


## CLINICAL ARTICLE

# Patellofemoral Joint after Opening Wedge High Tibial Osteotomy: A Comparative Study of Uniplane versus Biplane Osteotomies

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**Objective:** To the best of our knowledge, there has been no comparative study of changes in radiographic parameters in the sagittal plane between biplane opening wedge high tibial osteotomy (OWHTO) with plate fixation and uniplane OWHTO with spacer implantation. The aim of the study was to compare sagittal radiographs between the procedures of biplane and uniplane OWHTOs in patients with genu varum and to investigate the impact on the patellofemoral joint.

**Methods:** A retrospective study of 71 patients ( $58.0 \pm 5.0$  years of age, 58 females and 13 males) with varus-aligned medial compartment knee osteoarthritis treated with OWHTO was performed during the period from January 2016 to February 2019. Thirty-three patients underwent biplane osteotomy with plate fixation (biplane group), and 38 patients underwent uniplane osteotomy with absorbable wedged spacer fixation (uniplane group). Independent t tests were used to compare the two groups according to the preoperative and postoperative radiographic parameters of hip-knee-ankle (HKA) angle, posterior tibial slope (PTS), tibial tubercle prominence (TTP), Caton–Deschamps (CD) index, and Blackburne–Peel (BP) index. During the last follow-up assessment, patients were asked to rate their patellofemoral joint status using the Samsung Medical Center (SMC) patellofemoral (PF) scoring system. The visual analog scale (VAS) was also used to rate knee joint pain when walking.

**Results:** There was no significant difference between the two groups in any of the demographic, clinical, or radiological characteristics at baseline ( $p > 0.05$ ). Comparisons of postoperative sagittal radiographic parameters between patients in the uniplane group and patients in the biplane group showed significant differences in the PTS ( $13.4^\circ$  vs  $16.6^\circ$ ,  $t = 4.465$ ,  $p < 0.001$ ), TTP (9.0 mm vs 4.2 mm,  $t = 7.950$ ,  $p < 0.001$ ), and CD index (0.81 vs 0.70,  $t = 4.035$ ,  $p < 0.001$ ). At the final follow-up assessment (minimum, 2 years), the SMC PF function score was significantly lower in patients in the uniplane group than in patients in the biplane group (27.8 vs. 32.1,  $t = 2.458$ ,  $p = 0.016$ ), but there were no significant differences in the SMC PF pain score or VAS score ( $p > 0.05$ ).

**Conclusion:** The essential difference in the postoperative sagittal radiographic changes between biplane and uniplane OWHTO was the tibial tubercle prominence, indicating the posterior displacement of the tibial tubercle. Uniplane OWHTO may yield better function of the patellofemoral joint compared to biplane OWHTO.

**Key words:** knee osteoarthritis; opening wedge high tibial osteotomy; patellar height; posterior tibial slope; retrospective; tibial tubercle prominence

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## Introduction

Osteoarthritis (OA) of the knee joint is one of the most common joint disorders in elderly individuals. The medial compartment, which is most commonly involved, carries 60%–80% of the vertical stress experienced by the knee joint as the mechanical axis of the lower extremity normally passes medial to the center of the tibial plateau<sup>1,2</sup>.

High tibial osteotomy (HTO) is a set of safe, effective, and well-established surgical techniques to treat medial compartmental knee OA with associated varus malalignment. The opening wedge high tibial osteotomy (OWHTO) was proposed by Hernigouin 1987 to address varus deformities. Compared to closing wedge osteotomy, OWHTO can achieve more predictable correction, maintain bone stock, and have a low risk of peroneal nerve injury; moreover, this approach has become mainstream in recent years<sup>3,4</sup>.

However, OWHTO still has its shortcomings. OWHTO has been reported to have a negative effect on the patellofemoral joint postoperatively due to a decrease in patellar height (PH) and an increase in patellofemoral contact pressure<sup>5–7</sup>. Biomechanical studies indicated that the alteration in sagittal patellar height can be attributed to distalization of the tibial tuberosity following OWHTO, which leads to the patella being pulled down toward the joint lines<sup>8</sup>. Studies have shown that an increased posterior tibial slope sagittally after OWHTO can lead to overload of the anterior cruciate ligament and the development of flexion contracture<sup>9</sup>.

The OWHTO procedure was initially performed in a uniplane fashion, and the biplane osteotomy technique was later developed by Lobenhoffer<sup>10</sup>. The biplane cut is favored over the uniplane technique since it increases the bone contact area, which may be beneficial for healing, and increases the primary sagittal and rotational stabilities by the ascending osteotomy. Another major benefit of the biplane approach is that it has fewer constraints in terms of the cutting plane orientation due to the patellar ligament insertion<sup>11</sup>. However, the larger cutting surface in the biplane technique would increase blood loss, and fixation with the medial proximal tibia plate requires a longer incision.

Uniplane osteotomy and spacer fixation are not new concepts<sup>12,13</sup>. However, the  $\beta$ -TCP/PLGA wedge-shaped spacer used in this study is a unique design, featuring its material, nonuniform thickness, and fin-like spikes, which are designed to compensate for the drawbacks of uniplane osteotomy. Both biplane and uniplane OWHTOs are able to effectively correct the coronal mechanical axis of the operated leg according to our clinical experience; both of these techniques entail concerns regarding the posterior tibial slope<sup>14–16</sup> and the problem of postoperative patella baja and consequent patellofemoral disorders<sup>17,18</sup>. However, differences in the sagittal position of the tibial tubercle inherently produced by the biplane and uniplane cutting designs were noted intraoperatively and postoperatively, and this may affect the position of the patella and the patellofemoral

mechanics. Therefore, the purposes of this study were (i) to illustrate the different positions of the tibial tubercle after biplane and uniplane OWHTOs by sagittal radiographic parameters and (ii) to explore the effect of biplane and uniplane OWHTOs on the patellofemoral joint due to the different positions of the tibial tubercle. We hypothesized that compared to biplane osteotomy, which resulted in posterior displacement of the tibial tubercle, uniplane osteotomy could maintain the prominence of the tibial tubercle and therefore may benefit patellofemoral mechanics.

