

# Opening wedge high tibial osteotomy affects both the lateral patellar tilt and patellar height

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**Abstract** In the current study, we evaluated changes in the patellofemoral joint indices in 49 knees from 39 patients (11 men and 28 women with a median age of 64 years; range 53–79) who had undergone an opening wedge high tibial osteotomy (OWHTO). Osteoarthritis had been diagnosed in 39 knees and osteonecrosis in the other 10 knees in this patient cohort. Radiographs showing anteroposterior and true lateral views of the knee joints while standing, and also skyline views while standing with a 30° flexion, were taken both pre- and postoperatively. Radiographic assessments were then performed using the following five parameters: femorotibial angle (FTA), modified Blackburne-Peel ratio (mBP), tibial slope (TS), lateral patellar tilt (LPT), and lateral patellar shift (LPS). The average LPT decreased significantly from  $7.4^\circ \pm 3.7^\circ$  to  $5.2^\circ \pm 3.6^\circ$  ( $P < 0.01$ ). Patients treated with a greater than 15° correction showed a significantly bigger change in their LPT than those with corrections of 15° or less. No statistical differences were found between the preoperative ( $10.2 \pm 4.5\%$ ) and postoperative ( $10.2 \pm 4.7\%$ ) LPS measurements. Changes in the radiographic parameters were also observed in the patellofemoral joint after OWHTO. It is unclear to what extent the postoperative patellar shift and tilt affects the long-term clinical outcomes but our current results suggest that OWHTO negatively affects the congruency of the patellofemoral joint and should not exceed a correction of 15°.

**Keywords** Opening wedge high tibial osteotomy · Patellofemoral joint · Radiographic study · Lateral patellar tilt · Lateral patellar shift

## Introduction

High tibial osteotomy (HTO) is currently one of the most effective surgical procedures in the treatment of medial compartment osteoarthritis (OA) and osteonecrosis (ON) of the knee [2, 27]. Satisfactory long-term outcomes following HTO have been well documented to date [1, 9, 10, 17]. In addition, several reports have described the radiographic changes in the lower limb alignments following this procedure [3, 20, 28]. However, despite the clinical success associated with performing valgus corrections by various methods, patella baja remains a possible postoperative complication resulting from these corrective procedures [5, 8, 9, 13–16, 21, 23, 26, 29–31]. The alteration of the patella height via a lateral closed wedge HTO (CWHTO) is caused by interstitial scarring of the patella ligament and bone formation behind this ligament [23]. In medial opening wedge HTO (OWHTO), this complication is caused by a distalization of the tibial tuberosity [13, 23, 29]. In addition to changes in the patellar height, patellar tracking may also be affected by HTO. The resulting alterations in the patellofemoral (PF) congruency and contact stress would thus increase the cartilage pressure and lead to patellofemoral osteoarthritis [11].

Although there are many reports of patella baja, few of these studies have addressed the changes to the PF joint after HTO. Saito et al. [22] reported that the width of the lateral facet joint space is extensively opened after closed wedge HTO by the reverse effects on PF articulation, which is performed in case the medial facet joint space is

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larger than its lateral counterpart preoperatively. In another earlier study, Gaasbeek et al. [12] have assessed dynamic patellar tracking after OWHTO and CWHTO using cadavers.

This study was designed to test the hypothesis that distalization and minor lateralization of the tibial tuberosity during OWHTO increase the lateral inclination and deviation of the patella. The radiographic indices in the PF joint after OWHTO were assessed, and the relationship between the correction angle and the patellar dynamics was clarified.

