Relationship between increased knee joint line obliquity after medial open-wedge high tibial osteotomy and patient-reported outcome measures

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Abstract

Introduction This study evaluated the correlation between postoperative knee joint line obliquity after medial open-wedge high tibial osteotomy and patient-reported outcome measures excluding excessively overcorrected knees. This study further identified preoperative radiological factors related to the increased postoperative knee joint line obliquity.

Materials and methods We retrospectively evaluated patients who underwent medial open-wedge high tibial osteotomy between March 2013 and March 2021. Postoperative excessively overcorrected knees with hip-knee-ankle angle $> 7°$ were excluded. We investigated radiological parameters and patient-reported outcome measures preoperatively and at the last follow-up. The following radiologic parameters were measured: hip-knee-ankle angle, weight-bearing line ratio, mechanical medial proximal tibial angle, mechanical lateral distal femoral angle, lateral distal tibial angle, joint line convergent angle, knee joint line obliquity, ankle joint line obliquity, hip abduction angle, tibial posterior slope, Carton-Deschamps index, and patella tilting angle. Clinical outcomes were evaluated using Japanese knee outcome measures. This assessment criterion is based on the Western Ontario McMaster Universities Arthritis Index and MOS Short Form 36. Multiple regression analysis was performed to evaluate the association between postoperative knee joint line obliquity and patient-reported outcome measures or preoperative radiological factors ($P < .05$).

Results A total of 52 knees were included. The mean age at the time of the surgery was 61.6 ± 9.0 years and the mean follow-up period was 30.6 ± 10.1 months. Increased postoperative knee joint line obliquity was associated with lower Japanese knee outcome measures. The preoperative hip-knee-ankle angle was significantly associated with postoperative knee joint line obliquity.

Conclusions Increased knee joint line obliquity after medial open-wedge high tibial osteotomy is associated with inferior clinical outcomes. Care should be given to the center of the rotational angulation in around-knee osteotomy to avoid postoperative increased knee joint line obliquity.

Level of evidence Retrospective comparative study, Level III.

Abbreviations

AJLO	Ankle joint line obliquity
CDI	Carton-Deschamps index
CORA	Center of the rotational angulation
DFO	Distal femoral osteotomy
HAA	Hip abduction angle
HKA	Hip-knee-ankle
JLCA	Joint line convergent angle
LDTA	Lateral distal tibial angle
MOWHTO	Medial open-wedge high tibial osteotomy
mLDFA	Mechanical lateral distal femoral angle
mMPTA	Mechanical medial proximal tibial angle
OA	Osteoarthritis
PROMs	Patient-reported outcome measures
PT	Patella tilting angle
TPS	Tibial posterior slope

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WBLR   Weight-bearing line ratio

WOMAC   Western Ontario McMaster Universities Arthritis Index

Introduction

Medial open-wedge high tibial osteotomy (MOWHTO) is a well-established treatment for symptomatic medial unicompartmental knee osteoarthritis (OA) with varus deformity [1]. However, single-level osteotomy of the tibia may result in pathological knee joint line obliquity (KJLO) [2, 3].

An excessively high KJLO elicits problems, such as unfavorable knee kinematics and increased articular cartilage shear stress [4–6]. Whether excessive KJLO leads to poor clinical outcomes remains controversial. Goshima et al. reported that mechanical medial proximal tibial angle (mMPTA) $>$ $>$95° did not affect clinical outcomes [7]. Conversely, Akamatsu et al. reported that patients with KJLO $>$4° had a higher risk of short survivorship [8]. Additionally, Babis et al. stated that patients with mMPTA $>$95° had inferior clinical outcomes [2]. Most studies that reported a negative effect of excessive KJLO included overcorrected knees leading to poor clinical outcomes. MOWHTO changes not only the coronal inclination of the tibia, but also sagittal and axial alignments [9, 10]. Many reports investigated the relationship between coronal alignment factors and the KJLO. However, no study indicated a relationship between postoperative KJLO and postoperative 3-dimensional geometric changes, including the tibial posterior slope (TPS), Carton-Deschamps index (CDI), and patella tilting angle (PT).

Thus, this present novel study: (1) evaluated the correlation between postoperative KJLO and patient-reported outcome measures (PROMs) excluding excessively overcorrected knees, (2) identified preoperative radiological factors related to increased postoperative KJLO, and (3) evaluated the relationship between postoperative KJLO and three-dimensional geometric changes. Our hypotheses were as follows: (1) an increased postoperative KJLO was correlated with inferior PROMs; (2) an increased postoperative KJLO was associated with preoperative hip-knee-ankle (HKA), mechanical lateral distal femoral angle (mLDFA), and joint line convergent angle (JLCA); and (3) a postoperative KJLO was correlated with postoperative TPS, CDI, and PT.

Materials and methods

Patients

A total of 78 patients (84 knees) who underwent MOWHTO between March 2013 and March 2021 at a single institution were enrolled in this study. The exclusion criteria were a history of inflammatory arthritis, ligament surgery, concurrent distal femoral osteotomy (DFO), follow-up of $<$2 years, insufficient data, and excessive overcorrection. We defined postoperative HKA $>$7° as excessive overcorrection because postoperative HKA 2° to 7° valgus was considered ideal alignment after MOWHTO, and the HKA value in non-osteoarthritis knees ranged from 7.6° varus to 7.1° valgus [11, 12]. The surgical indications for MOWHTO were symptomatic OA and ON of the medial compartment with varus malalignment and active patients who complied with the post-operating rehabilitation program. The contraindications for MOWHTO were a history of joint infection, symptomatic OA of the lateral compartment or patella femoral (PF) joint, and flexion contracture of $>$15°. Additionally, we performed closed wedge osteotomy or double-level osteotomy (DLO) with expected postoperative correction angle $>$15°or postoperative mMPTA $>$95°preoperatively.