## Materials and Methods

### Patients

Approval of the Ethics Committee of the Institutional Review Board (IRB) was obtained for this retrospective study (IRB number: 2020-001-1). One hundred and fourteen patients with medial compartment knee OA who were treated with OWHTO from January 2016 to February 2019 were retrospectively reviewed.

The indications for medial OWHTO included symptomatic medial compartment OA of the knee joint with a functional intact lateral compartment, an HKA angle less than 180°, a medial proximal tibia angle (MPTA) less than 85°, a knee extension deficit no more than 5°, and intact cruciate ligaments and collateral ligaments. The contraindications were as follows: valgus limb alignment with a HKA angle over 180°; a knee extension deficit over 5°; knee instability; history of femoral head necrosis, prior trauma and surgery of the affected limb; rheumatoid arthritis, crystal-induced arthritis, ankylosing spondylitis, metabolic bone disease, and other related bone diseases.

All patients' medical records and imaging data were retrospectively reviewed. The inclusion criteria of the current study were as follows: (i) tibial osteotomy was performed either in a uniplane manner with absorbable wedge-shaped spacer implantation or in a biplane manner with proximal tibial locking plate fixation, (ii) no to moderate patellofemoral joint degeneration (Kellgren–Lawrence/K-L grade 0–II) on radiographic assessment before surgery, (iii) a complete postoperative follow-up record of at least 2 years, and (iv) standard weight-bearing full-length anteroposterior radiographs and lateral views of the affected knee obtained (the medial and lateral condyles of the femur overlap well) before surgery and at the 1-year follow-up. Patients with severe patellofemoral degeneration (K-L grade III–IV) before surgery and those with incomplete clinical or radiological data were excluded from the study. Patients who received OWHTOs other than the above two procedures were also excluded.

As a result, 15 patients with less than 2 years of follow-up, 25 patients with incomplete radiographs, and three knees with severe PF degeneration were excluded. Finally, 33 patients who underwent biplane tibial osteotomy and 38 patients who underwent uniplane tibial osteotomy were included in this study.

**Surgical Essentials and Rehabilitation**

All surgical procedures were performed by the same experienced surgical team under fluoroscopic guidance, following the same indications and surgical principles for HTO. The choice between the two procedures was based on the preference of the surgeon and the informed decision of the patient; randomized allocation was not employed due to the retrospective nature of the study. Diagnostic arthroscopy was performed for all patients to confirm the indication for OWHTO. When the Outerbridge grading of the lateral ventricular cartilage was greater than or equal to 2°, OWHTO was not performed.

**Biplane procedure:** The operation followed the procedure published by the AO foundation. The pes anserinus tendon was preserved, and the superficial medial collateral ligament (sMCL) was completely released during exposure. The horizontal oblique osteotomy, aiming toward the tip of the fibular head, was established just above the insertion of the pes anserinus tendon and parallel to the tibial slope. Oblique coronal osteotomy was performed 110° to the horizontal oblique osteotomy (Figure 1A,B). After completing the biplane cut, the osteotomy site was increased until the mechanical axis of the limb passed through 55%–62% of the tibial plateau width from the medial margin, and the final mechanical axis was confirmed by fluoroscopy. The target mechanical axis was determined based on degeneration of the lateral compartment, and the range of the postoperative HKA angle was set at 180°–182°. Then, the osteotomy site was fixed with a T-shaped locking compression plate and screws. For a gap opening less than 10 mm, no filler was applied. For a gap greater than 10 mm, allogenic bone grafts were inserted at the gap.

**Uniplane procedure:** The same technique was followed that was previously described in the literature<sup>19</sup>. The proximal tibia was exposed following the same steps as those performed for the biplane osteotomy, with the pes anserinus tendon preserved and the sMCL completely released. The horizontal oblique osteotomy, aiming toward the tip of the fibular head, was established parallel to the

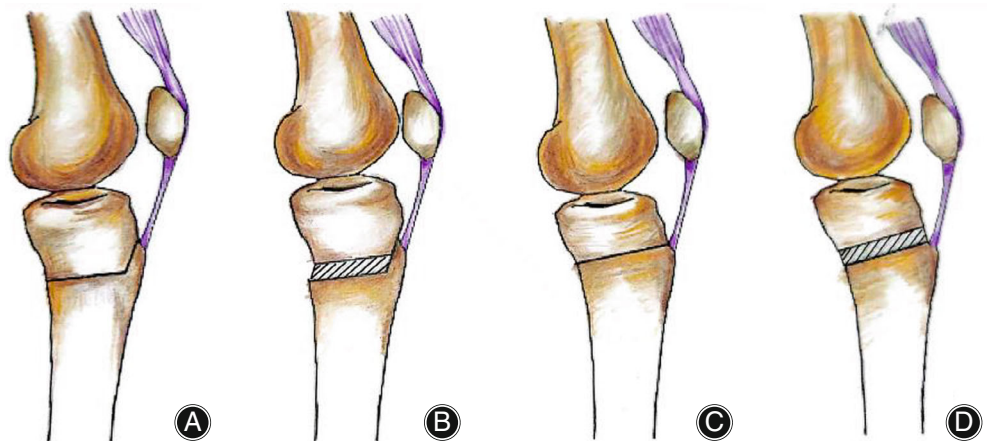
tibial slope and passed just above the tibial tubercle (Figure 1C,D). The osteotomy gap was created by a set of progressive wedge-shaped spreaders until the target mechanical axis was achieved under fluoroscopy<sup>20</sup>. The target mechanical axis was determined following the same principles as those used for biplane osteotomy. Subsequently, an absorbable  $\beta$ -TCP/PLGA (tricalcium phosphate and poly [lactic-co-glycolic acid]) spacer of suitable size was implanted (WEGO, Shan Dong, China)<sup>19</sup>. The thickness of the spacer was designed according to the anterior-posterior ratio of the height of the osteotomy space to provide strong support along the medial cortex of the tibia and maintain the original posterior tibial slope simultaneously. The two rows of small fin-like spikes on both superior and inferior surfaces of the spacer were embedded in the cancellous bone. Thus, to prevent withdrawal of the spacer and rotation of osteotomy ends, for uniplane OWHTO, patients included in this study had a maximum correction angle of 12°.

