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Joint line obliquity was maintained after double-level osteotomy, but was increased after open-wedge high tibial osteotomy

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Abstract

Purpose To compare the radiographic, clinical, and arthroscopic outcomes of varus osteoarthritic knees treated with an open-wedge high tibial osteotomy (OWHTO) alone or with a double-level osteotomy (DLO). It was hypothesized that treatment with DLO would maintain the joint line obliquity (JLO) and acquire better arthroscopic and clinical outcomes after surgery than OWHTO alone.

Methods Knees with predicted medial proximal tibial angle (MPTA) > 95° were treated with OWHTO alone or with DLO. Preoperatively, age, body mass index, and hip-knee-ankle angle (HKA) differed between the two groups. Therefore, after adjustment for those factors, 34 knees with OWHTO alone and 34 knees with DLO were compared. On whole-leg radiographs for a single leg, HKA, weightbearing line (WBL) ratio, lateral distal femoral angle (LDFA), MPTA, and JLO were measured before and 2 years after surgery. Clinical outcomes were evaluated by the Knee Society Score (KSS) knee, KSS function, Lysholm, and Knee injury and Osteoarthritis Outcome Score (KOOS) scores before and 2 years after surgery. Arthroscopic findings were obtained before and 1 year after surgery. Various factors were compared between the two groups.

Results JLO increased significantly from 1.4° to 6.3° in the OWHTO group ($p < 0.001$) and changed from 1.0° to 1.3° in the DLO group (n.s.). Postoperative MPTA and JLO in the OWHTO group were significantly higher than those in the DLO group (both $p < 0.001$). There were no significant differences in the KSS knee, KSS function, and KOOS scores between the two groups. Postoperative Lysholm score in the DLO group was higher than that in the OWHTO group ($p < 0.025$). Femoral and tibial cartilage regeneration in the medial condyles and deterioration in the lateral condyles did not differ between the two groups on second-look arthroscopy.

Conclusions JLO was not significantly changed after surgery in the DLO group. DLO enabled the acquisition of physiological JLO compared with OWHTO alone.

Level of evidence Retrospective comparative study, Level III.

Keywords Double-level osteotomy · Open-wedge high tibial osteotomy · Joint line obliquity · Medial proximal tibial angle

Introduction

The normal knee joint is parallel to the ground in the stance phase during walking [14]. Although it remains unclear whether the knee joint line after knee osteotomy should be the same as that in normal knees, open-wedge high tibial osteotomy (OWHTO) alone results in excessive joint line obliquity (JLO) [20]. The acceptable upper limit of the medial proximal tibial angle (MPTA) after OWHTO is 94°–95° [2, 17, 18, 22]. In a finite element model analysis, JLO of 5°–10°, approximately corresponding to postoperative MPTA of 95°, induced shear stress in the articular cartilage after OWHTO [17]. Knees with MPTA > 95° after OWHTO had significantly higher JLO and worse clinical results than knees with MPTA ≤ 95° [2]. Therefore, low JLO after knee osteotomy is essential for patients with high activity. Meanwhile, OWHTO alone can create a large opening gap at the medial proximal tibia and cause delayed bone healing in cases with severe knee osteoarthritis (OA) [9]. Double-level osteotomy (DLO) maintained acceptable JLO [3]. Therefore, DLO was performed for the purpose of

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preserving the physiologic JLO [18, 20, 22], and is expected to resolve any increased shearing force on cartilage, tibiofemoral subluxation, imbalance of soft tissue, and difficulty in conversion to total knee arthroplasty [18].

DLO, as a combined distal femoral osteotomy (DFO) with OWHTO, for rheumatoid arthritis and knee OA was first reported by Benjamin in 1969 [4]. Satisfactory radiological and clinical outcomes of DLO in patients with knee OA were reported by Babis et al. [3] in 2002, but the procedure did not become popular. With the development of rigid fixation in the distal femur and proximal tibia, DFO and DLO have gained popularity [5, 15, 23]. Recently, DLO with the minimally invasive technique using a locking compression plate has been performed in Germany and Japan [18, 22]. Surgeons can choose either single osteotomy or DLO by reference to deformity analyses based on the normal orientation angle of each joint in the whole lower leg. However, the differences in radiographic, clinical, and arthroscopic outcomes between OWHTO alone or with DLO have remained unclear.

The purpose of this study was to compare the radiographic, clinical, and arthroscopic outcomes of knees treated with OWHTO alone or with DLO at 2 years after surgery. It was hypothesized that treatment with DLO would maintain JLO, which treatment with OWHTO alone increased, and that knees treated with DLO would acquire better clinical scores and improve cartilage regeneration in the medial condyles and deterioration in the lateral condyles at the time of second-look arthroscopy compared with knees treated with OWHTO alone after surgery under the same indications for knee osteotomy.

