based on the result of multivariate regression. Significance was assumed for *p* values of less than 0.05. A post hoc test for the Mann-Whitney U test was performed to determine whether the sample size provided sufficient statistical power to detect significant factors. The post hoc power analysis showed that a sample size of 42 achieved a power of 80% and significance level of 5%, which verified the adequacy of the present sample size. All radiographic parameters were measured independently by two orthopedic surgeons. Reliability of the measurements was assessed by estimating the intra- and interobserver reliability using the intraclass correlation coefficient (ICC). The ICC were 0.81 to 1.00 (intraobserver variance) and 0.81 to 1.00 (interobserver variance). Statistical analyses were performed using SPSS software (version 23.0, IBM Corp., Armonk, NY, USA).

Results

The radiographic parameters are presented in Table 2. Compared with preoperative values, there was a significant improvement in the mean postoperative MA ($p < 0.001$), significant increase in the mean postoperative mMPTA and KJLO ($p < 0.001$), and significant decrease in the mean postoperative JLCA ($p < 0.001$), postoperative AJLO ($p < 0.001$), hindfoot angle ($p = 0.001$), and postoperative hindfoot alignment angle ($p < 0.001$).

There were 20 knees in the U-group and 23 knees in the A-group. Compared with the A-group, the U-group had a significantly smaller mean preoperative MA ($p = 0.007$), significantly larger mean preoperative mLDFA ($p = 0.003$), significantly smaller mean preoperative hindfoot alignment angle ($p = 0.036$) and mean postoperative MA ($p < 0.001$), and significantly larger mean postoperative mLDFA ($p = 0.015$) and mean postoperative hindfoot alignment angle ($p = 0.012$) (Table 3).

The combinations of the postoperative AJLO and hindfoot angle presented as six patterns (Fig. 4). The most common combination was a varus inclined postoperative AJLO and valgus inclined postoperative hindfoot angle (n = 14 knees). Six knees had a postoperative valgus inclined AJLO and postoperative hindfoot angle, seven knees had a varus inclined postoperative AJLO and normally inclined postoperative hindfoot angle, seven knees had a valgus inclined postoperative AJLO and normally inclined postoperative hindfoot angle, five knees had a varus inclined postoperative AJLO and postoperative hindfoot angle, and four knees had a valgus inclined postoperative AJLO and varus inclined postoperative hindfoot angle.

Univariate regression analysis showed that the factors potentially associated with the postoperative MA were the preoperative mLDFA ($t = -3.579$, $p = 0.001$), talar tilt ($t = -2.516$, $p = 0.016$), AJLO ($t = -2.386$, $p = 0.022$), hindfoot angle ($t = -2.025$, $p = 0.049$), and preoperative hindfoot alignment angle ($t = -3.002$, $p = 0.005$) (Table 4). Multiple regression performed with these five parameters as dependent variables revealed that the significant predictors of postoperative MA in MOWHTO were the preoperative mLDFA ($\beta = -0.402$, $p = 0.005$) and preoperative hindfoot alignment angle ($\beta = -0.315$, $p = 0.024$) (Table 5).

The ROC curve showed that the preoperative hindfoot alignment angle was a useful parameter to determine a cut-off value at which the postoperative MA became undercorrected after MOWHTO. The optimal cut-off value for the preoperative hindfoot alignment angle was 15.9 degrees, with an area under the curve of 0.68, sensitivity of 73.9%, and specificity of 65.0% (Fig. 5).

Discussion

The most important finding of the present study was that hindfoot alignment affects the lower limb alignment after MOWHTO. In recent years, much attention has been paid to the relationship between MOWHTO and the hindfoot alignment [16-18, 21]. Lee et al. [18] reported that the varus inclined AJLO improved from 8.8 ± 3.2 degrees preoperatively to 2.0 ± 3.9 degrees postoperatively. Another study reported that the preoperative valgus inclination of the hindfoot angle was decreased by surgery [17]. In the present study, the inclination of the AJLO and hindfoot angle was improved after surgery, and the change in the hindfoot alignment was affected by the hindfoot mobility. The present study is the first to propose the possible influence of hindfoot deformity on knee deformity.