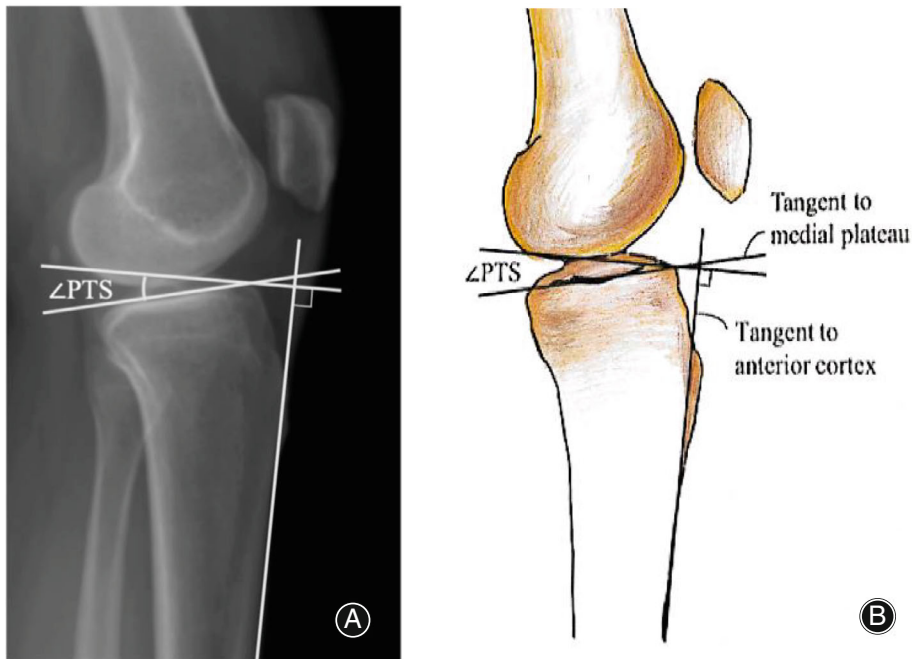
Rehabilitation started at postoperative day 1 with isometric contraction of the quadriceps and passive range of motion. The operated leg was required not to bear weight for 3 weeks, achieved with the aid of crutches; then, partial weight bearing was started and gradually transitioned to full weight bearing within 4–6 weeks. Patients were routinely followed up at 3, 6, 12, and 24 months after surgery.

**Radiographic Measurement**

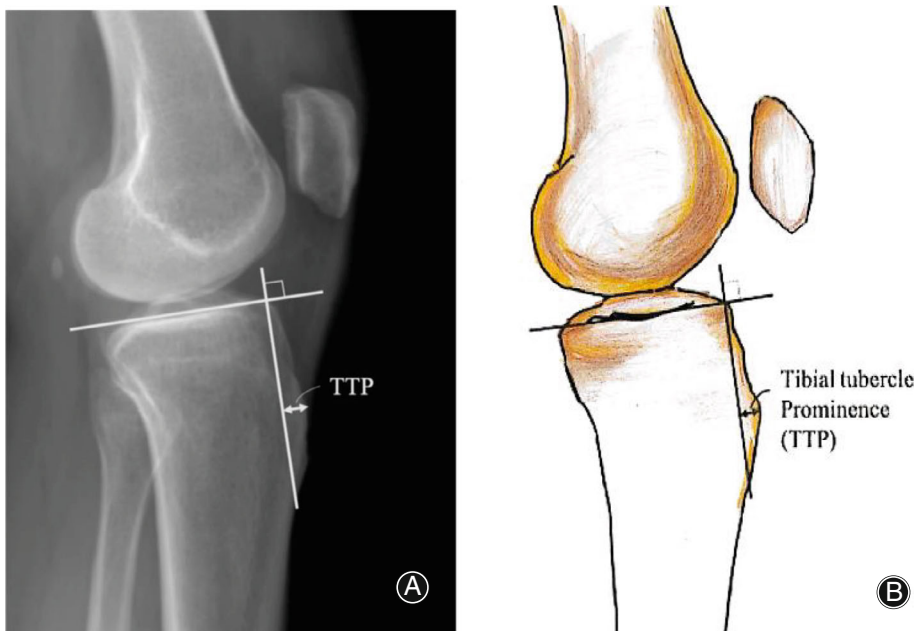
Image data obtained before and 1 year after surgery were imported into the RadiAnt DICOM Viewer (64-bit) system. The HKA angle was measured on weight-bearing full-length anteroposterior radiographs. The posterior tibial slope (PTS) (Figure 2), tibial tubercle prominence (TTP) (Figure 3), Caton–Deschamps (CD) index (Figure 4), and Blackburne–Peel (BP) index (Figure 5) were measured on the lateral radiographs. To test the reliability of the TTP measurements, two authors measured all of the images independently. One of the two authors repeated the measurements 2 weeks later.

