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New angle measurement device to control the posterior tibial slope angle in medial opening wedge high tibial osteotomy

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Abstract

Introduction Medial opening wedge high tibial osteotomy has been associated with an unintentional increase in the posterior tibial slope angle. We aimed to evaluate the effectiveness of a novel bone spreader angle rod to maintain the native posterior tibial slope angle in medial opening wedge high tibial osteotomy.

Materials and methods Data from 92 consecutive knees in 83 patients who underwent medial opening wedge high tibial osteotomy for knee osteoarthritis between March 2015 and June 2016 were analysed. The osteotomy was performed without the use of a bone spreader angle rod in the first 50 cases (control group) and with the use of the angle rod in the subsequent 42 cases (angle rod group). The wedge insertion angle, defined as the angle between a line drawn along the posterior aspect of the wedge spacer and a line tangential to the posterior aspect of the femoral condyles, and the posterior tibial slope angle were evaluated on pre- and postoperative lateral knee radiographs and postoperative computed tomography images.

Results Wedge insertion angle showed that wedge spacers were inserted in a more direct horizontal direction in the angle rod group than in the control group ($16.0 \pm 8.8°$ and $23.0 \pm 10.0°$, respectively, $P < 0.001$). The pre- to postoperative change in posterior tibial slope angle was significantly smaller in the angle rod group ($0.6 \pm 1.6°$) compared to that in the control group ($3.2 \pm 3.2°$; $P < 0.0001$). A change of posterior tibial slope angle > 3° (outlier) was identified in 1 case (2.4%) in the angle rod group compared to 27 cases in the control group (54.0%).

Conclusions The direct horizontal insertion of wedge spacers with the assistance of our novel bone spreader angle rod maintains the native posterior tibial slope angle better than conventional methods.

Level of evidence IV.

Keywords High tibial osteotomy · Posterior tibial slope · Wedge insertion angle · Osteoarthritis · Anterior cruciate ligament

Introduction

Medial opening wedge high tibial osteotomy (OWHTO) is indicated for relatively young, active individuals with knee osteoarthritis (OA) of the medial compartment with varus malalignment [1]. However, OWHTO has been associated with an unintentional increase in the posterior tibial slope angle (PTSA) [2–5]. Satisfactory outcomes after surgery require optimal realignment [6] both in the sagittal and coronal planes; poor realignment may lead to unsatisfactory clinical outcomes [7–11]. An increase in the PTSA produces an anterior translation of the tibial plateau with overloading of the anterior cruciate ligament (ACL) [12–17], which consequently may result in degradation of the articular cartilage and progression of knee OA [8, 11]. Thus, an unintentional change of the PTSA in OWHTO is a cause for concern, while an intentional change can be used in ACL- or PCL-deficient knees [15].

Song et al. [18] reported that a normal tibial posterior slope can be maintained with an anterior opening gap of approximately 67% of the posterior opening gap. This method is easy to use, but may not be sufficiently exact due to individual differences in the thickness and width of the unosteotomized tibial tuberosity. Thus, the exact change

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in the PTSA is hard to control using current techniques. Recently, it has been reported that the change in PTSA depends on the direction and position in which wedge spacers are inserted in the osteotomy gap, and that wedge spacers inserted directly horizontal would maintain the native PTSA [19]. Therefore, we developed a surgical instrument, a bone spreader angle rod, which assists surgeons in controlling the direction of the wedge spacer, thereby maintaining the native PTSA. We hypothesized that the use of our bone spreader angle rod would result in less unintentional decrease in the PTSA compared to that using conventional techniques without the angle rod [20]. The aim of the present study was to test this hypothesis, and establish a new angle rod-assisted technique to exactly control the change of the PTSA in OWHTO.

Methods

This study was approved by the institutional review board of our university and informed consent for the use of their medical information was obtained from all patients. Data from 92 consecutive knees in 83 patients (62 women and 21 men; mean age at the time of surgery, 63.0 ± 7.8 years; age range, 37–80 years) who underwent OWHTO for knee OA between March 2015 and June 2016 were analysed. The first 50 consecutive knees underwent OWHTO without the use of the bone spreader angle rod (control group), and the subsequent 42 cases underwent OWHTO with the use of the angle rod (rod group). All surgeries were performed by one of two surgeons (H.O. and K.M.). The clinical indications for OWHTO were the presence of medial compartment knee OA, with varus malalignment of the lower extremity. Exclusion criteria for OWHTO were the presence of severe OA of the patellofemoral joint, a flexion contracture of the knee more than 15°, and abnormal ligamentous laxity (insufficient anterior or posterior cruciate ligament).