The pre- and postoperative AJLO and hindfoot angle did not significantly differ between the two groups, although we had expected that the cases in which the pre- and postoperative AJLO had a larger varus inclination and the hindfoot angle had a larger valgus inclination would be undercorrected because of the abnormal hindfoot alignment. There were six combinations of the postoperative AJLO and hindfoot angle (Fig. 4). The 20 knees in the U-group had five combinations of the postoperative AJLO and hindfoot angle; 10 knees (50%) had a varus inclined postoperative AJLO and valgus inclined postoperative hindfoot angle, three knees (15%) had a valgus inclined postoperative AJLO and postoperative hindfoot angle, three knees (15%) had a varus inclined postoperative AJLO and normal postoperative hindfoot angle (2–6 degrees) [26, 27], two knees (10%) had a varus inclined postoperative AJLO and postoperative hindfoot angle, and two (10%) knees had a valgus inclined postoperative AJLO and varus inclined postoperative hindfoot angle. No knees in the U-group had a valgus inclined postoperative AJLO and normal postoperative hindfoot angle. The hindfoot alignment becomes valgus to compensate for varus knee, while the hindfoot alignment becomes varus to compensate for valgus knee [14]. However, there were no cases of hindfoot compensation for valgus knee [29]. There were a variety of patterns of hindfoot and knee alignments; it was not only difficult to predict the hindfoot mobility from the preoperative hindfoot alignment, but also to predict the postoperative hindfoot alignment. The difference in the hindfoot mobility in each case is probably the reason for the variety of postoperative AJLO and hindfoot angle combinations, and the reason that the AJLO and hindfoot angle did not differ between the two groups. In addition to this, the talus is surrounded by the ankle joint and the subtalar joint. The subtalar joint has a compensatory function in ankle malalignment [23], and the ankle joint and subtalar joint have a reciprocal relationship. Therefore, when considering the hindfoot alignment as an indicator of the hindfoot mobility, the AJLO and hindfoot angle should be evaluated comprehensively rather than independently.

Both the pre- and postoperative hindfoot alignment angles were larger in the U-group than the A-group because of the abnormal hindfoot alignment. The cases with a larger preoperative hindfoot alignment angle would have had instability or contracture of the subtalar joint because of the abnormal hindfoot mobility. These cases would not have normal hindfoot mobility, and the ideal hindfoot alignment would not be obtained postoperatively. In such an abnormal subtalar joint, the hindfoot mobility could not compensate for the change of knee alignment in MOWHTO and led to undercorrection of the lower leg alignment. Previous studies have reported that subtalar joint stiffness reduced the compensation ability of the subtalar joint [16], and that the mobility of the subtalar joint varied between individuals and determined the ability of the subtalar joint to compensate for the change in the knee alignment [22, 30-32]. We considered that the abnormal subtalar joint decreased the hindfoot mobility because of the contracture or abnormal joint laxity. Originally, the hindfoot mobility was evaluated based on the mobility of the subtalar joint. There is a need for the development of a new radiographic method to evaluate the mobility of the subtalar joint.

The postoperative hindfoot alignment angle was significantly larger in the U-group than the A-group. Although we feared that there would be remaining varus of the AJLO or valgus of the hindfoot angle due to inadequate correction of the tibia, the postoperative mMPTA did not significantly differ between the two groups. In addition, the postoperative mMPTA showed no loss of tibial correction during a 3-month period.