## Materials and methods

This study cohort comprised 35 knees from 28 women and 14 knees from 11 men for whom OWHTO was performed by the same surgeon from 2005 to 2008. The median age of the patients was 64 years (range, 53–79) at the time of surgery and all knees were radiographically evaluated both before and after the procedure. Thirty-nine knees of 29 patients were diagnosed with a medial compartmental OA and 10 knees of the remaining 10 patients with a spontaneous ON of the medial femoral condyle. Our inclusion criteria for receiving OWHTO were (1) isolated medial compartmental OA or ON of the medial femoral condyle, which included patients with a varus malalignment of the leg and persistent pain in spite of having undergone conservative treatment for more than 3 months; (2) active compliance with our postoperative rehabilitation program; and (3) a range of motion of more than 120° flexion. There were no age restrictions. Patients with infection of the knee, severe OA of the PF joint, an FTA of over 185° (5° anatomical varus), an ACL or PCL tear, or a flexion contracture of over 15° were excluded.

### Surgical procedures

An oblique osteotomy was initiated at a point 35 mm distal to the medial tibial plateau and ending 5 mm from the lateral cortical margin just at the upper level of the proximal tibiofibular joint. A frontal osteotomy was then commenced at a point 10–20 mm proximal to the insertion of the patellar tendon and ending at the first osteotomy plane (biplanar osteotomy). The dilatation width was determined to be an FTA of 170° (10° anatomical valgus angulation) using a goniometer under fluoroscopic control [26]. Two wedge-shaped blocks composed of  $\beta$ -tricalcium phosphate with a 60% porosity (Osferion 60, Olympus Terumo Biomaterial, Tokyo, Japan) were placed into the osteotomy gap to provide added stability, particularly in the sagittal plane. The osteotomy site was fixed using a Locking Compression Plate System (TomoFix™, Synthes, Solothurn, Switzerland).