Methods

Patients

Between April 2016 and March 2017, 104 knees were treated with conventional OWHTO alone. Fifty-nine knees with predicted MPTA ≤ 95° during preoperative planning were excluded from the knees with OWHTO because DLO was performed in knees with predicted MPTA > 95°. Between April 2017 and March 2018, 39 knees were assigned to undergo DLO. The remaining 45 knees treated with OWHTO alone and the 39 knees treated with DLO were adjusted for patient age, body mass index, and hip-knee-ankle angle (HKA). Preoperatively, patient age, body mass index, and HKA differed between the knees treated with OWHTO alone and DLO. To compare two groups under the same indications for knee osteotomy, in the OWHTO group, knees with the upper six threshold values of patient age, upper one threshold value of body mass index, and lower four threshold values of HKA were excluded. Similarly, in the DLO group, knees with the upper five threshold values of HKA were excluded. Finally, the radiographic and clinical data before and after surgery were compared between 34 knees with OWHTO alone and 34 knees with DLO (Fig. 1). The study at the introduction of DLO in April 2017 was

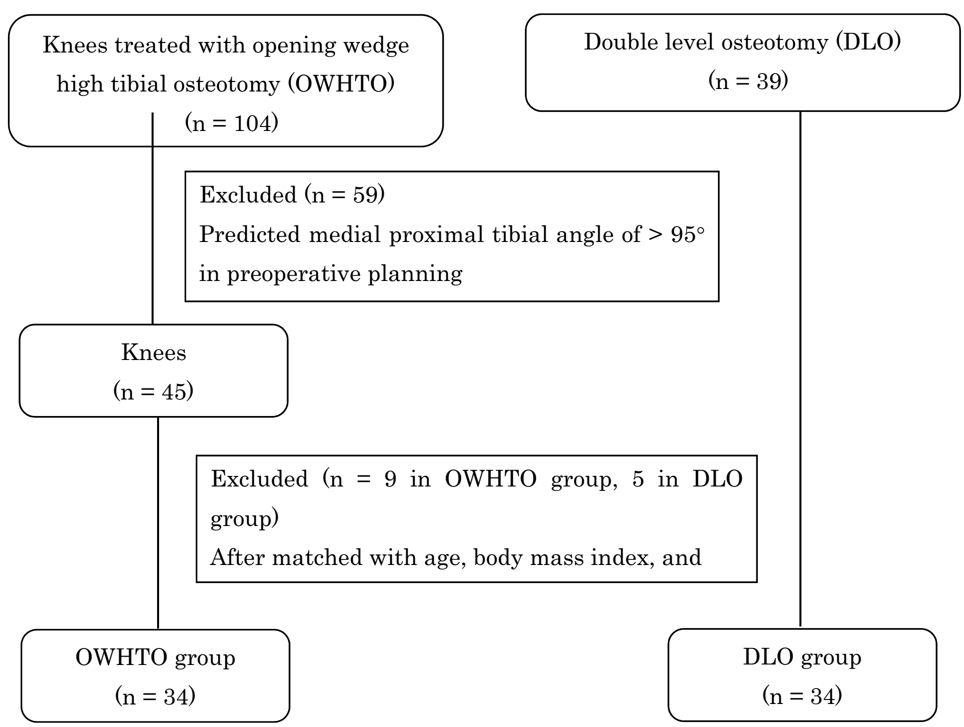

Fig. 1 Flow chart showing the randomization process and reasons for exclusion in patients scheduled for OWHTO. *OWHTO* open-wedge high tibial osteotomy, *DLO* double-level osteotomy

started. All clinical and radiographic data were recorded prospectively and the study was performed retrospectively.

Indications for OWHTO were flexion contracture ≤ 15° and predicted opening gap ≤ 15 mm during preoperative planning. DLO was planned if OWHTO alone during preoperative planning had MPTA > 95° and preoperative lateral distal femoral angle (LDFA) > 88°. The patients had no patellofemoral symptoms and no degenerative changes of the lateral compartment on radiographs. DLO was also performed in knees with severe OA [18, 22] and patients with high activity. All surgery was performed by a single surgeon.

Radiographic evaluation

The radiographs were projected using a Fuji Computed Radiography system (Fujifilm Co. Ltd., Tokyo, Japan) and deformity analyses for the coronal alignment and joint orientation angles were performed using mediCAD digital planning software (Hectec, Landshut, Germany) [21]. Anteroposterior and lateral whole-leg radiographs were obtained with patients in the one-leg standing position, followed by anteroposterior, lateral, and skyline views of the knee. The HKA was defined as the lateral angle between a line from the center of the femoral head to the center of the tibial spines and a line from the center of the tibial spines to the center of the talus. The weightbearing line (WBL) ratio was defined as the ratio of the length from the medial edge of the tibial plateau to the intersection point to the length of the tibial plateau. The WBL ratio reflected the medial tibial edge at 0% and the lateral tibial edge at 100% [8]. During preoperative planning, a WBL ratio of 62% on the whole-leg radiograph was anticipated in both groups [1, 13, 24]. The tibial posterior slope (TPS) was measured using the whole tibia. The joint line convergence angle (JLCA) was defined as the angle between the tangents to the femoral condyles and the tibial plateau. To classify the severity of OA in each knee, the Kellgren–Lawrence grade was used [12]. All patients underwent radiographic follow-up evaluations at 2 years postoperatively.