Surgical procedures using a bone spreader angle rod

The preoperative planning and main surgical procedures have been previously described [19, 20]. Briefly, the target postoperative %weight-bearing line (%WBL) was set at 62.5% using Miniaci's method [19, 21]. Prior to OWHTO, an arthroscopic microfracture was performed at an articular cartilage lesion in all the patients. Then, the knee was extended and the lower leg was set horizontally, and a biplanar OWHTO was performed as in previously reported studies [22–24]. The osteotomy gap was carefully opened, and a bone spreader attached to a custom-made angle rod (Olympus Terumo Biomaterials, Tokyo, Japan) was inserted directly horizontal into the osteotomy gap to maintain the

opening gap with the knee extended and facing upward (Figs. 1a–d, 2a). Knee position was confirmed via an image intensifier and was maintained for the exact control of the bone spreader angle rod. The exact upright position of the angle rod with the knee facing upward was carefully confirmed from the viewpoint of the patients' feet by at least two surgeons (Fig. 2b). Two β-TCP wedge spacers (Osferion60, Olympus Terumo Biomaterials, Tokyo, Japan) were used for the initial axial and rotational stability at the osteotomy site [25] and were shaped to the size of the gap during surgery. The posterior part of the bone spreader was then detached (Fig. 2c), and the first wedge spacer was inserted into the posterior gap along the inserted bone spreader (Fig. 2d). Then, the remaining part of the bone spreader was removed, and the second wedge spacer was inserted into the anterior gap along the first wedge spacer (Fig. 2e, f). Finally, the medial osteotomy site was rigidly fixed using a Tris medial HTO Plate system (Olympus Terumo Biomaterials, Tokyo, Japan).

Based on the standard postoperative rehabilitation program, active and passive range of motion exercises were started on postoperative day 3, with partial weight-bearing initiated on postoperative day 7, progressing to full weight-bearing on postoperative day 14. All patients obtained full extension of the knee within 3 weeks postoperatively.

Radiographic evaluation

While patients stood with equal weight-bearing on both lower extremities, full-length anteroposterior (AP) radiographs, with the patella facing anteriorly, were obtained preoperatively and at 6 months postoperation. From the full-length AP radiographs, the %WBL was calculated as the horizontal distance from the WBL to the medial edge of the tibial plateau divided by the width of the tibial plateau [26, 27]. The hip–knee–ankle (HKA) angle, defined as the angle between the mechanical axes of the femur and the tibia (varus, negative values; valgus, positive values), was also measured on the full-length AP radiographs. The medial proximal tibial angle (MPTA) [28] defined as the angle between the tibial plateau and mechanical axis of the tibia, was measured on the AP radiographs of the knee. To ensure reproducibility of the MPTA, which is known to be sensitive to variation in the projection angle, the AP view of the knee was consistently obtained with the knee in full extension, with the centre of the joint aligned with the centre of the X-ray beam, and in a standardized position of the lower limb with the patella facing anteriorly [28]. A CT scan of the knee was obtained within 1 week after surgery. The wedge insertion angle (WIA) was defined as the angle between a line drawn along the posterior edge of the inserted wedge spacer and a line tangential to the posterior edge of the femoral condyles on the axial view (Fig. 3a, b). The