Radiographic and clinical evaluations

We retrospectively reviewed anteroposterior (AP) long-standing HKA radiographs with the patella facing forward at shoulder width, lateral view, and skyline view, with the knee flexed to 45° both preoperatively and during follow-up. The following radiological parameters were measured: HKA, Weight-bearing line ratio (WBLR), mMPTA, mLDFA, lateral distal tibial angle (LDTA), JLCA, KJLO, ankle joint line obliquity (AJLO), hip abduction angle (HAA), TPS, CDI, and PT. TPS and CDI were measured using the lateral view and PT in the skyline view. Other parameters were deliberated using long-standing HKA radiographs (Fig. 1). All radiological parameters for 30 randomly selected knees were measured twice by two orthopedic surgeons (xx and yy), with a 2-week interval between each measurement (Appendix Table). The observers were blinded to previous observations using a picture archiving and communication system (SYNAPSE Enterprise-PACS; Fujifilm).

PROMs were evaluated using the Japanese knee osteoarthritis measure (JKOM) [13] preoperatively and at the last follow-up. The JKOM is an assessment criterion based on the Western Ontario McMaster Universities Arthritis Index (WOMAC), the MOS Short Form 36 (SF-36) [14], and a patient-based self-answered evaluation scoring system to reflect the specific Japanese cultural lifestyle: pain and stiffness (8 questions, 0–30 points), activities of daily living (10 questions, 0–40 points), participation in social activities (5 questions, 0–20 points), and general health conditions (2 questions, 0–10 points), with a maximum score of 100 points (0 indicating no symptoms and 100 indicating extreme symptoms). Based on previous studies [2], we also divided postoperative KJLO into two groups: normal group,
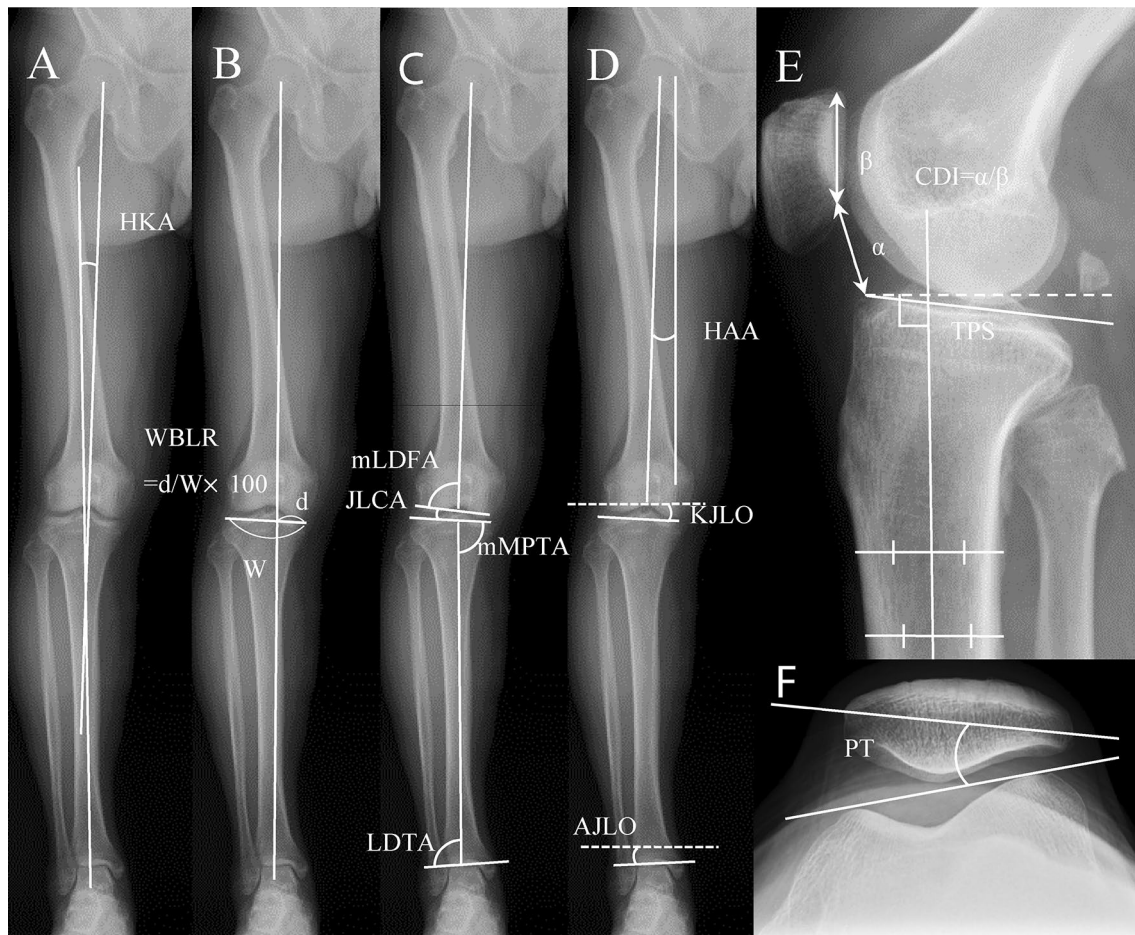
Fig. 1 Radiographic assessment. **A** HKA: HKA is the angle formed between the mechanical femoral and mechanical tibial axes (varus, negative). **B** Weight-bearing line ratio (WBLR): WBLR is defined as the horizontal distance from the WBL to the medial edge of the tibial plateau divided by the width of the tibial plateau. **C** Mechanical medial proximal tibial angle (mMPTA): The mMPTA is the medial angle formed between the mechanical tibial axis and the joint line of the proximal tibia. Mechanical lateral distal femoral angle (mLDFA): The mLDFA is the lateral angle formed between the mechanical femoral axis and the joint line of the distal femur. Lateral distal tibial angle (LDTA): LDTA is the lateral angle formed between the mechanical tibial axis and the joint line of the distal tibia. Joint line convergent angle (JLCA): JLCA is the angle between the tangents to the femoral condyles and the tibial plateau, with a positive value for JLCA denoting lateral joint opening. **D** Knee joint line obliquity (KJLO): KJLO is the angle between a line parallel to the ground and the tangent to the proximal tibia with a lateral tilt defined as a positive value. Ankle joint line obliquity (AJLO): AJLO is the angle between a line parallel to the ground and the tangent to the talar dome with lateral tilt defined as a positive. Hip abduction angle (HAA): HAA is the angle between the femoral mechanical axis and a line perpendicular to the ground, with abduction defined as a positive value. **E** Tibial posterior slope (TPS): TPS is the angle between the line perpendicular to the mid-diaphysis of the tibia and the posterior inclination of the tibial plateau. The Canton-Deschamps index (CDI): CDI was calculated. The distance from the inferior aspect of the patellar articular surface to the anterior edge of the tibial plateau was divided by the patellar articular surface length. **F** Patellar tilting angle (PT): PT is the angle between the line intersecting the widest bony structures of the patella and the line tangential to the anterior surface of the femoral condyles