Two of the authors (YA, HK) measured the HKA, WBL ratio, and TPS in all 68 knees on radiographs. The measurements were repeated twice, with a 2-month interval. The interclass correlation coefficients for the intraobserver and interobserver agreements regarding the HKA, WBL ratio, and TPS on the radiographs were 0.965–0.992 and 0.858–0.990, respectively.

Clinical evaluation

Range of motion (ROM) was measured using a goniometer in the supine position. The Knee Society Score (KSS) knee and function were used for the objective evaluation preoperatively and 2 years postoperatively [10], and the Lysholm knee score was used to evaluate the conditions of the knee ligament preoperatively and 2 years postoperatively [25]. For each measurement, a total score of 100 indicated full function. The Knee injury and Osteoarthritis Outcome Score (KOOS) was used to evaluate patient-based clinical outcomes preoperatively and 2 years postoperatively [19]. The KOOS has five subscales: pain, symptoms, activities in daily living, sport and recreational function, and knee-related quality of life. All clinical evaluations were performed by a physician who was independent of the surgical team.

Surgical procedure and postoperative rehabilitation

Using the mediCAD digital planning software, the distance between the upper and lower edges of the opened posteromedial osteotomy site was measured on a preoperative whole-leg radiograph as passing through 62% of the WBL ratio on the proximal tibia. In both groups, an arthroscopic examination was carried out in all patients before osteotomy. Osteophyte removal and partial meniscectomy were performed in all knees. However, arthroscopic procedures such as meniscus repair and cartilage treatment were not performed. A thigh tourniquet was not applied to patients in the supine position. For OWHTO, an approximately 4–5-cm incision was made longitudinally at the 4–5 cm medial portion of the anterior ridge of the tibia. The patellar tendon was freed from the medial border and protected using a retractor. The medial collateral ligament was released from the medial proximal tibia. The semitendinosus and gracilis tendons were released if the posterior soft tissue was tight. The osteotomy plane, directed from 30 to 35 mm distal to the medial tibial plateau to 10–15 mm distal to the lateral tibial plateau in the coronal plane, was marked by two Kirschner wires with threaded tips (Mizuho Corporation, Tokyo, Japan) under fluoroscopy. A transverse osteotomy was performed using osteotomes and a bone saw, leaving the lateral cortex intact as a hinge. After the ascending osteotomy and opening, the original TPS in the sagittal plane was aimed to be preserved postoperatively. The posterior β-TCP wedge (Olympus Terumo Biomaterials, Tokyo, Japan) was made into a triangular shape with the same width as the predicted opening gap at the posteromedial site. The medial opening gap was filled with two β-TCP wedges and fixed with a TomoFix anatomical plate and locking screws (DePuy Synthes, Solothurn, Switzerland) (Fig. 2).

The DLO was started from a lateral DFO. A 5–6-cm incision was made proximally at the center portion of the bone axis of the distal femur from the lateral femoral epicondyle. The lateral intermuscular septum between the vastus lateralis and iliotibial band was released. A proximal femoral insertion of the lateral head of the gastrocnemius muscle was opened and the posterior portion was exposed. Two Kirschner wires with threaded tips were inserted to make a length