Fig. 1 Bone spreader angle rod. **a** The bone spreader angle rod attached to a bone spreader (Olympus Terumo Biomaterials, Tokyo, Japan) is shown, with a conventional bone spreader shown in the left upper panel. **b** The length of the angle rod is 25 cm. **c** Formal theory shows that a 1-cm shift in the angle rod tip in the projection from the patients' feet is indicative of a 2.3° inclination in the angle rod and bone spreader in the axial plane. **d** A lateral inclination of the tip of the angle rod is indicative of an increase in PTSA, with a medial inclination being indicative of a decrease in PTSA
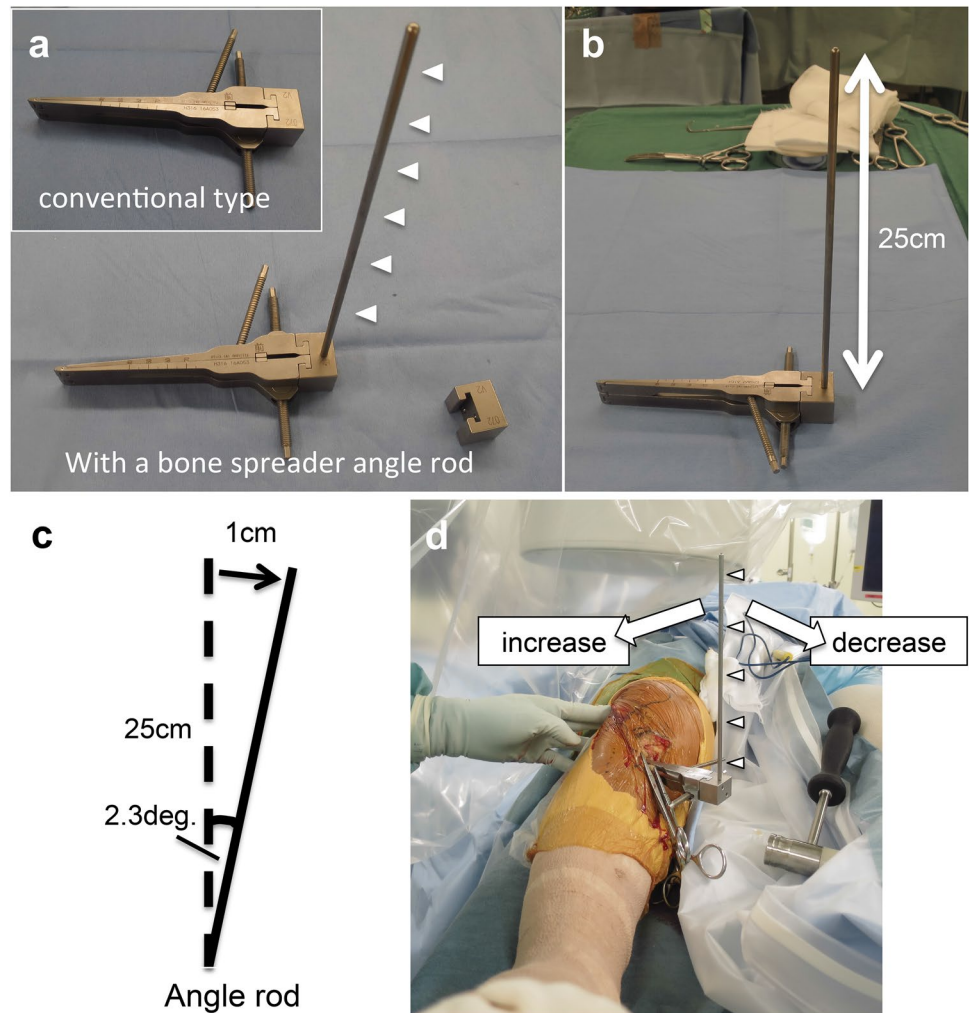
PTSA could then be defined for lateral radiographs of the knee as the angle between a line perpendicular to the posterior cortex of the tibia and the joint line of the proximal tibia (Fig. 3c). The change in PTSA (ΔPTSA) was calculated by subtracting the postoperative PTSA from the preoperative PTSA (ΔPTSA = postoperative PTSA − preoperative PTSA), with ΔPTSA values of > 3° judged as "outliers". Opening gap height on the CT coronal view and loss of correction on the AP radiographs were also assessed. Arthritic changes in the knee joint were evaluated using Kellgren–Lawrence (KL) grades.

Statistical analysis

All radiographic measurements were performed by two independent observers in a blinded manner. The intra- and inter-observer reliabilities were expressed as intra-class correlation coefficients (ICC), which varied from zero (no agreement at all) to one (total agreement). The values of the ICCs were characterized as follows: poor agreement (less than 0.40), fair to good agreement (0.40–0.75) and excellent agreement that is beyond chance (bigger than 0.75) [29].

Statistical comparisons were performed using SPSS version 13.0 software (SPSS Inc., Chicago, IL). Tests for normality and distribution were performed using the Kolmogorov–Smirnov test. Student's t tests and Mann–Whitney U tests were used to analyse parametric and non-parametric data, respectively. An F test was used to evaluate between-group differences in the distribution of WIA and ΔPTSA. A post hoc power analysis was conducted with use of G*Power (version 3.0.3) for the group comparisons. The level of significance was set at $p < 0.05$.