Multiple regression analysis revealed that the preoperative hindfoot alignment angle was a significant predictor of postoperative MA in MOWHTO. A cut-off value of the preoperative hindfoot alignment angle of 15.9 degrees predicted undercorrection after

MOWHTO. Therefore, cases with a preoperative hindfoot alignment angle of ≥ 15.9 degrees would have abnormal hindfoot mobility. In such cases, the postoperative lower limb alignment became undercorrected even if the tibia was corrected by the angle calculated preoperatively. Choi et al. [17] reported that the change in the hindfoot angle did not need to be considered when the knee correction angle was planned because the valgus inclined hindfoot angle decreased after high tibial osteotomy. However, we consider that the correction needs to be larger because the correction of only the tibia would lead to undercorrection in patients with abnormal hindfoot alignment. Other options in patients with abnormal hindfoot alignment are total knee arthroplasty or no surgical osteotomy, considering the age and activity of the patient.

The mLDFA was significantly larger in the U-group than the A-group, and was a significant predictor of postoperative MA. We consider that the U-group had a significantly smaller preoperative MA and more progressed knee osteoarthritis compared with the A-group. On standing full-length anteroposterior view radiographs, the lower leg needed to be rotated more internally than usual when the patella was forced to face forward. Thus, the mLDFA became larger because the lateral condyle of the femur looked larger due to the internal rotation of the lower leg. In such cases, the grade of varus looked lower than the original grade on standing full-length anteroposterior view radiographs. Therefore, if the correction angle was planned preoperatively as it was, the planned correction angle would be too small and lead to undercorrection. For these reasons, the pre- and postoperative mLDFA were also significantly larger in the U-group than the A-group.

The present study had some limitations. First, this study used two-dimensional imaging (plain radiographs) to assess lower limb alignment, which is a three-dimensional deformity. Second, we did not use radiography or other methods to directly evaluate the subtalar joint and the subtalar joint mobility. Although the hindfoot alignment angle was evaluated as an indicator of hindfoot mobility, different radiographic conditions were used for the AJLO and the hindfoot angle. Therefore, we need to develop a radiographic method to directly evaluate the subtalar joint and its mobility or use weightbearing CT imaging, which provides more information about the subtalar joint alignment [33, 34]. Third, the sample size was small. However, the number of patients exceeded the minimum number of patients required for the post hoc analysis to show a power of 0.8. Fourth, the surgeries were performed by multiple operators, and multiple types of surgery (microfracture, drilling, meniscectomy, or meniscal repairs) were performed within the same patient cohort. The differences in postoperative rehabilitation protocols for these different surgical procedures may have affected the results.Fifth, we could not investigate the overcorrection group because of the small cohort. Therefore, there is a need for a large cohort study that includes an overcorrection group. Sixth, this study was retrospective and only analyzed the short-term results and follow-up outcomes. Lastly, future research should not only focus on radiographic parameters, but clinical parameters as well in assessing the results of surgery as well as patient reported outcomes.

Conclusion

Hindfoot alignment affects the postoperative lower limb alignment after MOWHTO. The preoperative AJLO and hindfoot angle should be considered in the preoperative evaluation before MOWHTO. Surgeons should consider changing the operative procedure or adjusting the correction angle when the preoperative hindfoot alignment angle is ≥ 15.9 degrees.

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Figure legends

Fig. 1 Study flowchart

Fig. 2 The mMPTA was checked with an image intensifier during medial opening wedge high tibial osteotomy

The mMPTA enlarged image on the standing long-leg radiograph that was used for planning (a). The mMPTA used in preoperative planning was reproduced (b). The postoperative mMPTA planned preoperatively was reproduced (c).

mMPTA, mechanical medial proximal tibial angle

Fig. 3 Radiographic parameters for the evaluation of the coronal alignment of the knee and ankle joint on standing full-length anteroposterior view, and evaluation of the hindfoot alignment angle on hindfoot alignment view

a) Mechanical axis; b) mechanical medial proximal tibial angle; c) mechanical lateral distal femoral angle; d) mechanical lateral tibial angle; e) talar tilt; f) joint line convergence angle; g) knee joint line obliquity relative to the ground (a negative value was interpreted as valgus deviation of the proximal knee joint line); h) ankle joint line orientation relative to the ground (a negative value was interpreted as valgus deviation of the talus surface); i) hindfoot angle. The hindfoot angle was defined by Williamson et al. [24] as the angle formed by the intersection between the tibial axis and the calcaneal axis. The tibial axis was drawn by bisecting two pairs of points on the tibial shaft cortex drawn 100 mm and 150 mm proximal to the tibial plafond. The calcaneal axis was determined by bisecting two transversals between two lines adapted to the lateral and medial osseous contours of the calcaneus