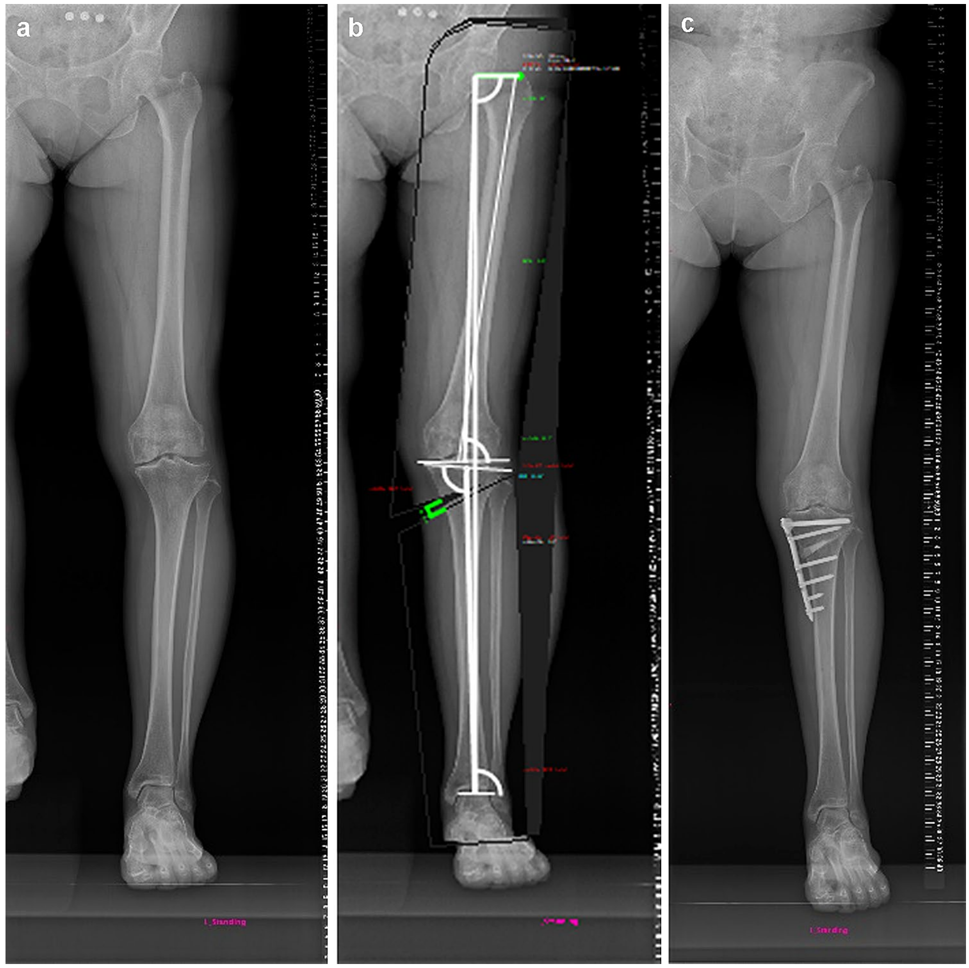

Fig. 2 A 62-year-old woman treated with open-wedge high tibial osteotomy (OWHTO). **a** The preoperative weightbearing line (WBL) ratio, lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), and joint line obliquity (JLO) were 19.6%, 88.6°, 84.5°, and 2.2°, respectively, in a standing anteroposterior long-leg radiograph. **b** Preoperative planning indicated a medial OWHTO of 12 mm. **c** The postoperative WBL ratio, LDFA, MPTA, and JLO were 64.4%, 87.5°, 95.7°, and 3.8°, respectively

between the wires that was preoperatively planned as the lateral closed osteotomy under fluoroscopy. A radiolucent retractor was placed to protect the popliteal artery. Transverse and ascending osteotomies were performed using a Precision Oscillating Tip Saw (Stryker, Kalamazoo, MI). The gap was closed and fixed using a TomoFix medial distal femur anatomical plate (DePuy Synthes), which was bent for the lateral distal femur. The subsequent OWHTO was performed as described above (Fig. 3). Increased operation time of 34 min and fluoroscopy time of 7.5 min were observed in the DLO group compared with the OWHTO group. The operation and fluoroscopy times in the DLO group were significantly longer than those in the OWHTO group (both $p < 0.001$).

All patients received thromboembolism prophylaxis in the form of low-molecular-weight heparin and venous impulse foot pumps. Active and passive ROM exercises, straight-leg-raising exercises, and transfer in a wheelchair were permitted on the day after surgery. The drain was removed at 2 days after surgery. Full weightbearing was permitted from 1 week after surgery.

Hinge fractures in the medial distal femur occurred in two patients in the DLO group during DFO and were fixed with an additional 3.5 reconstruction plate containing 5 holes and 4 screws (DePuy Synthes). Hinge fractures in the lateral proximal tibia occurred in 13 patients in the OWHTO group and two patients in the DLO group. The rate of hinge fractures in the DLO group was lower than that in the OWHTO group ($p < 0.001$). There were no patients with nonunion, metal breakage, or infection at 2 years postoperatively. No patients had converted to unicompartmental or total knee arthroplasty at 2 years postoperatively.

Arthroscopic evaluation

The cartilage condition in the medial femoral and tibial condyles was evaluated according to the stage of regeneration, and was classified into regeneration and no regeneration groups [11]. The regeneration group had findings of white scattering with fibrocartilage, partial coverage with fibrocartilage, or even coverage with fibrocartilage at the time of second-look arthroscopy.