Results

Bone union of the osteotomy was obtained in all patients, and there were no delayed unions or required corrections in any of the cases during the follow-up period (mean, 16.2 ± 9.9 months). Evaluation of the severity of osteoarthritis in the medial compartment showed that 42 and 35 knees

Fig. 2 Wedge spacer insertion with the assistance of a bone spreader angle rod. **a** A bone spreader attached to an angle rod was inserted into the osteotomy gap with the knees facing upright under an image intensifier. **b** The upright angle rod is confirmed via the projection from the viewpoint of patients' feet by at least two surgeons, suggesting a direct horizontal insertion of the bone spreader. **c** The posterior part of the bone spreader is detached. **d** A wedge spacer is inserted along the directly horizontally inserted bone spreader. **e** The inserted wedge spacer is shown after removal of the bone spreader. **f** The second wedge spacer is inserted in the anterior gap along the first spacer
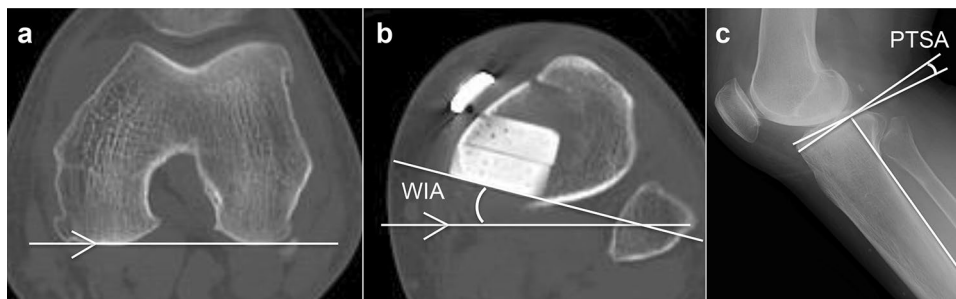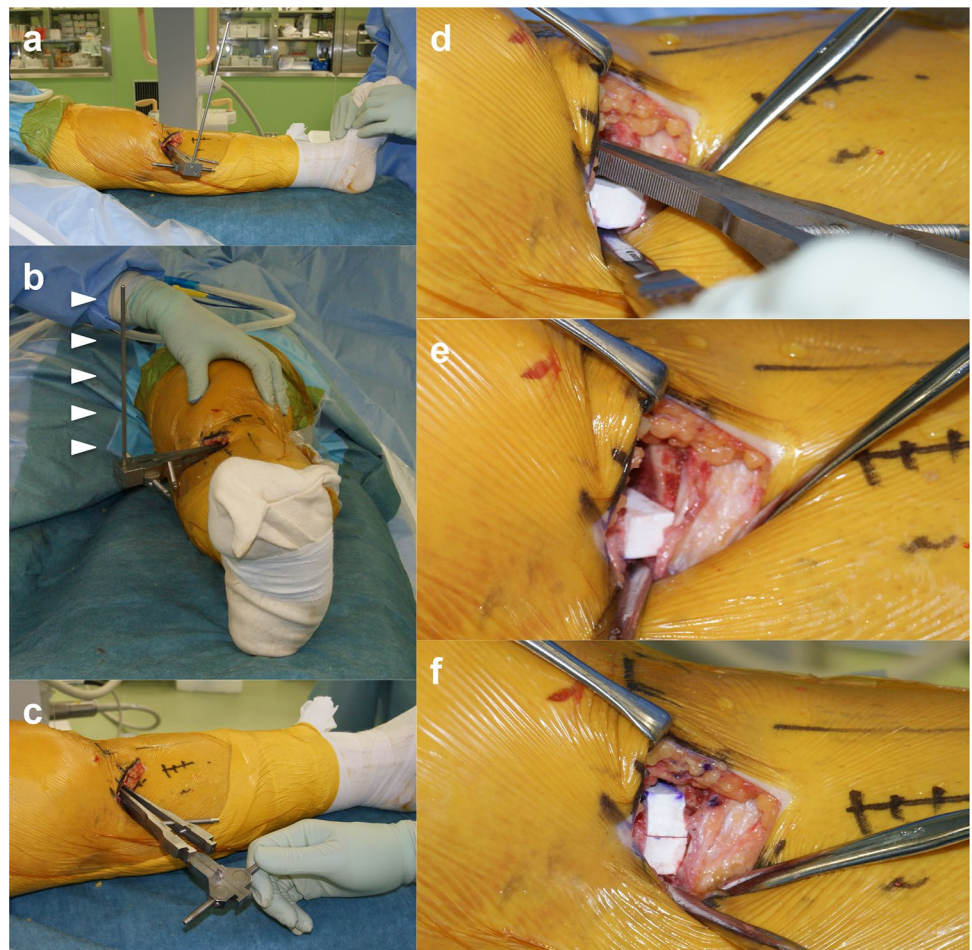