KJLO$\leq$4° ($n = 47$), pathological group, KJLO $>$ 4° ($n = 6$), and the subgroup analysis was performed.

Surgical procedure and postoperative rehabilitation

Preoperative planning was done using AP long-standing HKA radiographs by the method described by Miniaci et al. [15]. The target WBLR was 62.5% [16]. Arthroscopy was routinely performed before HTO, and additional intra-articular lesions were treated accordingly based on a previously reported standing procedure [17, 18]. The medial proximal tibia was exposed through an oblique incision. The semitendinosus and gracilis tendons were preserved, and the superficial medial collateral ligament was released distally. Under fluoroscopic guidance, two K-wires were inserted 4 cm below the medial joint line, just proximal to the tibiofibular joint. Biplanar ascending osteotomy of the tuberosity was performed within 1 cm of the lateral cortex.

Several chisels were used to gradually open the osteotomy and a lamina spreader was used for the final opening. Two β-tricalcium phosphate wedges (Olympus Terumo Biomaterial) were inserted into the osteotomy site. A fixed-angle plate with locking screws (TomoFix Osteotomy System; DePuy Synthes, Tris medial HTO plate system; Olympus Terumo Biomaterial, Puddu spacer plate; Arthlex Inc., HTO plate system; Teijin Nakashima Medical, Japan) was used to fix the proximal tibia. Passive and active range of motion exercises, isometric exercises of the quadriceps, and straight leg raising were started on postoperative day 1. The patients were allowed partial weight-bearing at 1 week postoperatively, and full weight-bearing at 2 weeks.

Ethical approval

The study protocol was approved by an appropriate Ethics review board, and all patients provided informed consent for the surgical procedures.

Statistical analyses

All statistical analyses were performed using EZR ver1.60 (Saitama Medical Centre, Jichi Medical University), a graphical user interface for R (The R Foundation for Statistical Computing) [19], which is a modified version of R Commander, designed to add statistical functions frequently used in biostatistics. The Wilcoxon signed-rank sum test compared the radiological parameters and JKOM preoperatively and at the last follow-up. The Mann–Whitney U test assessed demographics, JKOM, and radiological parameters between the normal and pathological KJLO groups. Stepwise multivariable linear regression analysis identified the independent factors associated with JKOM, such as patient age, sex, BMI, KL grade, postoperative mMPTA, postoperative KJLO, postoperative TPS, postoperative CDI, and postoperative PT. Multivariable linear regression analysis examined the radiological preoperative risk factors for postoperative increased KJLO. We chose preoperative HKA, mMPTA, mLDFA, LDTA, and JLCA from previous studies [20, 21]. Spearman's rank correlation analysis identified the correlation between postoperative KJLO, JKOM, and postoperative TPS, CDI, and PT. Statistical significance was set at $p < 0.05$. A priori power analysis calculated the minimum sample size necessary for correlating postoperative KJLO and PROMs (moderate effect size [r], 0.5; α value; 0.05, and power; 0.9) using G*Power (Version 3.1. 9.6; Franz Faul, Christian-Albrechts-Universitätzu Kiel). The analysis indicated that the required sample size was 34 knees. Furthermore, for multiple regression analysis, a posthoc statistical power calculation was performed (effect size [f²]; observed R^2, α value; 0.05, total sample size, and number of predictors) using G*Power 21 [22].