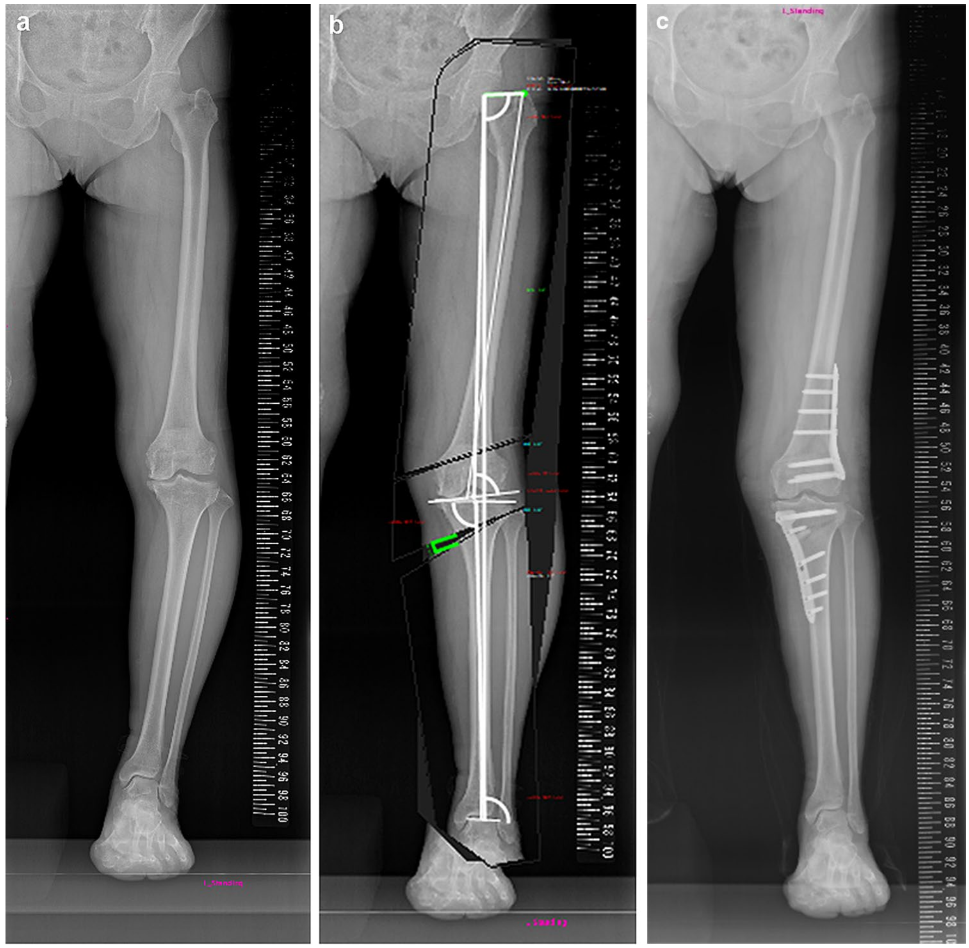

Fig. 3 A 66-year-old woman treated with double-level osteotomy. **a** The preoperative weightbearing line (WBL) ratio, lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), and joint line obliquity (JLO) were 5.8%, 88.6°, 83.9°, and – 4°, respectively, in a standing anteroposterior long-leg radiograph. **b** Preoperative planning indicated a lateral closed distal femoral osteotomy of 4 mm and open-wedge high tibial osteotomy of 8 mm. **c** The postoperative WBL ratio, LDFA, MPTA, and JLO were 72.8%, 84.2°, 93.8°, and 0.1°, respectively

The cartilage condition in the lateral femoral and tibial condyles was graded according to the International Cartilage Repair Society (ICRS) articular cartilage injury classification at the time of osteotomy and at the time of second-look arthroscopy [6]. The cartilage changes in the lateral femoral and tibial condyles after OWHTO were classified into deterioration and no deterioration groups based on the progression of ICRS grading. Knees with an increase in ICRS grade were defined as having cartilage deterioration.

Ethical approval

The study was approved by the Institutional Review Board of Yokohama City University Hospital (B120906024), and all patients provided informed consent for the surgical procedures.

Statistical analysis

IBM SPSS Statistics Desktop for Windows version 21 software (SPSS, Chicago, IL) was used for all statistical analyses. The significance level was set at 5%. Preoperative clinical and radiographic data were compared between the OWHTO and DLO groups. Similarly, postoperative clinical and radiographic data at 2 years after surgery were compared between the two groups. Data were checked for a normal distribution using the Shapiro–Wilk test. Differences between the groups were determined by a two-tailed *t* test for continuous variables with a normal distribution, by the Mann–Whitney test for continuous variables without a normal distribution, and by the Pearson chi-square test or Fisher's exact probability test for nominal variables.

The G*Power version 3.1 free program was used for power analysis before starting the study [7]. A Cohen effect size of 0.5, a confidence level of 95% ($\alpha = 0.05$), and a power (1–β) of 90% as determined by Student's *t* test suggested a sample size of 34 patients per group.

Results

Table 1 shows the patients' demographics and preoperative radiographic and clinical data, which did not differ between the two groups.

The postoperative data at 2 years are shown in Table 2. There were no significant differences in postoperative

Table 1 Preoperative data comparisons between the open-wedge high tibial osteotomy (OWHTO) and double-level osteotomy (DLO) groups