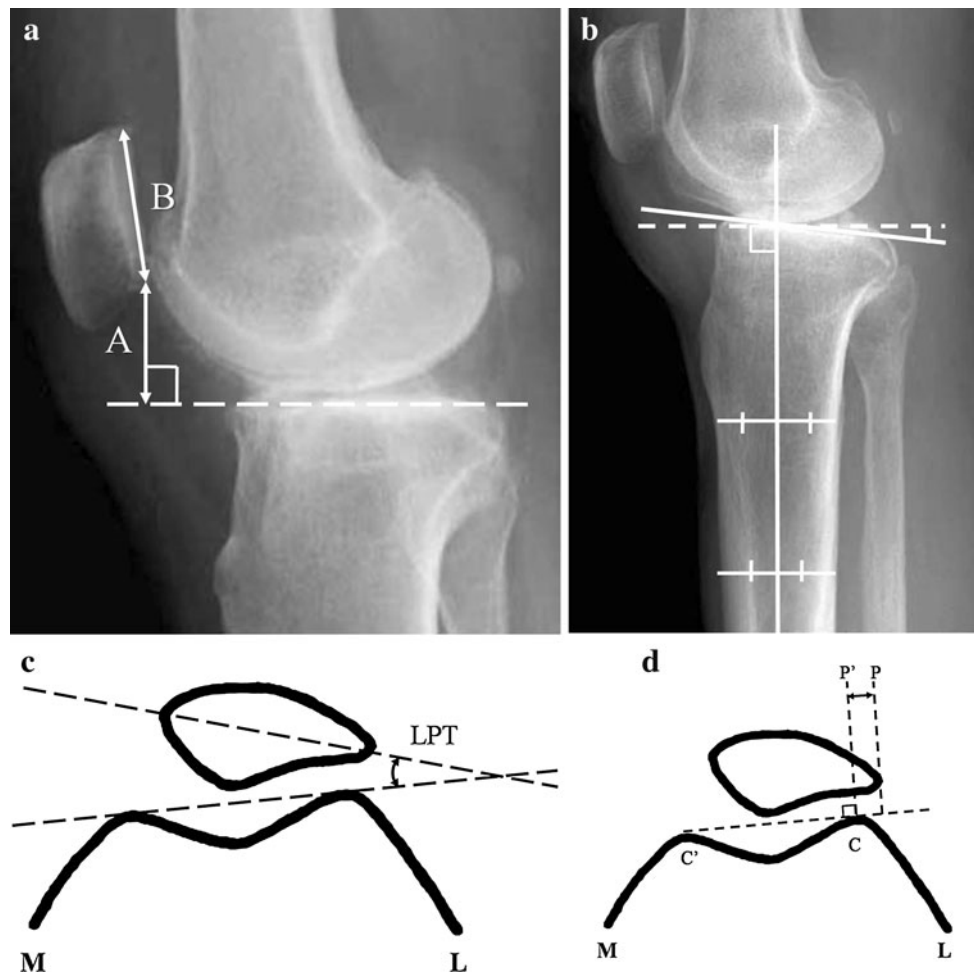
### Postoperative rehabilitation

None of the patients were treated with a cast. Standing exercises were also initiated immediately after OWHTO. One week after surgery, the patients were allowed to start partial weight-bearing exercise with a walker. Every patient in our treatment group was able to walk with a full weight load, with or without a T-cane, at two weeks postsurgery and was discharged within three weeks of their operation.

### Radiographic assessments

Standing anteroposterior and true lateral radiographs of the tibiofemoral joint were taken before the OWHTO procedure and at three months after this surgery. The standing skyline view was obtained with flexion of 30° from the vertical direction [6]. Radiographic assessments taken in a standing view included measurements of five parameters: (1) the femorotibial angle (FTA) by use of a standing AP view; (2) the modified Blackburne-Peel ratios (mBP) by use of a lateral standing view of the knee joint extension (Fig. 1a) [4]; (3) the tibial slope (TS, defined as the angle between the line perpendicular to the mid-diaphysis of the tibia and the posterior inclination of the tibial plateau) by use of a lateral standing view of the knee joint extension (Fig. 1b); (4) the lateral patellar tilt (LPT; defined as the angle between the line intersecting the widest bony structure of the patella and the line passing the anterior surfaces of the femoral condyles tangentially; Fig. 1c) by use of a standing skyline view [18]; and (5) the lateral patellar shift (LPS, defined as the PP'/CC' ratio; Fig. 1d) by use of a standing skyline view. CC' is defined as the distance between the summits of the medial and lateral femoral condyles of the femur. PP' is defined as the distance between the summit of the lateral femoral condyle and the point at which a line from the lateral edge of the patella that is perpendicular to the line that passes through the summits of the femoral condyles crosses that line. All radiographic measurements were made by two independent observers in a blind fashion. To ensure accuracy, the inter-observer variance was assessed using paired *t* tests, and no significant differences were found between the observers ( $P > 0.05$ ).

To assess the relationship between the correction angle and the change of the patellofemoral indices, the 49 knees in our study cohort were divided into three groups according to the change between the pre- and postoperative FTA ( $\Delta$ FTA); Group A ( $\Delta$ FTA < 12°), Group B ( $12^\circ \leq \Delta$ FTA  $\leq 15^\circ$ ), and Group C ( $\Delta$ FTA > 15°). Two patellofemoral indices were investigated, the first being the degree change between the pre- and post-LPT, defined as the  $\Delta$ LPT. The second index was the  $\Delta$ LPS, defined as the



**Fig. 1** Radiographic assessments. **a** modified Blackburne-Peel ratios (mBP). Modified Blackburne-Peel ratios (mBP) were measured by use of a lateral standing view with a knee joint extension. The original BP was measured using a lateral view of the knee flexed to at least 30° and with no weight bearing. “A” is the perpendicular height of the lower end of the articular surface of the patella from the tibial plateau line and “B” is the length of the articular surface of the patella. The A/B ratio provides a measure of the patella level. **b** Tibial slope (TS). The tibial slope was defined as the angle between the line perpendicular to the mid-diaphysis of the tibia and the posterior inclination of the tibial plateau. **c** Lateral patellar tilt (LPT). The LPT

was defined as the angle between the line intersecting the widest bony structure of the patella and the line passing the anterior surfaces of the femoral condyles tangentially via a standing skyline view. **d** Lateral patellar shift (LPS). In a standing skyline view, LPS is defined as the ratio of the distances  $PP'/CC'$ .  $CC'$  is defined as the distance between the summits of the medial and lateral femoral condyles of the femur.  $PP'$  is defined as the distance between the summit of the lateral femoral condyle and the point where a line from the lateral edge of the patella perpendicular to the line that passes through the summits of the femoral condyles crosses that line

change in the percentage between the pre- and postoperative LPS. In addition, we divided the patients into three additional groups using the  $\Delta BP$  (post-mBP/pre-mBP) as we surmised that we could consider the patellar reduction rate to equal the rate of change in the mBP; Group A' ( $\Delta BP < 70\%$ ), Group B' ( $70\% \leq \Delta BP \leq 85\%$ ), and Group C' ( $\Delta BP > 85\%$ ).