Results

Patient demographics, PROMs, and pre-postoperative radiological parameters

A total of 53 knees (51 patients, two bilateral knees) met the inclusion criteria. Figure 2 shows the inclusion process. The mean age at the time of the surgery was 61.6 ± 9.0 years and the mean BMI was 27.4 ± 4.1. The mean follow-up period was 30.6 ± 10.1 months. No nonunion/malunion or conversion to arthroplasty was observed during follow-up. The patient demographics, radiological parameters, and PROMs preoperatively at the last follow-up are summarized in Table 1. There were significant differences in all radiological parameters between the preoperative and last follow-up except for the mLDFA and JLCA ($p = 0.417$ and $p = 0.84$, respectively). KJLO changed from mean $-1.7 \pm 2.0°$ (medial tilt) to mean $2.0 \pm 2.8°$ (lateral tilt) after MOWHTO (Fig. 3). No significant differences were noted in preoperative demographic and radiological data between the subgroups. The pathological KJLO group (KJLO > 4°) had a lower postoperative HKA ($p = 0.02$). Postoperative JLCA was larger in the pathological KJLO group than in the normal, although the difference was not significant ($p = 0.097$). Regarding clinical outcomes, there was a significant difference only in the JKOM subscale: participation in social activities ($p = 0.04$); the pathological group tended to have inferior clinical outcomes overall Tables 2, 3 and 4.

Correlation between postoperative KJLO and PROMs

There was a correlation between postoperative KJLO and JKOM subscales: general health condition ($r = 0.378$, $p = 0.014$) and total score ($r = 0.317$, $p = 0.041$) (Table 5). In the multiple regression analysis, postoperative increased KJLO and decreased CDI were correlated with the inferior JKOM subscale: general health conditions (adjusted $R^2 = 0.5318$). Additionally, increased BMI, postoperative increased KJLO, and increased TPS were correlated with an inferior JKOM total score (adjusted $R^2 = 0.4632$) (Table 4). These multiple regression analyses revealed good power in the post hoc calculation (0.99; observed $R^2 = 0.4632$[or = 0.5318], α = 0.05, total sample size = 53, and number of predictors = 9).

Multivariable regression analysis of the preoperative factors with postoperative KJLO

In the multivariate regression analysis, preoperative HKA was significant (Adjusted $R^2 = 0.186$). This multiple regression analysis revealed good power in the post
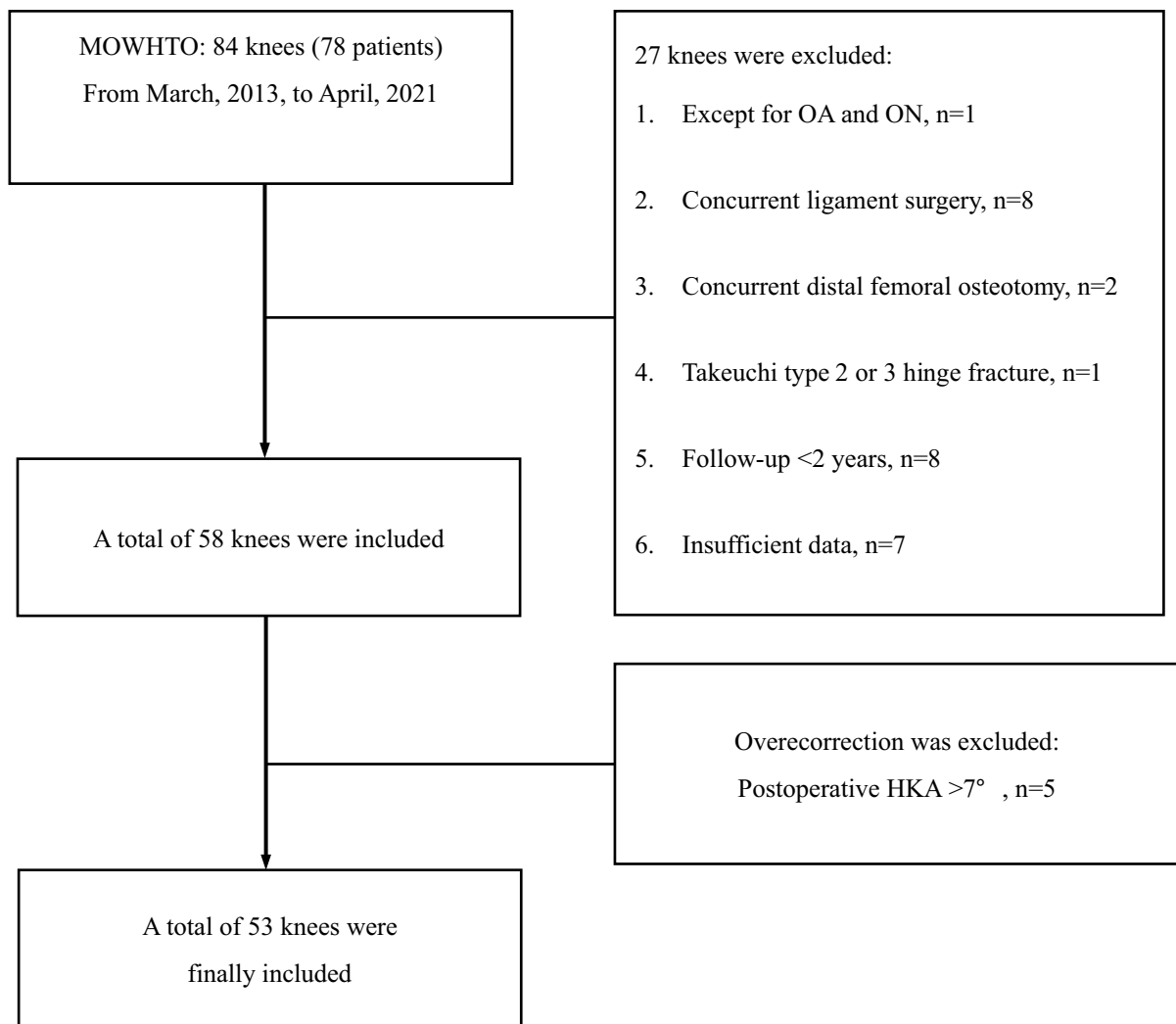
Fig. 2 Flowchart showing reasons for exclusion. *MOWHTO* medial open-wedge high tibial osteotomy *OA* osteoarthritis *ON* osteonecrosis *HKA* hip knee ankle angle