	OWHTO group ($n=34$)	DLO group ($n=34$)	p
Age, year	65.0 ± 5.9	61.3 ± 9.3	n.s.†
Body mass index	24.9 ± 1.8	25.7 ± 1.7	n.s.*
Female/male	23/11	24 / 10	n.s.‡
Left/right	19/15	12/22	n.s.‡
Kellgren Lawrence grade (2/3/4)	1/9/24	2/2/30	n.s.‡
Hip knee ankle angle (HKA), °	− 8.9 ± 3.8	− 10.1 ± 2.4	n.s.†
Weight bearing line (WBL) ratio	− 7.1 ± 7.9	− 3.9 ± 7.2	n.s.*
Tibial posterior slope (TPS), °	10.4 ± 4.1	11.8 ± 4.0	n.s.*
LDFA, °	89.0 ± 1.8	89.5 ± 1.6	n.s.†
JLCA, °	4.9 ± 1.9	5.4 ± 2.0	n.s.*
MPTA, °	84.1 ± 2.1	83.7 ± 2.0	n.s.*
Joint line obliquity (JLO), °	1.4 ± 2.2	1.0 ± 2.4	n.s.*
Range of motion (ROM), °	127.9 ± 12.0	124.0 ± 14.8	n.s.†
KSS knee	50.5 ± 8.8	51.2 ± 6.3	n.s.†
KSS function	77.5 ± 7.1	77.2 ± 8.8	n.s.†
Lysholm score	49.1 ± 13.5	50.1 ± 12.6	n.s.*
KOOS Pain	51.7 ± 18.1	47.1 ± 17.8	n.s.*
Symptoms	57.2 ± 21.8	52.3 ± 22.1	n.s.*
Activities in daily living	66.8 ± 15.8	62.5 ± 18.4	n.s.*
Sport and recreational function	26.9 ± 20.8	23.8 ± 21.5	n.s.†
Knee-related quality of life	28.8 ± 15.4	26.4 ± 16.6	n.s.†

LDFA lateral distal femoral angle, *JLCA* joint line convergence angle, *MPTA* medial proximal tibial angle, *KSS* Knee Society Score, *KOOS* Knee injury and Osteoarthritis Outcome Score

*Unpaired two-tailed *t* test

†Mann–Whitney test

‡Chi-square test

HKA, WBL ratio, TPS, change in TPS, JLCA, change in JLCA, ROM, KSS, and KOOS scores between the two groups. JLO increased significantly from 1.4° to 6.3° in the OWHTO group ($p < 0.001$), and changed from 1.0° to 1.3° in the DLO group (n.s.). Postoperative LDFA, MPTA, and JLO in the OWHTO group were significantly higher than those in the DLO group (all $p < 0.001$).

Postoperative Lysholm score in the DLO group was significantly higher than that in the OWHTO group ($p < 0.025$). There were no significant differences in the postoperative ROM, KSS, and KOOS subscales between the two groups. KSS, Lysholm scores, and all KOOS subscales were significantly improved after surgery in the OWHTO and DLO groups (all $p < 0.001$).

Cartilage regeneration in the medial femoral and tibial condyles and cartilage deterioration in the lateral femoral and tibial condyles on second-look arthroscopy did not differ significantly between the two groups at 1 year after OWHTO (Table 3).

Discussion

The most important finding in our study was that JLO was not significantly changed in the DLO group, but was significantly increased in the OWHTO group after surgery. In this study, patients with predicted MPTA > 95° were treated with OWHTO alone or with DLO. In cases with predicted MPTA > 95°, DLO was able to avoid excessive JLO followed by high MPTA.

JLO of 0° in the one-leg standing position or − 3° in the both-legs standing position is essential for a normal physiologic knee with HKA of 0°, LDFA of 87°, and MPTA of 87° [14]. However, it remains unclear whether this assumption can be adopted in knees with medial knee OA [20]. Approximate HKA of 4°, LDFA of 87°–84°, and MPTA of 90°–95° were aimed, although the relationship between our target joint orientation angles and the target JLO was unknown. Nevertheless, previous papers

Table 2 Postoperative data comparisons between the open-wedge high tibial osteotomy (OWHTO) and double-level osteotomy (DLO) groups

	OWHTO group ($n=34$)	DLO group ($n=34$)	p
Hip knee ankle angle (HKA), °	4.8 ± 2.6	4.4 ± 3.4	n.s.*
Weight bearing line (WBL) ratio (%)	73.3 ± 8.7	69.9 ± 15.8	n.s.*
Tibial posterior slope (TPS), °	11.3 ± 3.6	12.2 ± 4.0	n.s.*
Change in TPS, °	0.8 ± 2.9	0.4 ± 3.9	n.s.†
LDFA, °	88.8 ± 1.8	84.9 ± 1.9	< 0.001*
JLCA, °	3.7 ± 1.9	3.6 ± 2.2	n.s.*
Change in JLCA, °	1.2 ± 1.6	1.9 ± 2.3	n.s.†
MPTA, °	98.3 ± 2.2	92.5 ± 3.0	< 0.001†
Joint line obliquity (JLO), °	6.3 ± 2.5	1.3 ± 2.7	< 0.001*
Change in JLO, °	4.9 ± 2.4	0.1 ± 2.9	< 0.001*
Operation time	89.2 ± 17.3	123.1 ± 15.6	< 0.001*
Fluoroscopy	4.0 ± 1.4	11.5 ± 2.1	< 0.001*
Range of motion (ROM), °	128.5 ± 13.2	126.7 ± 14.9	n.s.†
KSS knee	83.8 ± 6.9	84.3 ± 7.5	n.s.*
KSS function	97.8 ± 5.1	98.5 ± 3.6	n.s.†
Lysholm score	89.9 ± 9.2	94.4 ± 6.3	0.025†
KOOS Pain	83.4 ± 13.9	82.6 ± 6.1	n.s.†
Symptoms	80.3 ± 15.5	75.5 ± 10.8	n.s.†
Activities in daily living	87.6 ± 11.3	83.7 ± 8.4	n.s.†
Sport and recreational function	53.4 ± 20.9	48.9 ± 10.1	n.s.†
Knee-related quality of life	63.9 ± 21.2	60.5 ± 11.5	n.s.†
Hinge fracture, yes/ no	13/21	4/30	< 0.001§