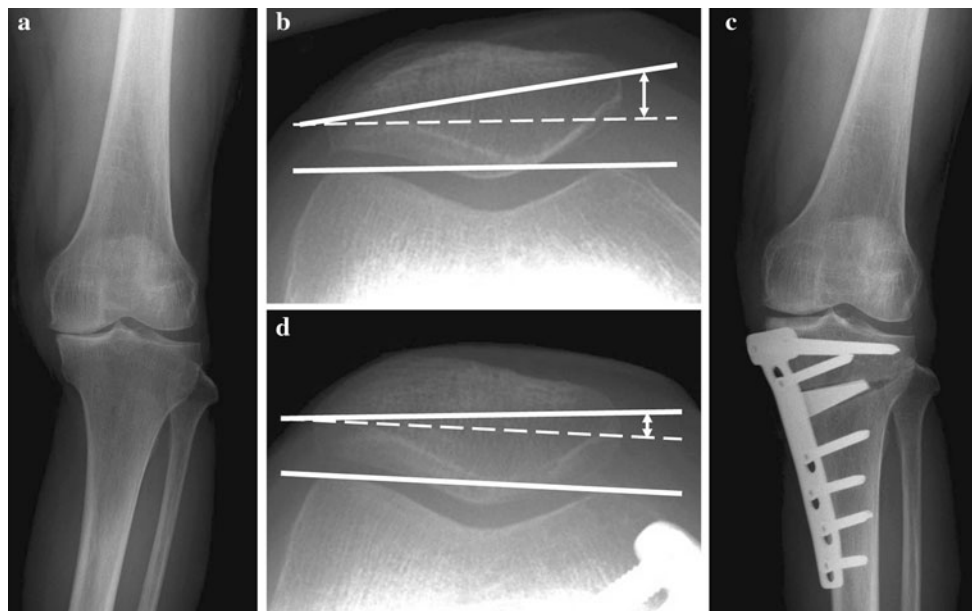
#### Statistical analysis

Paired *t* test or Wilcoxon signed-ranks test was used to test for statistically significant differences in the measured

indices between pre- and posttreatment cases. For correlations among the three patient groups, statistical differences were evaluated using one-factor ANOVA for independent samples, and the Student's *t* test was used to verify the differences between two groups. *P* values of less than 0.05 were considered significant.

#### Results

Following OWHTO, the mean femorotibial angle (FTA) changed significantly, from  $182.3^\circ \pm 2.2^\circ$  ( $2.3^\circ$  of



**Fig. 2** Representative case study of a 69-year-old woman with OA. **a** A preoperative FTA of 184°. **b** A standing skyline view before OWHTO. The LPT is 8°, and the LPS is 5.3%. **c** A postoperative FTA

of 166° at 3 months after an OWHTO procedure with TomoFix. **d** The LPT has decreased 3° postoperatively, and the LPS is 6%

**Table 1** Mean (and SD) values for indices before and after OWHTO

Measurements	Preoperative	Postoperative	<i>P</i> value
FTA (°)	182.3 (2.2)	169.6 (2.6)	<0.01
mBP	0.9 (0.1)	0.7 (0.1)	<0.01
TS (°)	8.4 (3.5)	11.9 (3.5)	<0.01
LPT (°)	7.4 (3.7)	5.2 (3.6)	<0.01
LPS (%)	10.2 (4.5)	10.2 (4.7)	n.s.