**Fig. 1** Schematic diagrams showing the tibial osteotomy plane(s) of the two procedures. (A, B) The two osteotomy planes at an angle of 110° in the biplane procedure before and after the horizontal oblique osteotomy space was enlarged. (C, D) The osteotomy plane in the uniplane procedure before and after the osteotomy space was enlarged





**Fig. 2** The PTS was determined by the Moore–Harvey method. The PTS is the angle between the tangent to the medial plateau and the perpendicular line of the tangent to the anterior tibial cortex. (A) Lateral radiograph. (B) Schematic diagram



**Fig. 3** The tibial tubercle prominence (TTP) was defined as the vertical distance from the most prominent point of the tibial tubercle to the perpendicular line of the tangent of the medial tibial plateau passing through the anterosuperior angle of the tibial outline (the same point used for the CD index). (A) Lateral radiograph. (B) Schematic diagram

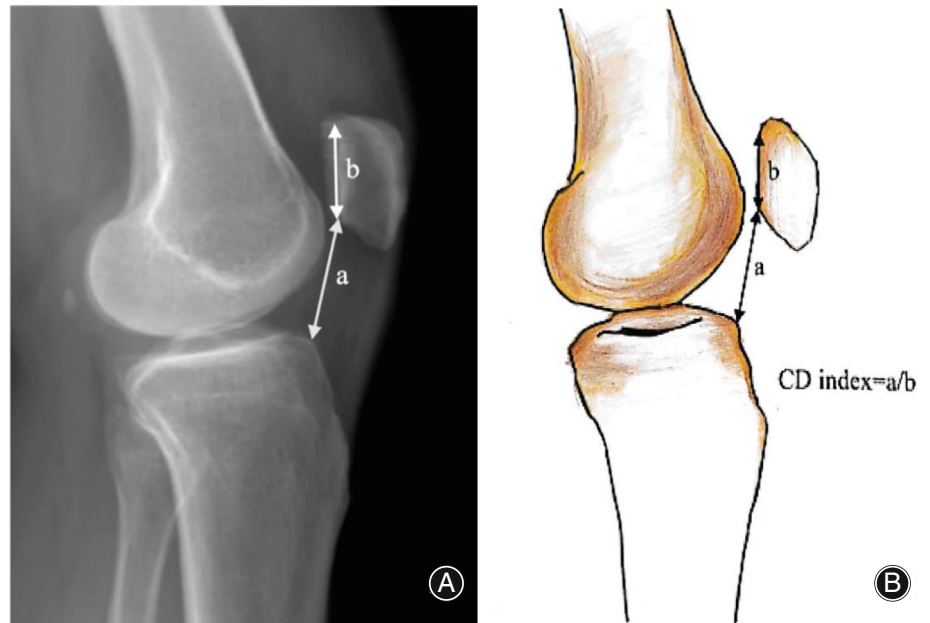
### Clinical Assessment

The Samsung Medical Center (SMC) patellofemoral scoring system<sup>21</sup> was used before surgery and at the final follow-up to evaluate the anterior knee pain and the degree of difficulty in performing activities that load the patellofemoral joint. A smaller overall SMC patellofemoral score indicated less pain and better function. The visual analog scale (VAS) was also used to rate knee joint pain during walking.

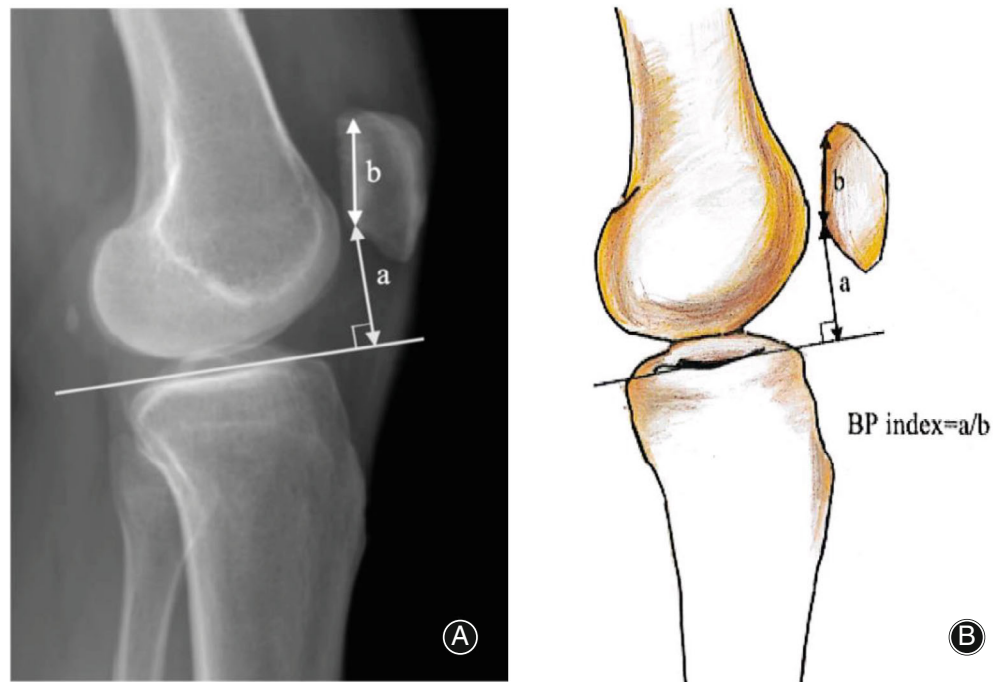
### Statistical Analysis

Statistical analysis was performed using SPSS software (version 25.0, SPSS, Inc., Chicago, IL, USA). Continuous and categorical variables are displayed as the mean  $\pm$  standard deviation (SD) and ratio, respectively. The preoperative and postoperative clinical scores and radiographic results were analyzed using a paired t test, and continuous variables were compared between the study groups using an independent t test. The chi-square





**Fig. 4** The Caton–Deschamps (CD) index for evaluating patella height. The CD index is the ratio of the distance from the lowest point of the articular surface of the patella to the anterosuperior angle of the tibial outline (a) to the length of the articular surface of the patella (b). (A) Lateral radiograph. (B) Schematic diagram



**Fig. 5** The Blackburne–Peel (BP) index for evaluating patella height. The BP index is the ratio of the perpendicular distance from the lowest point of the articular surface of the patella to the tangent of the medial tibial plateau (a) to the length of the articular surface of the patella (b). (A) Lateral radiograph. (B) Schematic diagram