LDFA lateral distal femoral angle, *JLCA* joint line convergence angle, *MPTA* medial proximal tibial angle, *KSS* Knee Society Score, *KOOS* Knee injury and Osteoarthritis Outcome Score

*Unpaired two-tailed *t* test

†Mann–Whitney test

§Fisher exact probability test

Table 3 Cartilage regeneration in the medial condyles and cartilage deterioration in the lateral condyles after surgery in the open-wedge high tibial osteotomy (OWHTO) and double-level osteotomy (DLO) groups

	OWHTO group ($n=34$)	DLO group ($n=34$)	p
Regeneration in the medial femoral condyle (yes/no)	21/13	22/12	n.s.‡
Rate of regeneration in the medial femoral condyle (%)	62	65	
Regeneration in the medial tibial condyle (yes/no)	16/18	23/11	n.s.‡
Rate of regeneration in the medial tibial condyle (%)	47	68	
Deterioration in the femoral lateral condyle (yes/no)	5/29	10/24	n.s.‡
Rate of deterioration in the lateral femoral condyle (%)	15	29	
Deterioration in the tibial lateral condyle (yes/no)	2/32	7/27	n.s.§
Rate of deterioration in the lateral tibial condyle (%)	6	21	

‡Chi-square test

§Fisher exact probability test

supported the notion that the physiologic knee with JLO of 0° in the one-leg standing position should be preserved after osteotomy [18, 22]. JLO changed from 1.4° preoperatively to 6.3° postoperatively in our OWHTO group. Meanwhile, JLO changed from 1.0° preoperatively to 1.3° postoperatively in the DLO group, with no significant difference. All of the clinical scores improved after surgery in both groups, but showed no significant differences between the two groups other than the Lysholm scores. These postoperative clinical outcomes could not lead to superiority in the DLO group. The Lysholm score was originally designed for assessment of ligament injuries of the knee [25] but has been used for a variety of knee conditions. Increased JLO after increased MPTA induced shear stress in the femorotibial articular cartilage after OWHTO [17]. Knees with MPTA > 95° had higher JLO and had lower KOOS Sports/Rec subscale score than knees with MPTA ≤ 95° after OWHTO [2]. Therefore, lower shearing force on the cartilage followed by maintained JLO may have resulted in the higher Lysholm score in the DLO group. The mid-term and long-term outcomes may reveal differences between the two groups. The femoral and tibial cartilage regeneration in the medial condyles at 1 year after surgery was 62% and 67% in the OWHTO group and 47% and 58% in the DLO group, respectively. Contrary to our expectation, there were no significant differences between the two groups. The femoral and tibial cartilage deterioration in the lateral condyles at 1 year after surgery was 15% and 17% in the OWHTO group and 30% and 21% in the DLO group, respectively. Second-look arthroscopy at 1 year after surgery and simultaneously with plate and screw removal were performed. Therefore, the arthroscopic findings at mid-term and long-term follow-ups cannot be examined. MRI examinations may clarify any changes in the cartilage findings.

Babis et al. [3] performed preoperative planning using a computer-based system (OASIS: Osteotomy analysis and simulation software) after DLO with two closed osteotomies but did not show the joint orientation angles of MPTA and LDFA. Saragaglia et al. [20] proposed indications for DLO with femoral closed and tibial open osteotomies, which were preoperative HKA ≥ − 8° and LDFA ≥ 89°, and specific target angles, comprising HKA 2° ± 2°, LDFA 87° ± 2°, and MPTA 90° ± 2°. Nakayama et al. [18] described that the indications for DLO were predicted MPTA ≥ 95° or medial opening gap ≥ 15 mm during preoperative planning for OWHTO alone. They performed DLO for knees with preoperative HKA > − 10° and LDFA > 88°, with target HKA of 0.5°–1°, LDFA of 85°, and MPTA of 90°. They stated that there was no consensus regarding the target alignment and joint orientation angles. Schröter et al. [22] chose DLO for predicted MPTA > 94° or 93° after OWHTO alone, and selected OA knees with preoperative LDFA > 90° and MPTA < 87°. They targeted HKA of 0° − 2°, and planned mean LDFA of 86° ± 1° and mean MPTA of 91° ± 2° during preoperative planning. In previous studies [2, 17], DLO was performed in knees with predicted MPTA > 95° during preoperative planning. Knees with preoperative LDFA ≥ 88°, and targeted a WBL ratio of 62% are chosen. It is reasonable that the minimum length at the lateral cortex for lateral closed DFO was 4 mm because a Precision Oscillating Tip Saw was used. First, LDFA of 87°–84° was decided. In this study, the knees were corrected up to LDFA of 84° at minimum and MPTA of 95° at maximum. Future studies will resolve the problems of minimum LDFA, and maximum or target MPTA.