hoc calculation (0.87; observed $R^2 = 0.1896$, $\alpha = 0.05$, total sample size $= 53$, and number of predictors $= 5$). Our regression model also revealed that the preoperative HKA $> -9.8°$ predicted postoperative KJLO $> 4°$, when mMPTA, mLDFA, JLCA, and LDTA were our mean values. The preoperative mLDFA and JLCA scores were not correlated. Moreover, multivariate logistic regression analysis between the subgroups revealed no significant factors (Table 5).

Correlation between postoperative KJLO and TPS, PF alignment factors (CDI, PT)

There was no correlation between postoperative KJLO and TPS, CDI, or PT (Appendix Table).

Discussion

The main finding of this study was that increased postoperative KJLO was correlated with inferior PROMs, although excessively overcorrected knees were excluded. The preoperative decreased HKA (varus alignment) was defined as a risk factor for postoperative KJLO increase. The postoperative KJLO did not correlate with postoperative TPS, CDI, or PT. In the subgroup analysis, there was no significant difference in radiological parameters and PROMs.

Recently, excessive postoperative KJLO has received substantial attention [21, 23–26]. Studies indicated that pathological KJLO following MOWHTO leads to abnormal knee kinematics and joint incongruence [4, 6].

Table 1 Demographics, radiological parameters, and PROMs

Age, year	61.8 ± 9.0 (41–71)		
Male/female, n	18/35		
Body mass index, kg/m^2	27.4 ± 4.1 (20.5–41.1)		
Left/Right, n	27/26		
Kellgren-Lawrence grade (2/3/4), n	33/18/2		
Open correction width, mm	8.6 ± 2.1 (5–12)		

Radiological	Preoperative	Last follow-up	P-value
HKA, °	−3.8 ± 2.7	2.8 ± 1.6	< .001
WBLR, %	29.3 ± 10.5	60.6 ± 6.6	< .001
mMPTA, °	85.5 ± 2.4	91.8 ± 1.8	< .001
mLDFA, °	87.4 ± 2.1	87.2 ± 2.1	.417
LDTA, °	93.4 ± 4.0	91.7 ± 4.8	.006
JLCA, °	1.5 ± 2.2	1.9 ± 2.0	.840
HAA, °	0.9 ± 2.3	−2.3 ± 2.4	< .001
KJLO, °	−1.7 ± 2.5	2.0 ± 1.8	< .001
AJLO, °	6.8 ± 4.4	3.3 ± 4.0	< .001
TPS, °	8.8 ± 3.1	10.8 ± 3.4	< .001
CDI	0.9 ± 0.2	0.7 ± 0.2	< .001
PT	11.0 ± 5.1	9.2 ± 6.1	.003

PROMs: JKOM	Preoperative	Last follow-up	P-value
VAS	58.8 ± 24.7	13.9 ± 13.6	< .001
Pain and stiffness	16.6 ± 8.0	5.9 ± 5.4	< .001
Activities of daily living	13.2 ± 9.1	5.4 ± 5.1	< .001
Participation in social activities	8.7 ± 5.5	3.6 ± 3.2	< .001
General health conditions	3.3 ± 1.9	1.9 ± 1.6	< .001
Total	42.4 ± 20.8	16.7 ± 12.7	< .001

*PROMs* patient-reported outcome measures, *JKOM* Japanese knee outcome measures,

VAS visual analog scale, *HKA* hip knee ankle angle, *WBLR* weight-bearing line ratio, *mMPTA* mechanical medial proximal tibial angle, *mLDFA* mechanical lateral distal femoral angle, *LDTA* lateral distal tibial angle, *JLCA* joint line convergent angle, *HAA* hip abduction angle, *KJLO* knee joint line obliquity, *AJLO* ankle joint line obliquity, *TPS* tibial posterior slope, *CDI* Canton-Deschamps index, *PT* patella tilting angle

Excessive shear stress on the tibial articular cartilage was induced in the knee with KJLO > 5° in a three-dimensional finite element analysis model [5]. However, the correlation between postoperative KJLO and clinical outcomes after MOWHTO is not proven.