Fig. 4 The combinations of the postoperative AJLO and hindfoot angle

AJLO, ankle joint line orientation relative to the ground

Fig. 5 ROC curve analysis for the preoperative hindfoot alignment angle

A preoperative hindfoot alignment angle cut-off value of 15.9° (arrow) discriminates undercorrection from acceptable correction

ROC, receiver operating characteristic; AUC, area under the curve

Table 1 Patients' demographic characteristics (n = 43)

Patient characteristics	
Age (years)	64.8 ± 9.1 (range 47–86)
Sex (male/female)	12/31
Body mass index (kg/m^2)	26.0 ± 3.1 (range 20.6–32.7)
Kellgren-Lawrence grade(I/II/III/IV)	0/11/26/6

Data are presented as mean ± standard deviation or number of patients unless otherwise indicated

Table 2 Differences in mean radiographic parameters as determined by paired *t* test

Parameter	Pre-MOWHTO	Post-MOWHTO	Difference	P value
Mechanical axis (%)	18.3 ± 15.2	56.5 ± 9.3	-38.2 ± 12.5	< 0.001
mMPTA (°)	84.7 ± 2.6	92.5 ± 1.7	-7.8 ± 2.3	< 0.001
mLDFA (°)	88.0 ± 2.0	87.9 ± 1.8	0.1 ± 1.1	0.426
mLDTA (°)	91.3 ± 3.6	91.7 ± 3.8	-0.3 ± 2.7	0.425
Talar tilt (°)	0.8 ± 0.9	1.0 ± 0.9	-0.2 ± 1.0	0.185
JLCA (°)	3.6 ± 2.1	2.7 ± 1.8	0.9 ± 1.4	< 0.001
KJLO (°)	-1.0 ± 2.4	2.4 ± 2.2	-3.4 ± 2.1	< 0.001
AJLO (°)	6.2 ± 3.6	1.3 ± 4.5	4.9 ± 3.3	< 0.001
Hindfoot angle (°)	8.7 ± 4.9	6.2 ± 5.0	2.5 ± 4.0	0.001
Hindfoot alignment angle (°)	15.4 ± 6.4	10.5 ± 4.4	4.9 ± 5.3	< 0.001

MOWHTO, medial opening wedge high tibial osteotomy; mMPTA, mechanical medial proximal tibial angle; mLDFA, mechanical lateral distal femoral angle; mLDTA, mechanical lateral distal tibial angle; JLCA, joint line convergence angle; KJLO, knee joint line orientation relative to the ground; AJLO, ankle joint line orientation relative to the ground

Data are presented as the mean ± standard deviation

Table 3 Comparison of preoperative and 3-month postoperative radiographic parameters between the U-group and A-group