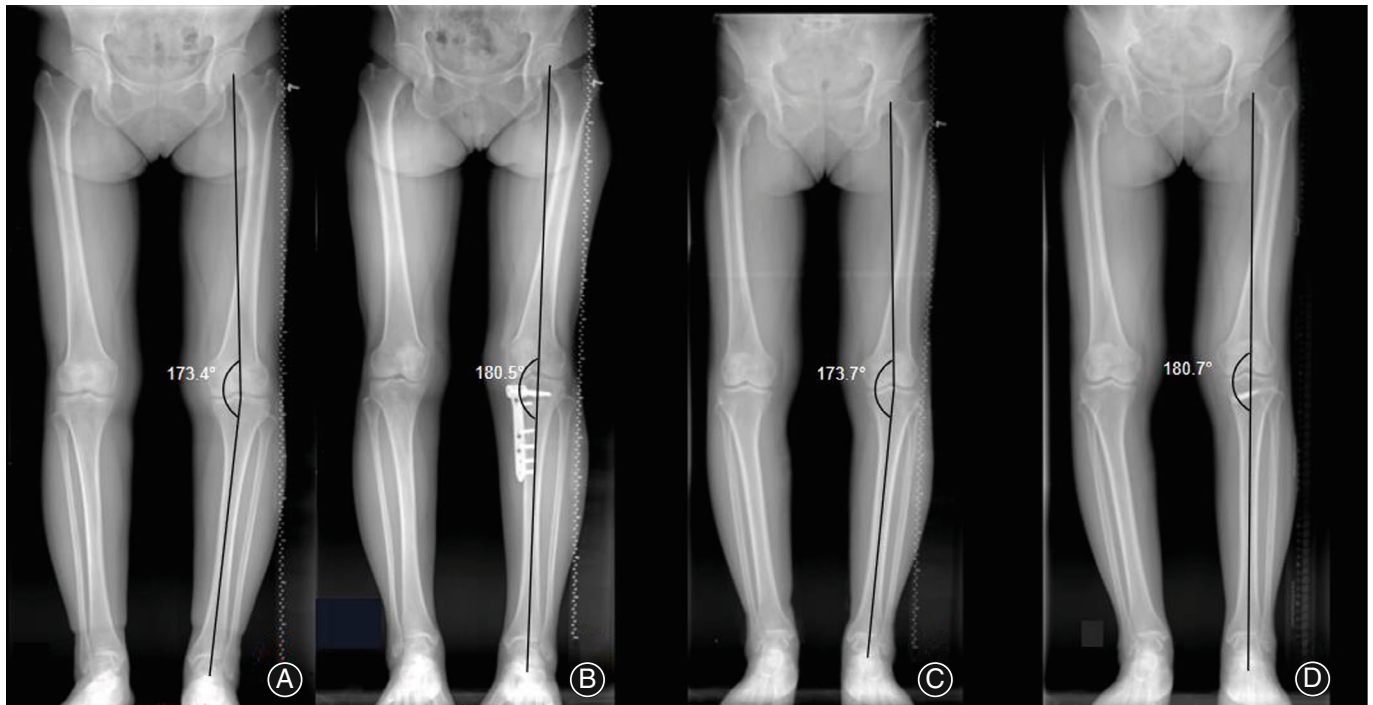
test or Fisher's exact test was used for categorical variables. A value of  $P < 0.05$  was considered statistically significant.

The interobserver and intraobserver reliabilities for TTP measurements were verified by the intraclass correlation coefficient (ICC). ICC values between 0.8 and 0.9 were considered good.

## Results

### Patient Characteristics

According to the inclusion and exclusion criteria of this study, 33 patients who underwent biplane tibial osteotomy with proximal tibial locking plate fixation were enrolled in



**Fig. 6** The two types of OWHTO procedures performed in this study are illustrated by full-length weight-bearing anteroposterior radiographs. (A, B) Biplane tibial osteotomy with proximal tibial locking compression plate fixation and preoperative and postoperative radiographs. (C, D) Uniplane tibial osteotomy with absorbable wedge-shaped spacer implantation and preoperative and postoperative radiographs

**TABLE 1** Comparison of demographic, radiological, and clinical parameters between the two groups

Parameters	Uniplane group (N = 38)	Biplane group (N = 33)	t/ $\chi^2$	p Values
Male:Female	7:31	6:27	0.001	0.979
Age (years)	58.8 ± 5.2	57.1 ± 5.0	-1.470	0.152
BMI (kg/m <sup>2</sup> )	27.2 ± 3.3	27.7 ± 3.1	0.700	0.486
TF KL grade 0/I/II/III/IV	0/0/23/15/0	0/0/24/9/0	—	0.322
PF KL grade 0/I/II/III/IV	13/21/4/0/0	14/17/2/0/0	—	0.676
Pre-op				
VAS	7.5 ± 1.1	7.2 ± 1.1	-1.250	0.394
SMC PF Pain Score	8.2 ± 5.3	7.8 ± 3.8	-0.382	0.704
SMC PF Function score	10.7 ± 4.6	9.8 ± 5.9	-0.704	0.484
Final follow-up				
VAS <sup>a</sup>	2.3 ± 0.9	2.3 ± 0.7	-0.166	0.727
SMC PF Pain Score <sup>a</sup>	19.4 ± 6.1	19.8 ± 5.9	0.278	0.782
SMC PF Function score	27.8 ± 7.0	32.1 ± 7.7	2.458	0.016

BMI, body mass index; KL, Kellgren-Lawrence; PF, patellofemoral; SMS, Samsung Medical Center; TF, tibiofemoral; VAS, visual analog scale.;  
<sup>a</sup> There was significant difference comparing with preoperative measurements/scores ( $p < 0.05$ ).

the biplane group (Figure 6A,B), and 38 patients who underwent uniplane tibial osteotomy with absorbable wedge-shaped spacer implantation were enrolled in the uniplane group (Figure 6C,D). The average follow-up periods were 34.9 months (range, 27–46 months) in the uniplane group and 33.0 months (range, 26–43 months) in the biplane group. All tibial osteotomy sites had healed at the 1-year follow-up evaluation. For all patients in this study, there were no complications, such as wound infection, breakage or

migration of the fixation device, paralysis of the common peroneal nerve, or tibial plateau fracture.