Many studies stated that a postoperative MPTA > 95° is associated with inferior clinical outcomes [1, 8]. A postoperative mMPTA > 95.2° would lead to an excessive KJLO increase [25]. Patients with postoperative KJLO > 4° had inferior KSS objective and functional scores in multivariable regression analysis [27]. In contrast, some studies indicated that postoperative mMPTA > 95° is not associated with inferior clinical outcomes [7, 21, 24] as compensatory changes would occur in the hip and ankle joints [7]. However, patients with overcorrection are at risk of experiencing lateral compartment pain [24].

Most studies that reported a negative effect of postoperative increased KJLO on clinical outcomes and survivorship included knees with overcorrection. Hence, it was challenging to determine whether these adverse outcomes were caused by excessive valgus alignment or increased KJLO. In this study, although postoperative overcorrection knees were excluded, an increased postoperative KJLO was correlated with an inferior JKOM total score and subscale of general health conditions. Clinical outcome evaluations differed based on the study. Many studies reported that an excessive KJLO was associated with clinical outcomes; "functional," "sports activities," "QOL," and "mental health." However, few studies reported a correlation between "pain" and "symptom." Postoperative pain or stiffness is mainly associated with the lateral tibiofemoral compartment or patellofemoral compartment caused by excessive valgus overcorrection or patellar height change [9, 10, 28]. Shear stress caused by excessive KJLO may not cause these problems, although abnormal kinematics negatively influence function, sports activities, QOL, and mental health. The JKOM is a
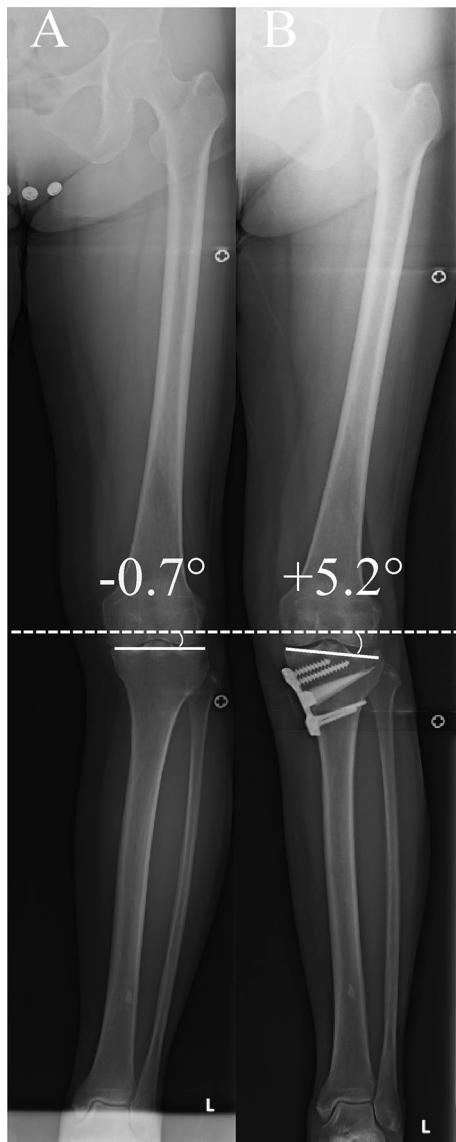
Fig. 3 A case of a 66-year-old woman with increased KJLO after MWHTO. **A** Preoperative KJLO is −0.7° (medially tilt). **B** Postoperative KJLO is +5.2° (laterally tilt)

PROM that strongly reflects the Japanese lifestyle. Japanese people prefer postures such as sitting on their knees and rising from the floor to a standing position. Hence, kinematic change with increased KJLO may have resulted in inferior JKOM.

Previous studies have reported that increased postoperative KJLO was correlated with preoperative HKA, mLDFA, and JLCA [20, 21, 29]. The KJLO would increase after MOWHTO when surgeons corrected the femoral deformity or intra-articular deformity only with the tibia or due to a technical error resulting in excessive valgus overcorrection of the lower limb. In this study, only preoperative HKA was associated with postoperative KJLO, whereas mLDFA and JLCA were not. Moreover, in the multivariable logistic regression analysis, there was no correlation between the subgroups, whereas preoperative HKA tended to predict postoperative pathological KJLO. Preoperative decreased HKA with slightly varus mMPTA and slightly valgus mLDFA would be a risk factor for increased postoperative KJLO. The first reason was that we excluded postoperative excessive valgus HKA and performed a closed wedge osteotomy or DLO if a correction angle > 15°or postoperative MPTA > 95° was expected preoperatively. Few patients had preoperative excessive varus lower limb alignment, femoral varus deformity, or increased JLCA. The second reason could be due to soft-tissue laxity such as varus-valgus laxity. Several studies have reported that preoperative varus-valgus laxity caused over- or under-correction after HTO [30–32]. As the KL grade increases, the degree of deformity and soft-tissue laxity increases [33]. Ogawa et al. reported that varus laxity was associated with the deference between the preoperative and postoperative JLCA values [30]. Our results showed a higher tendency for the deference in the JLCA value in the pathological KJLO group than in the normal. To avoid correction errors, a varus-valgus stress radiograph was recommended to assess and classify soft-tissue laxity [31, 32]. However, we did not take a varus-valgus stress radiograph, so further studies are needed to investigate the soft-tissue laxity.