	U-group n = 20	A-group n = 23	P value
Age (years)	67.2 ± 9.0	63.0 ± 8.9	0.136
Sex (male/female)	7/13	5/18	0.345
Body mass index (kg/m^2)	25.8 ± 3.1	26.0 ± 3.1	0.823
Kellgren-Lawrence grade (I/II/III/IV)	(0/4/11/5)	(0/7/15/1)	0.105
Preoperative			
MA (%)	11.8 ± 14.2	24.0 ± 14.0	0.007
mMPTA (°)	84.0 ± 2.9	85.2 ± 2.2	0.162
mLDFA (°)	88.9 ± 1.8	87.2 ± 1.8	0.003
mLDTA (°)	91.0 ± 4.5	91.6 ± 2.6	0.616
Talar tilt (°)	0.9 ± 1.1	0.7 ± 0.7	0.474
JLCA (°)	3.8 ± 2.1	3.5 ± 2.1	0.604
KJLO (°)	-0.7 ± 2.6	-1.3 ± 2.2	0.375
AJLO (°)	6.9 ± 4.2	5.6 ± 2.9	0.232
Hindfoot angle (°)	9.7 ± 5.7	7.7 ± 3.9	0.196
Hindfoot alignment angle (°)	17.6 ± 6.9	13.5 ± 5.4	0.036
Postoperative			
MA (%)	48.6 ± 7.4	63.4 ± 3.0	$<$ 0.001
mMPTA (°)	92.0 ± 1.9	92.9 ± 1.4	0.072
mLDFA (°)	88.6 ± 1.4	87.3 ± 2.0	0.015
mLDTA (°)	91.4 ± 4.4	91.9 ± 3.4	0.667
Talar tilt (°)	0.9 ± 0.9	1.0 ± 0.9	0.657
JLCA (°)	3.1 ± 2.1	2.5 ± 1.5	0.286
KJLO (°)	3.0 ± 2.3	1.8 ± 2.0	0.063
AJLO (°)	2.4 ± 4.3	0.3 ± 4.6	0.129
Hindfoot angle (°)	7.3 ± 5.9	5.2 ± 3.9	0.169
Hindfoot alignment angle (°)	12.3 ± 3.9	9.0 ± 4.3	0.012

A-group, patients with acceptable correction (postoperative MA 57–67%); U-group, patients with undercorrection (postoperative MA < 56%); MA, mechanical axis; mMPTA, mechanical medial proximal tibial angle; mLDFA, mechanical lateral distal femoral angle; mLDTA, mechanical lateral distal tibial angle; JLCA, joint line convergence angle; KJLO, knee joint line orientation relative to the ground; AJLO, ankle joint line orientation relative to the ground

Data are presented as the mean ± standard deviation

Table 4 Univariate regression to predict the postoperative MA from preoperative radiographic parameters

Postoperative MA (%)	T value	P value
Age	-1.953	0.058
Sex	1.614	0.114
Body mass index	0.648	0.521
Preoperative		
mMPTA (°)	1.814	0.077
mLDFA (°)	-3.579	0.001
mLDTA (°)	0.575	0.568
Talar tilt (°)	-2.516	0.016
JLCA (°)	-1.630	0.111
KJLO (°)	-1.797	0.080
AJLO (°)	-2.386	0.022
Hindfoot angle (°)	-2.025	0.049
Hindfoot alignment angle (°)	-3.002	0.005

MA, mechanical axis; mMPTA, mechanical medial proximal tibial angle; mLDFA, mechanical lateral distal femoral angle; mLDTA, mechanical lateral distal tibial angle; JLCA, joint line convergence angle; KJLO, knee joint line orientation relative to the ground; AJLO, ankle joint line orientation relative to the ground

Table 5 Multiple regression to predict the postoperative MA based on preoperative radiographic parameters

Postoperative MA (%)	Coefficient	Standard error	β	P value	95% CI
Preoperative					
mLDFA(°)	-4.88	0.629	-0.402	0.005	-3.152 to -0.608
Hindfoot alignment angle (°)	-4.25	0.195	-0.315	0.024	-0.851 to -0.062

MA, mechanical axis; mLDFA, mechanical lateral distal femoral angle; CI, confidence interval