#### Clinical Outcomes

There was no significant difference ( $p > 0.05$ ) between the biplane and uniplane groups in any of the demographic and clinical characteristics at baseline (Table 1). The improvements in postoperative VAS scores from baseline were significant in both groups ( $p < 0.05$ ). However, patellofemoral pain and

function worsened postoperatively in both groups ( $p < 0.05$ ). At the final follow-up, no difference was found between the two groups regarding the VAS and SMC patellofemoral pain scores ( $t = 0.166$ ,  $p = 0.727$  and  $t = 0.278$ ,  $p = 0.782$ ), while the SMC patellofemoral function score was significantly lower in the uniplane group than in the biplane group ( $t = 2.458$ ,  $p = 0.016$ ; Table 1).

### Radiographic Outcomes

There was no significant difference ( $p > 0.05$ ) in preoperative radiographic parameters between participants in the biplane and uniplane groups. The improvements in postoperative HKA from preoperatively were significant in patients in both groups ( $t = 15.237$ ,  $p < 0.05$  and  $t = 20.922$ ,  $p < 0.05$ , respectively). For the PTS and TTP, patients in the biplane group postoperatively showed a significant difference compared with the preoperative value ( $t = 4.924$ ,  $p < 0.001$  and  $t = 8.156$ ,  $p < 0.001$ , respectively), while there were no significant changes in the uniplane group ( $t = 1.652$ ,  $p = 0.632$  and  $t = 1.645$ ,  $p = 0.069$ , respectively). Regarding changes in the CD, the mean values were decreased postoperatively compared with the preoperative values for patients in both groups ( $t = 6.161$ ,  $p < 0.001$  and  $t = 12.871$ ,  $p < 0.001$ ). For the BP index, the mean values were decreased postoperatively compared with the preoperative values for patients in both groups ( $t = 8.105$ ,  $p < 0.001$  and  $t = 15.169$ ,  $p < 0.001$ ). However, values decreased more for

**TABLE 3 Correlation coefficients of TTP measurements in the two groups**

	Uniplane group Intra- and Inter- observer CCs	Biplane group Intra- and Inter- observer CCs
Pre-op	0.89 and 0.88	0.86 and 0.84
Post-op	0.84 and 0.86	0.89 and 0.88

patients in the biplane group than for patients in the uniplane group (Table 2).

With respect to the intra- and interobserver reliability, excellent agreement was observed for both reliability measures for pre- and postoperative TTP (ICC values ranging from 0.84 to 0.89) (Table 3).

### Discussion

The most important finding of the present study was that uniplane osteotomy could maintain the prominence of the tibial tubercle, and it was associated with greater postoperative patella height and better patellofemoral function. We measured the position of the tibial tubercle on sagittal radiographs using TTP and found that, compared with the position after uniplane osteotomy, the tibial tubercle was shifted posteriorly after biplane osteotomy.

**TABLE 2 Descriptive and inferential statistics for sagittal radiographic parameters**

Parameters	Uniplane group (N = 38)	Biplane group (N = 33)	t	p Values <sup>a</sup>
Posterior tibial slope (°)				
Pre-op	13.0 ± 2.8	14.1 ± 2.9	1.367	0.123
Post-op	13.4 ± 2.7	16.6 ± 3.3	-4.465	<0.001
t	1.652	-4.924		
p values <sup>b</sup>	0.632	<0.001		
Tibial tubercle prominence (mm)				
Pre-op	9.2 ± 2.4	8.5 ± 2.4	-1.254	0.206
Post-op	9.0 ± 2.3	4.2 ± 2.5	7.950	<0.001
t	1.645	8.156		
p values <sup>b</sup>	0.069	<0.001		
Caton–Deschamps index				
Pre-op	0.89 ± 0.10	0.92 ± 0.13	1.181	0.311
Post-op	0.81 ± 0.10	0.70 ± 0.11	4.035	<0.001
t	6.161	12.871		
p values <sup>b</sup>	<0.001	<0.001		
Blackburne–Peel index				
Pre-op	0.79 ± 0.10	0.83 ± 0.11	1.608	0.067
Post-op	0.69 ± 0.11	0.66 ± 0.09	-1.265	0.256
t	8.105	15.169		
p values <sup>b</sup>	<0.001	<0.001		
Hip–Knee–Ankle (°)				
Pre-op	172.4 ± 2.7	173.1 ± 1.8	1.441	0.169
Post-op	180.7 ± 2.1	181.3 ± 2.4	1.177	0.243
t	-15.237	20.922		
p values <sup>b</sup>	<0.001	<0.001		

<sup>a</sup>Independent t-test.; <sup>b</sup>Paired t-test.

Whether a uniplane or a biplane opening wedge high tibial osteotomy is performed, the goal of the procedure is to transfer the mechanical load axis from the damaged medial compartment of the knee joint to the intact lateral compartment<sup>22</sup>. The postoperative HKA angles of the two groups at the 1-year follow-up in this study were equivalent ( $180.7^\circ$  vs  $181.3^\circ$ ,  $t = 1.177$ ,  $p = 0.243$ ), indicating that uniplane osteotomy with implantation of the novel spacer was able to achieve and maintain the target mechanical axis, similar to biplane osteotomy with plate fixation. Therefore, we consider this novel technique as an alternative option to the well-accepted biplane OWHTO with plate fixation for correcting varus deformities in medial compartmental knee OA. This is the key prerequisite for comparing the two techniques on the sagittal plane.