MOWHTO leads not only to coronal changes in the tibia but also to sagittal and axial changes in the proximal and distal tibia. These three-dimensional geometric changes may affect postoperative WBL formation [24], thereby influencing postoperative KJLO. However, there was no significant correlation between postoperative KJLO and TPS, CDI, or PT in this study, as compensation in the hip and ankle joints may have affected the results. Moreover, changes in sagittal and axial alignment should be studied further.

It is important to correct limb alignment at the center of rotational angulation (CORA) [34]. When a large correction with varus deformity of both the femur and tibia is necessary, DLO may be considered to avoid postoperative pathological KJLO. Recent studies indicated good clinical outcomes after DLO [23, 35–37]. In a long-standing HKA radiographic study with varus malalignment patients, two-thirds of the patients were corrected with isolated MOWHTO, and the others required DLO if postoperative mMPTA < 95° was target [3]. Nakayama et al. recommended DLO when mMPTA > 95° or KJLO > 5° was estimated after MOWHTO [5]. In a study comparing

Table 2 Comparison of preoperative data between normal and abnormal KJLO

	Normal (postoperative KJLO < 4°)	Abnormal (postoperative KJLO > 4°)	*P*-value
Knees, *n*	47	6	
Age, year	61.4 ± 9.1	65.7 ± 8.8	.140
Men/Women, *n*	18/29	0/6	
Body mass index, kg/m^2	26.9 ± 3.7	27.6 ± 7.5	.418
Follow-up, mo	30.7 ± 10.5	29.3 ± 7.4	.863
Kellgren–Lawrence grade (2/3/4), *n*	31/15/1	2/3/1	
HKA, °	−3.6 ± 2.6	−5.1 ± 3.6	.354
WBLR, %	29.1 ± 9.8	25.6 ± 10.3	.448
mMPTA, °	85.2 ± 2.0	86.2 ± 3.1	.208
mLDFA, °	87.3 ± 2.2	88.1 ± 2.0	.319
LDTA, °	93.6 ± 4.3	92.1 ± 1.5	.292
JLCA, °	1.5 ± 2.1	1.2 ± 3.2	.584
HAA, °	0.8 ± 2.4	1.5 ± 1.8	.811
KJLO, °	−1.9 ± 2.5	−0.3 ± 2.5	.119
AJLO, °	6.8 ± 4.5	6.3 ± 4.2	.811
TPS, °	8.7 ± 3.1	9.8 ± 3.5	.555
CDI	0.9 ± 0.2	0.8 ± 0.1	.213
PT	10.7 ± 5.2	12.8 ± 5.1	.430

HKA hip knee ankle angle, *WBLR* weight-bearing line ratio, *mMPTA* mechanical medial proximal tibial angle, *mLDFA* mechanical lateral distal femoral angle, *LDTA* lateral distal tibial angle, *JLCA* joint line convergent angle, *HAA* hip abduction angle, *KJLO* knee joint line obliquity, *AJLO* ankle joint line obliquity, *TPS* tibial posterior slope, *CDI* Canton-Deschamps index, *PT* patella tilting angle

MOWHTO and DLO during 2 years of follow-up, KJLO changed from 1.4° to 6.3° postoperatively in the MOW-HTO group, while it changed only from 1.0° to 1.3° in the DLO group [23]. Iseki et al. compared MOWHTO with DLO for severe varus malignment when preoperative HKA > -10°. They showed that DLO could prevent postoperative pathological joint line [36]. Our findings were similar to theirs. Preoperative HKA > −9.8°was the cut-off value for postoperative KJLO > 4°, when preoperative mMPTA and mLDFA were within the range of normal value. Thus, DLO could be recommended for severe varus malalignment. However, there was no significant difference in the clinical outcomes between the MOWHTO and DLO groups. As DLO is more invasive and costly, further investigations regarding mid to long-term clinical outcomes are mandated [23].

This study had several limitations. First, it was a retrospective study with a short follow-up period. Second, the number of patients in the postoperative pathological KJLO group was small. However, post hoc analysis was powerful in detecting multiple regression analysis differences. Third, the cut-off value between postoperative

pathological KJLO and preoperative radiological factors was not determined. Fourth, we did not fully investigate soft-tissue laxity. Fifth, patients who were older and had low activity levels were included which influenced clinical outcomes. Future studies should exclude such patients. The strengths of our study are as follows: we excluded patients with mechanical axis overcorrection, which represents a confounding factor often associated with increased KJLO and inferior clinical outcomes. Additionally, several radiological parameters were examined.

Conclusions

Increased KJLO after MOWHTO is associated with inferior clinical outcomes. Preoperative decreased HKA is a preoperative risk factor for increased postoperative KJLO. Hence, care of the CORA in the surrounding knee osteotomy is necessary to avoid postoperative increased KJLO. Further studies should investigate the effect of soft-tissue laxity.