Nakayama et al. [18] stated that there was no consensus regarding the target alignment in DLO. The target alignment for long-term outcomes in closed-wedge HTO was 62–62.5% [8, 13]. Schröter et al. [22] and Nakayama et al. [18] anticipated HKA of 0°–2° and 0.5°–1° during preoperative planning for DLO, respectively. WBL ratio of 62%, reflecting anatomical femorotibial angle of 170° in OWHTO and closed-wedge HTO was aimed [1, 13, 24]. Therefore, the WBL ratio of 62% in the DLO group was also aimed. The target alignment in the previous studies was more slightly varus than our target alignment, and the present and previous studies showed good short-term clinical results. Based on the previous studies, if the joint line was parallel to the ground in the one-leg standing position, the target alignment in DLO may be closer to the normal WBL ratio of 50% than the original target WBL ratio of 62%. Long-term clinical outcomes would clarify this issue.

The operation time in the DLO group was 34 min longer than that in the OWHTO group, and the fluoroscopy time in the DLO group was 7.5 min longer than that in the OWHTO group. Use of a navigation system will shorten the exposure time, but lengthen the operation time [1]. Thirteen lateral proximal tibial hinge fractures in the OWHTO group, and two medial distal femoral hinge fractures and two lateral proximal tibial hinge fractures in the DLO group were experienced. The rate of hinge fracture in the DLO group was lower than that in the OWHTO group in the present study. The rate of hinge fracture was related to the width of the opening gap in the medial proximal tibia [16]. DLO had a shorter osteotomy gap in the medial proximal tibia compared with OWHTO alone, because of the distribution of the correction angle to the distal femur and proximal tibia. This may decrease the rate of hinge fractures in the distal femur and proximal tibia and the rate of the delayed union after osteotomy. The rate of hinge femoral fracture was 6% (2/34) in our DLO group. Schröter et al. [22] reported lateral femoral hinge fracture in 4% (1/28). In our and their studies, hinge fractures were treated with an additional medial femoral plate and screws. The patients were permitted to move in a wheelchair at 1 day after surgery and started load training using a walker or parallel bar at 2 days after OWHTO and DLO. Patients were able to walk using one cane at 10 days to 2 weeks after surgery. The development of femoral and tibial TomoFix plates enabled this accelerated rehabilitation.

This study had several limitations. First, it was previously reported that patients with predicted MPTA > 95° had worse radiographic and clinical outcomes after OWHTO that those with predicted MPTA ≤ 95° [2]. Therefore, a randomized control study to compare the OWHTO group with the DLO group was not planed. Second, to enable comparisons of the radiographic and clinical outcomes between the OWHTO group and DLO group, patients with a severe deformity in the DLO group and patients with a slight deformity in the

OWHTO group were excluded from the study. Large opening gaps exceeding 13.0 mm in knees with OWHTO alone were shown to delay bone healing [9]. Therefore, the relatively greater correction in the OWHTO group may have affected the clinical outcomes. Third, knees with the upper six threshold values of patient age, upper one threshold value of body mass index were excluded from the OWHTO group. our findings may not be applicable to older patients or patients with a higher body mass index. Fourth, DLO required two osteotomies, and thus, the DLO group had a more invasive procedure than the OWHTO group. However, the progress of the rehabilitation was not recorded. Fifth, the number of subjects was relatively small.

The clinical relevance of the present study is that JLO was not significantly changed after surgery in the DLO group, but was higher in the OWHTO group. The clinical outcomes showed no significant differences between the two groups other than the Lysholm scores. However, the maintained JLO and shearing force on the cartilage in the DLO group may have affected the clinical outcomes in patients with high activity. These results can provide useful information when selecting operative methods for patients with high activity.

Conclusions

JLO was not significantly changed in the DLO group but was significantly increased in the OWHTO group after surgery. Knees with DLO acquired a more physiologic JLO than knees with OWHTO alone after surgery. There were no significant differences in the KSS and KOOS scores, but the Lysholm score in the DLO group was higher than that in the OWHTO group. Cartilage regeneration in the medial condyles and deterioration in the lateral condyles showed no significant differences between the two groups. Further studies are needed.

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Availability of data and material The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors report no conflicts of interest.

Ethics approval Ethical approval for the study was obtained from the Institutional Review Board of Yokohama City University Hospital (B120906024).

Consent to participate Written informed consent was obtained from all the participants.

Consent for publication Written informed consent was obtained from all the participants.

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