### **Sagittal Displacement of the Tibial Tubercle**

Although primarily indicated to correct the mechanical leg axis in the frontal plane, OWHTO has been described to unintentionally influence the sagittal plane after surgery. For example, there was a decrease in patellar height and PTS changes after HTO. PTS is a sagittal radiographic parameter mainly affecting the tibiofemoral joint, and it is related to the tibial resting position and the *in situ* forces of the cruciate ligaments<sup>23,24</sup>. A higher PTS influences anteroposterior translation, which may increase the strain experienced by the anterior cruciate ligament (ACL) and might pose a risk factor for noncontact ACL injuries<sup>25,26</sup>. The postoperative change in the PTS after OWHTO has been reported inconsistently in the literature<sup>27-30</sup>. However, small changes in the PTS showed no clinical or biomechanical significance<sup>24,31,32</sup>. In this study, the PTS after the biplane procedure was slightly increased by an average of  $2.3^\circ$  compared with preoperative values ( $t = -4.924$ ,  $p < 0.001$ ), similar to the findings in the previous study; meanwhile, as expected, a small change in the PTS was found after the uniplane procedure. Obviously, vertical osteotomy is the only difference between the two surgical procedures. When evaluating postoperative axial MRI in some patients, Suh *et al.* found a relationship between improper axial vertical osteotomy direction and increased PTS. They proposed that when vertical osteotomy is performed, the slope on the medial surface of the tibia tuberosity makes it difficult for the surgeon to undercut the tibial tuberosity because of the risk of sliding anteriorly during osteotomy<sup>9</sup>. This result provides significant evidence showing that uniplane osteotomy with absorbable spacer implantation is comparable or may be superior to biplane osteotomy with plate fixation in maintaining the relative position of the two ends of the osteotomy.

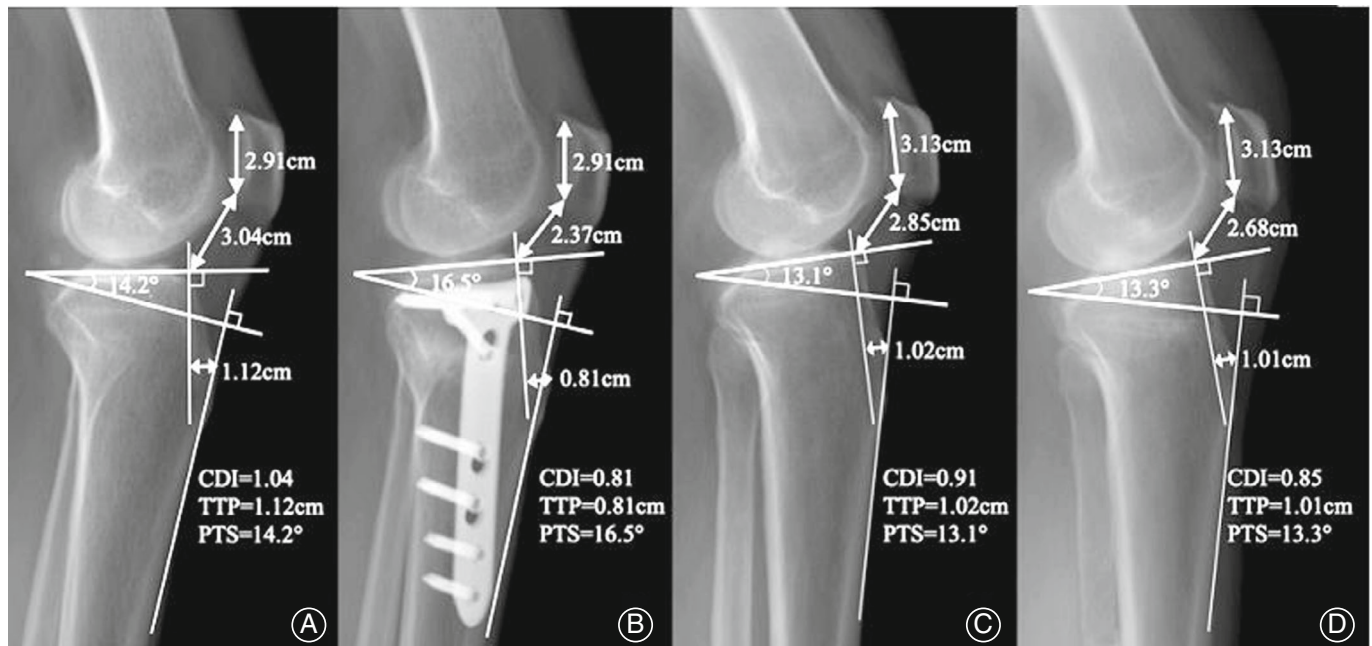
A decrease in PH results in patellofemoral osteoarthritis due to increased retropatellar cartilage pressure. On the sagittal plane, surgically induced descent of the tibial tubercle is a common problem of concern regarding the patellofemoral joint after either biplane ascending or uniplane OWHTO. An increased risk of patella baja has been previously reported<sup>33-35</sup>, and our results of decreased patella

height postoperatively were consistent with the literature. However, there is an essential difference between the biplane ascending osteotomy and the uniplane osteotomy, i.e. the posterior displacement of the tibial tubercle relative to the proximal fragment, which has not been described in publications. As illustrated in Figure 1, the oblique coronal cut of the biplane osteotomy ascends superoanteriorly; thus, the tibial tubercle moves inferoposteriorly along the cut when the proximal fragment is elevated; in contrast, the tibial tubercle is displaced downward more directly when the uniplane gap is spread. In other words, the tibial tubercle is not only shifted distally after biplane osteotomy but also shifted posteriorly relative to the proximal fragment, while the tibial tubercle is only shifted distally after uniplane osteotomy; this outcome may be the primary cause of the difference in postoperative TTP and PH between the two surgical methods.