Figure Legend

Fig1

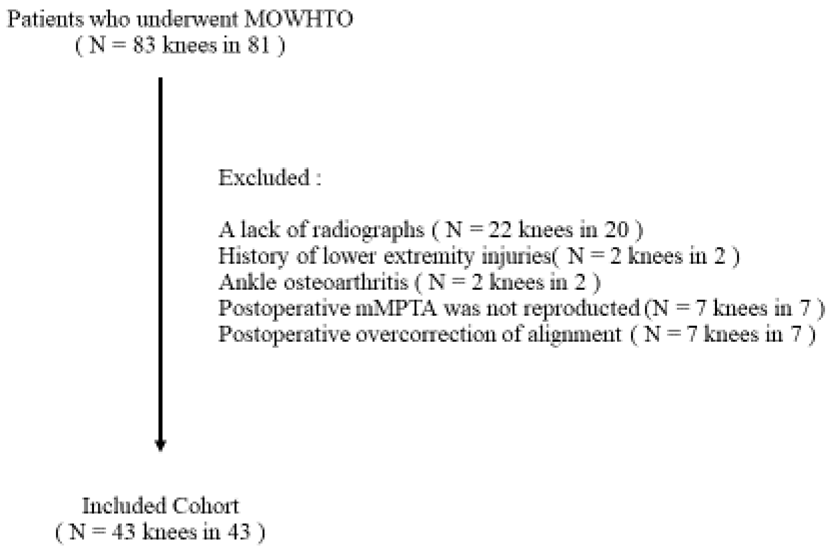


Fig2

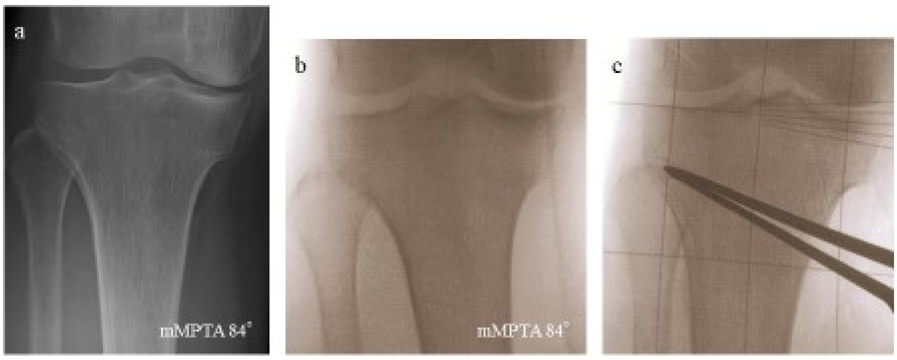


Fig3

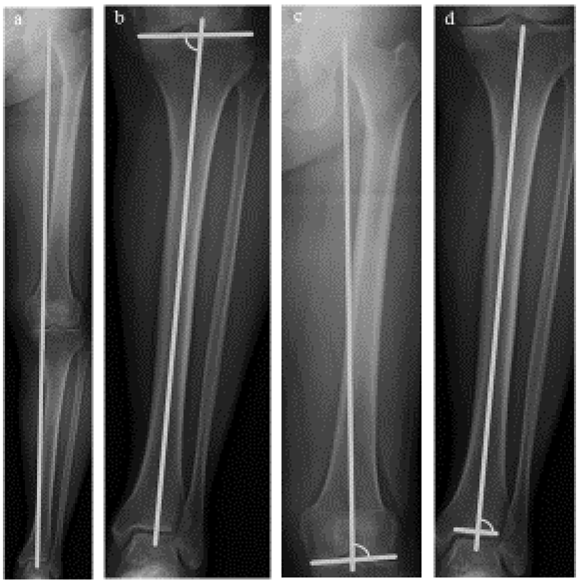


Fig3

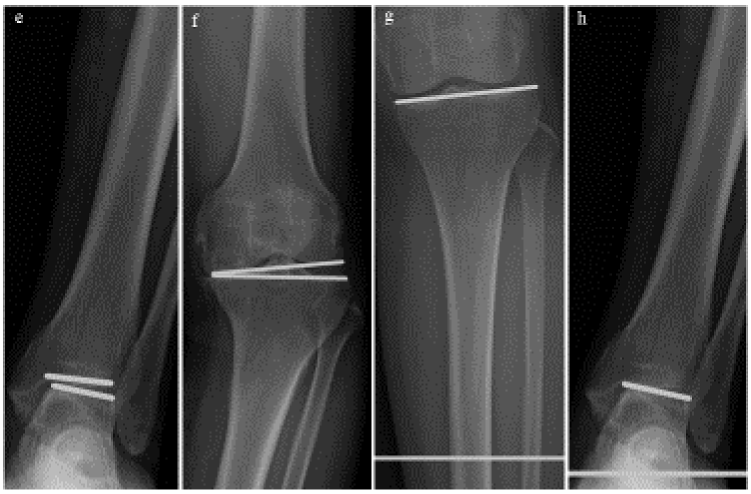
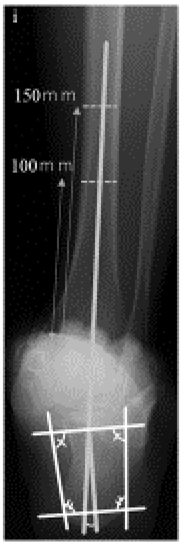
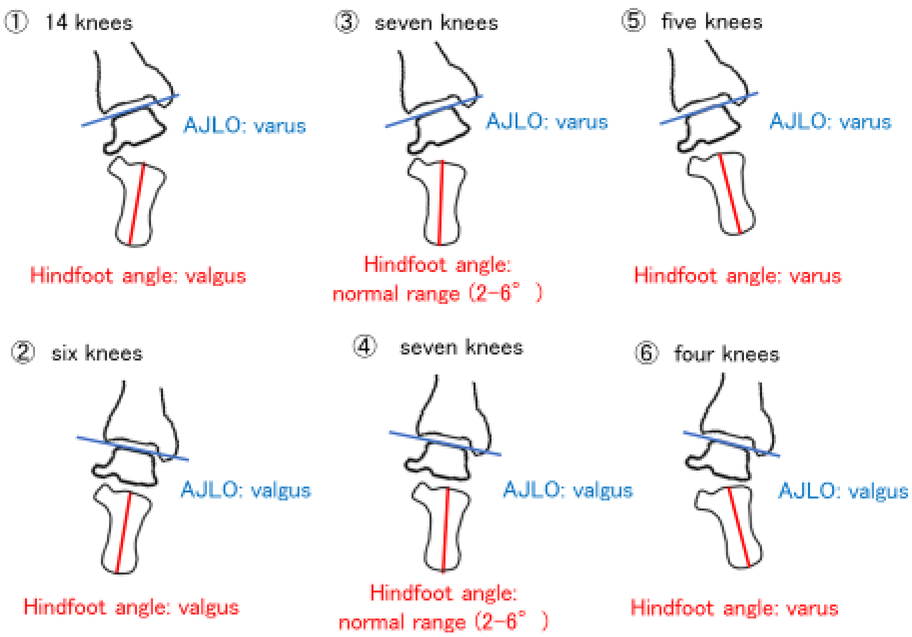


Fig3



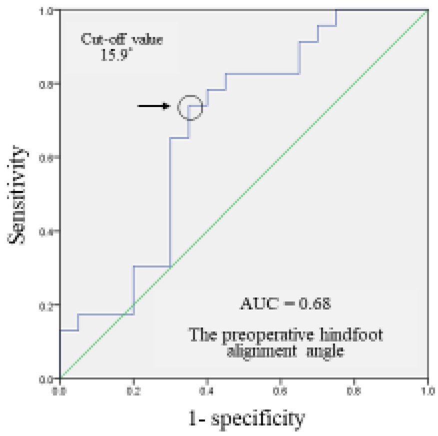
150mm
100mm

Fig4



① 14 knees
AJLO: varus
Hindfoot angle: valgus
③ seven knees
AJLO: varus
Hindfoot angle:
normal range (2-6°)
⑤ five knees
AJLO: varus
Hindfoot angle: varus
② six knees
AJLO: valgus
Hindfoot angle: valgus
④ seven knees
AJLO: valgus
Hindfoot angle:
normal range (2-6°)
⑥ four knees
AJLO: valgus
Hindfoot angle: varus

Fig5


Cut-off value
15.9°
AUC = 0.68
The preoperative hindfoot alignment angle
Sensitivity
1- specificity
0.0
0.2
0.4
0.6
0.8
1.0