Table 3 Comparison of postoperative data between normal and abnormal KJLO

	Normal (postoperative KJLO≤4°)	Abnormal (postoperative KJLO>4°)	P-value
HKA, °	3.0±1.6	1.4±1.4	.024
WBLR, %	61.3±6.6	55.5±5.2	.055
mMPTA, °	91.7±1.6	92.8±3.0	.292
mLDFA, °	87.1±2.1	88.2±2.3	.233
LDTA, °	93.6±4.3	92.1±1.5	.899
JLCA, °	1.7±1.8	3.5±2.8	.097
ΔJLCA, °	0.2±2.1	2.3±4.6	.432
HAA, °	−2.4±2.4	−2.0±3.2	.509
KJLO, °	1.5±1.3	5.3±1.7	<.001
AJLO, °	3.0±3.8	5.6±5.7	.097
TPS, °	10.7±3.4	11.6±3.1	.423
CDI	0.7±0.2	0.7±0.1	.535
PT	9.1±6.2	9.5±6.6	.760
JKOM			
VAS	12.1±10.8	20.9±24.3	.600
Pain and stiffness	5.4±4.3	7.6±9.8	.968
Activities of daily living	4.5±3.5	10.2±10.9	.377
Participation in social activities	3.0±2.7	9.0±6.7	.042
General health conditions	1.6±1.3	3.8±3.1	.134
Total-score	14.7±9.7	30.6±27.9	.213

HKA hip knee ankle angle, *WBLR* weight-bearing line ratio, *mMPTA* mechanical medial proximal tibial angle, *mLDFA* mechanical lateral distal femoral angle, *LDTA* lateral distal tibial angle, *JLCA* joint line convergent angle, *HAA* hip abduction angle, *KJLO* knee joint line obliquity, *AJLO* ankle joint line obliquity, *TPS* tibial posterior slope, *CDI* Canton-Deschamps index, *PT* patella tilting angle, *JKOM* Japanese knee outcome measures, *VAS* visual analog scale, Δ the difference between preoperative and postoperative values

JKOM Japanese knee outcome measures, *VAS* visual analog scale, *KJLO* knee joint line obliquity, *TPS* tibial posterior scale, *CDI* Canton-Deschamps index

Table 4 Correlation and Multivariable liner regression analysis by stepwise method between postoperative KJLO and JKOM

Correlation			r			P-value
VAS			0.295			0.0723
Pain and stiffness			0.226			0.155
Activities of daily living			0.179			0.262
Participation in social activities			0.293			0.0628
General health conditions			0.378			0.0147
Total-score			0.317			0.041

Multivariable linear regression analysis	General health conditions				Total-score			
	B±SE	R^2	A-R^2	P value	B±SE	R^2	A-R^2	P value
Intercept	3.0141±1.13	0.6678	0.5318	.0011	−55.6131±15.8611	0.6142	0.4632	0.003
Body mass index					1.5957±0.4686			0.0019
KJLO	0.6704±0.1343			.00002	4.562±1.115			0.0003
TPS					1.946±0.5950			0.0027
CDI	−3.512±1.4649			0.0231				

Table 5 Multivariable linear regression analysis and logistic regression analysis of postoperative KJLO factors after MOWHTO

	Multivariable linear regression analysis				Multivariable logistic regression analysis		
	B ± SE	R²	A-R²	*P*-value	OR	95% CI	*P*-value
Intercept	−24.41 ± 11.75	0.2691	0.1896	.0434			
HKA	−0.3407 ± 0.1242			0.00866	0.54	0.271–1.08	0.427
mMPTA	0.2406 ± 0.1401			0.0927	0.674	0.310–1.47	0.320
mLDFA	0.00959 ± 0.1546			0.9507	1.88	0.777–4.55	0.161
LDTA	0.0409 ± 0.0580			0.4836	0.972	0.712–1.33	0.857
JLCA	−0.1130 ± 0.1156			0.3297	0.762	0.433–1.34	0.345

HKA hip knee ankle angle, *mMPTA* mechanical medial proximal tibial angle, *mLDFA* mechanical lateral distal femoral angle, *LDTA* lateral distal tibial angle, *JLCA* joint line convergent angle, *KJLO* knee joint line obliquity, *MOWHTO* open-wedge high tibial osteotomy

Appendix

See below Appendix Tables 6 and 7.

Table 6 Intraclass correlation coefficients of the radiologic parameters

Parameter	Intrarater	Interrater
HKA	0.98	0.96
WBLR	0.98	0.96
mMPTA	0.97	0.94
mLDFA	0.97	0.93
LDTA	0.96	0.92
JLCA	0.94	0.84
HAA	0.95	0.91
KJLO	0.97	0.95
AJLO	0.97	0.95
TPS	0.96	0.93
CDI	0.93	0.84
PT	0.94	0.85

HKA hip knee ankle angle, *WBLR* weight-bearing line ratio, *mMPTA* mechanical medial proximal tibial angle, *mLDFA* mechanical lateral distal femoral angle, *LDTA* lateral distal tibial angle, *JLCA* joint line convergent angle, *HAA* hip abduction angle, *KJLO* knee joint line obliquity, *AJLO* ankle joint line obliquity, *TPS* tibial posterior slope, *CDI* Canton-Deschamps index, *PT* patella tilting angle

Table 7 Correlation between postoperative KJLO and postoperative TPS, CDI, and PT

	r	*P*-value
TPS	0.0874	0.534
CDI	−0.21	0.153
PT	0.00444	0.976

KJLO knee joint line obliquity, *TPS* tibial posterior slope, *CDI* Canton-Deschamps index, *PT* patellar tilting angle

Declarations

Conflict of interest The authors have no potential conflicts of interest, including financial interests, activities, relationships, and affiliations.

Ethical approval The study protocol was approved by the Ethics Committee of Sapporo Medical University Hospital (Institutional Review board No. 3320-3064).

Informed consent All patients involved in the study have received and approved an informed consent.

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