To compare the different positions of the tibial tubercle after biplane and uniplane OWHTOs, we used tibial tubercle prominence (TTP) to evaluate the position of the tibial tubercle relative to the metaphysis on lateral radiographs. TTP was measured as the vertical distance from the most prominent point of the tibial tubercle to the perpendicular line of the tangent of the medial tibial plateau passing through the anterosuperior angle of the tibia outline (Figure 3). This definition incorporates multiple factors associated with the relative position of the two osteotomized fragments; hence, its measurement varies with the height of the osteotomy gap, the angle between the two osteotomy planes in the biplane procedure, change in the PTS, and rotation of the proximal metaphyseal part. Additionally, the measuring method for TTP showed good reproducibility (ICCs > 0.8). Therefore, we believe that TTP is an important and reliable index to compare changes on the sagittal plane between uniplane and biplane OWHTOs. In this study, the measurements of postoperative TTP in the uniplane group remained unchanged preoperatively ( $t = 1.645$ ,  $p = 0.069$ ), while those in the biplane group showed a significant decrease compared to preoperative values ( $t = 8.156$ ,  $p < 0.001$ ), and there was a significant difference in postoperative TTP measurements between the two groups ( $t = 7.950$ ,  $p < 0.001$ ). This intergroup difference was mainly related to the posterior displacement of the tibial tubercle in the biplane group. In addition, the minor increase in PTS in the biplane group could also be a contributor.

Furthermore, the difference in tibial tubercle displacement may cause a difference in patella displacement between the two groups. The tibial tuberosity shifted posteriorly relative to the proximal fragment after biplanar osteotomy, resulting in increased displacement of the patella. The BP index may underestimate the change in patella position because it only reflects the vertical component of the displacement of the patella and may be influenced by the tibial slope. The results of the BP index in this study did not reveal a significant difference in the postoperative intergroup comparison ( $t = -1.265$ ,  $p = 0.256$ ). Therefore, we agree with some authors that the BP index is not a reliable index to





**Fig. 7** Radiographs from one patient for each procedure illustrating changes in the posterior tibial slope (PTS), CD index (CDI), and tibial tubercle prominence (TTP). (A, B) Biplane tibial osteotomy with plate fixation before and after surgery; (C, D) Uniplane tibial osteotomy with spacer implantation before and after surgery

assess patella height after HTO<sup>36,37</sup>. Different from the BP index, the postoperative measurements of the CD index in patients in the biplane group were significantly lower than those in patients in the uniplane group ( $t = 4.035, p < 0.001$ ) (Table 2, Figure 7). We believe this is a more accurate evaluation of the real change in patella height because the numerator of the CD index is the straight line distance from the patella to the tibial plateau, which has an additional horizontal component compared to that of the BP index. This horizontal component, which is the main origin of the postoperative intergroup difference in the CD index, should not be ignored; moreover, it is closely related to the prominence of the tibial tubercle. Based on these reasons, we recommend using the CD index to evaluate the patella height after OWHTOs.

#### Functional Outcome of the Patellofemoral Joint

It was reported that a surgically induced decrease in patella height might result in anterior knee pain, patellofemoral arthrosis, and decreased range of motion<sup>38–40</sup>. Subsequent patellofemoral biomechanical modifications were also demonstrated in previous studies with the development of patella or trochlear OA in 41% of patients who underwent OWHTO<sup>17,41</sup>. Moreover, experimental and limited model investigations have demonstrated that the patellofemoral contact force and/or peak pressure decreases as the tubercle elevation increases<sup>42–46</sup>. Both the patella height (CD index) and the prominence of the tibial tubercle after the uniplane procedure were greater than those after the biplane

procedure in this study. In addition, clinical follow-up data showed that patients in the uniplane group had better patellofemoral function than those in the biplane group according to the SMC score (27.8 vs 32.1,  $t = 2.458, p = 0.016$ ). Therefore, we believe that the procedure of uniplane OWHTO with absorbable wedge spacer fixation results in less disturbance to the patellofemoral joint than the biplane procedure.

#### Limitations and Strengths

There are several limitations of the present study. First, it was not a randomized or prospective study. The two procedures were determined according to the surgeon's choice without any indication or randomized allocation. Second, measurements on plain X-ray images may not be accurate due to overlap. Studies including more patients with three-dimensional imaging should be performed in the future. Third, although the patients in the study were followed up for at least 2 years, a longer-term follow-up review will be required to clarify the status of the patellofemoral joint after HTO.

Despite these limitations, our study reported detailed radiographic outcomes at the 12-month follow-up and at least 2 years of clinical functional outcomes of a consecutive series of patients affected by the genu varum and surgically treated by OWHTO. Furthermore, we used TTP to evaluate the position of the tibial tubercle relative to the metaphysis on lateral radiographs and found that the tibial tubercle shifted posteriorly relative to the proximal tibia after biplanar

OWHTO, resulting in increased downward displacement of the patella, which is an innovation of this study.

### Conclusions

Compared to the popular biplane osteotomy with plate fixation, the procedure of uniplane osteotomy with absorbable wedge spacer implantation may be a better option for OWHTO considering its equivalent ability to correct the mechanical axis of the lower limb and uniplane osteotomy could maintain the prominence of the tibial tubercle to reduce disturbance of the patellofemoral joint. Further biomechanical studies are warranted to validate the influence of tibial tubercle prominence on patellofemoral mechanics.

### Author Contributions

**Y**i Zheng: Drafting the manuscript, data collection, data reduction, data analysis; Zhijie Wang: Data reduction;

Hongzhi Lv: Data analysis; Jinbo Li: Data analysis; Runqi Zhuo: Figure painting; Juan Wang: Overall thesis guidance.

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### Ethics Statement

Approval of the Ethics Committee of the Institutional Review Board (IRB) was obtained for this retrospective study (IRB number: 2020-001-1).

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