*P* values of less than 0.05 were considered significant

FTA femoro tibial angle, mBP modified Blackburne-Peel ratio, TS tibial slope, LPT lateral patellar tilt, LPS lateral patellar shift

anatomical varus angulation) preoperatively to 169.6° ± 2.6° (10.4° of anatomical valgus angulation) postoperatively ( $P < 0.01$ ). There was also a statistically significant increase in the mean modified Blackburne-Peel ratio (mBP) value after this procedure, from 0.86 ± 0.15 preoperatively to 0.66 ± 0.14 postoperatively ( $P < 0.01$ ), and in the mean tibial slope (TS) from 8.4 ± 3.5° to 11.9 ± 3.5° ( $P < 0.01$ ). The average lateral patellar tilt (LPT) decreased significantly, from 7.4 ± 3.7° to 5.2 ± 3.6° ( $P < 0.01$ ). No statistical differences were found, however, between the preoperative (10.2 ± 4.5%) and postoperative (10.2 ± 4.7%) lateral patellar shift (LPS; Fig. 2 and Table 1). The mean  $\Delta$ LPT was  $-0.6^\circ$  (indicating a decreased LPT) in Group A,  $-2.2^\circ$  in Group B, and  $-4.2^\circ$  in Group C ( $P < 0.01$ ). In addition, significant differences were found between Group A and Group C ( $P < 0.01$ ) and between Group B and Group C ( $P < 0.05$ ).

There were no significant differences, however, between the  $\Delta$ LPS among the three groups of patients (Table 2). In classification using  $\Delta$ BP, there were no significant differences between the  $\Delta$ LPT and  $\Delta$ LPS values among the three groups (A', B', and C'), which was contrary to our expectations (Table 3). There was also no correlation found between the  $\Delta$ FTA and  $\Delta$ BP using a Pearson's correlation coefficient test.

## Discussion

The most important findings of the present study were the increases in the lateral inclination and deviation of the patella caused by distalization and minor lateralization of the tibial tuberosity during OWHTO. OWHTO is commonly accepted as a clinically effective procedure and has thus gained increased popularity in recent years. Several reports have described favorable postoperative clinical and functional outcomes of this surgery [19, 24, 26, 27]. Takeuchi et al. [26] previously reported the results of early full weight bearing after OWHTO and that 40 of 52 patients could sit comfortably in the Japanese style after this operation. However, many reports have highlighted that the open wedge technique results in a decrease in the patellar height, which may lead to patella baja complications. Patella baja following medial OWHTO leads to anterior knee pain, crepitus, patellar locking, and a reduced range of motion. Furthermore, OWHTO produces an alteration in the cartilage pressure, a factor linked to the

**Table 2** Mean (and SD) values for patellofemoral indices in 3 groups according to the degree of change between pre- and postoperative FTA ( $\Delta$ FTA)

Measurements	Group A ( $n = 14$ )	Group B ( $n = 14$ )	Group C ( $n = 12$ )	<i>P</i> value
LPT ( $^{\circ}$ )	-0.6 (2.8)	-2.2 (2.3)	-4.2 (2.4)	<0.01
LPS (%)	-0.5 (1.8)	0.3 (3.2)	0.2 (3.9)	n.s.

*P* values of less than 0.05 were considered significant

*FTA* femorotibial angle lateral patellar tilt, *LPS* lateral patellar shift,  $\Delta$ LPT post-LPT – pre-LPT,  $\Delta$ LPS post-LPS – pre-LPS

Group A:  $\Delta$ FTA <  $12^{\circ}$ , Group B:  $12^{\circ} \leq \Delta$ FTA  $\leq 15^{\circ}$ , Group C:  $15^{\circ} < \Delta$ FTA

**Table 3** Mean (and SD) values for patellofemoral indices in 3 groups divided it using  $\Delta$ BP (post-mBP/pre mBP)

Measurements	Group A' ( $n = 11$ )	Group B' ( $n = 26$ )	Group C' ( $n = 12$ )	<i>P</i> value
$\Delta$ TPPT ( $^{\circ}$ )	-1.8 (3.7)	-2.2 (2.6)	-2.6 (2.0)	n.s.
$\Delta$ LPS (%)	-1.2 (1.8)	0.6 (3.3)	0.2 (3.4)	n.s.

*P* values of less than 0.05 were considered significant

*mBP* modified Blackburne-Peel ratio, *LPT* lateral patellar tilt, *LPS* lateral patellar shift,  $\Delta$ LPT post-LPT – pre-LPT,  $\Delta$ LPS post-LPS – pre-LPS

Group A':  $\Delta$ BP < 70%, Group B':  $70\% \leq \Delta$ BP  $\leq 85\%$ , Group C':  $85\% < \Delta$ BP

degeneration of joint cartilage. Altered patellofemoral congruency and contact stress can eventually lead to patellofemoral osteoarthritis.

Buckland-Wright [7] have reported that in the supine position, the knee joint is under neither muscular nor mechanical load and that when the muscles and ligaments are relaxed, the joint space opens up resulting in a false radiographic evaluation. In this study, we used standing lateral and skyline views to evaluate the PF joint. The standing knee position places the joint under load, providing an evaluation of the functional height, tilt, and shift of the patella, which is not always achieved when the patient is radiographed in the supine position. The Blackburne-Peel Index has generally been used to evaluate patellar height and been measured both pre- and postoperatively to check for possible patella baja. We expected a greater reduction in the patellar height following OWHTO, which would require a massive correction angle, and also anticipated a negative correlation between the  $\Delta$ FTA and  $\Delta$ BP. However, no such correlation was evident.

The three principal causes of patella baja following OWHTO are a shortening of the patellar ligament, distal transfer of the tibial tuberosity, and elevation of the tibiofemoral joint line [8, 31]. In our current study, the TS increased significantly following OWHTO. Brouwer et al. [5] have reported previously that an increase in the tibial posterior slope is also significantly associated with patella baja, according to the BP index. Moreover, Kesmezacar et al. [15] have indicated that the BP index may alter depending on changes in the tibial posterior slope that are frequently seen after an opening wedge osteotomy. For this

reason, the BP index was not an appropriate measure of the patellar height following OWHTO in our current study.

The lateral patellar tilt and shift after OWHTO have not previously been investigated with any clarity. We expected that the distal and lateral transfer of the tibial tuberosity as a result of OWHTO would cause an increase in the LPT and LPS. However, these results indicate that the LPT significantly decreases and that the changes in the LPS are not significantly different following OWHTO. Gaasbeek et al. [12] have reported using cadaver knees that the patella tilts more medially and does not translate medially or laterally following OWHTO, and our current in vivo results corroborate these findings. In addition, Gaasbeek and colleagues further reported that the decreased LPT could be explained by the increased lateral pull on the patella as they found that the lateral patellar facet was pressed against the lateral wall of the trochlea and that the patella was forced up the lateral groove leading to a medial tilt. Stoffel et al. [25] have also reported that the cartilage pressure on the PF joint following OWHTO increases significantly when compared with an intact knee. We therefore speculate that the attenuation of the LPT causes increased contact pressure in the patellofemoral joint.

The patients examined in this study were divided into three groups using the  $\Delta$ FTA as an index, and the  $\Delta$ LPT and the  $\Delta$ LPS were evaluated between these groups. We thereby clarified that the  $\Delta$ LPT decreases significantly in the group with a  $\Delta$ FTA of greater than  $15^{\circ}$ . In this regard, Tigani et al. [29] have reported previously that in an OWHTO group with a greater than  $15^{\circ}$  knee axis correction, there was a significant decrease in the patellar height

using Caton's index. Hence, patellar tracking will be affected seriously if the correction of the knee axis exceeds  $15^\circ$ .

## Conclusions

The results of this study demonstrate that changes in the radiographic parameters occur in the PF joint following OWHTO. We have also found that the lateral patellar tilt decreases after OWHTO and that with a greater than  $15^\circ$  correction, the lateral patellar tilt decreases significantly and affects the congruency of the patellofemoral joint.

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