Fig. 3 Radiographic assessment. **a, b** The wedge insertion angle (WIA), defined as the angle between the direction of wedge insertion and a line tangential to the posterior edge of the femoral condyles on the axial view. **c** The posterior tibial slope angle (PTSA), defined as the angle between a line perpendicular to the posterior cortex of the tibia and the joint line of the proximal tibia on the lateral view

could be classified as KL grade 3, 8 and 7 as KL grade 4, in the control and angle rod groups, respectively. Radiographic measurements are summarized in Table 1. There were no significant between-group differences in preoperative and postoperative %WBL, HKA angle, MPTA, and opening gap height. There was no apparent loss of correction in any patient during the study period.

The WIA was significantly larger in the control group ($23.0 \pm 10.0°$) compared to that in the angle rod group

($16.0 \pm 8.8°$) ($P < 0.001$); however, the distribution of the WIA did not significantly differ between the groups ($F = 0.436$, Fig. 4). Although there was no significant group difference in the preoperative PTSA ($5.2 \pm 3.0°$, control group; $6.1 \pm 3.9°$, rod group; $P = 0.215$), the postoperative PTSA was significantly bigger in the control group ($8.4 \pm 3.9°$) than in the rod group ($6.7 \pm 3.9°$; $P = 0.034$). The ΔPTSA was consequently different between the two groups ($3.2 \pm 3.2°$, control group; $0.6 \pm 1.6°$, rod group; $P < 0.0001$),

Table 1 Radiographic parameters

		Control group ($N = 50$)	Angle rod group ($N = 42$)	P value
WBL%	Preop.	11.1 ± 19.1	15.8 ± 15.5	0.215
	Postop.	60.8 ± 9.4	59.1 ± 7.9	0.411
HKA angle (deg.)	Preop.	-8.7 ± 4.1	-7.6 ± 3.5	0.194
	Postop.	3.5 ± 2.0	2.6 ± 2.6	0.087
MPTA (deg.)	Preop.	84.8 ± 2.6	84.4 ± 2.9	0.537
	Postop.	94.0 ± 3.2	92.4 ± 3.8	0.079
WIA (deg.)		23.0 ± 10.0	15.2 ± 8.3	< 0.001
PTSA (deg.)	Preop.	5.2 ± 3.0	5.8 ± 3.9	0.408
	Postop.	8.4 ± 3.9	6.5 ± 4.0	0.027
ΔPTSA (deg.)		3.2 ± 3.2	0.6 ± 1.7	< 0.0001
Opening gap height (mm)		12.6 ± 2.9	11.6 ± 1.4	0.638

WBL weight-bearing line, *HKA* hip–knee–ankle, *MPTA* medial proximal tibial angle, *WIA* wedge insertion angle, *PTSA* posterior tibial slope angle
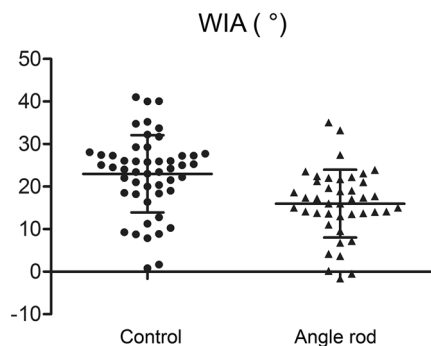

Fig. 4 Group differences in wedge insertion angle. The effect of the angle rod on the wedge insertion angle (WIA) is shown. The WIA is significantly lower in the angle rod group ($16.0 \pm 8.8°$) compared to that in the control group ($23.0 \pm 10.0°$; $P < 0.001$)

Fig. 5 Group differences in the posterior tibial slope angle. The effect of the angle rod on the posterior tibial slope angle (PTSA) is shown. The ΔPTSA is significantly lower in the angle rod group ($0.6 \pm 1.6°$) compared to that in the control group ($3.2 \pm 3.2°$; $P < 0.0001$). The incidence rate of outliers, defined by a ΔPTSA $> 3°$, is shown, with 1 case in the angle rod group (2.4%) compared to 27 cases in the control group (54%)

with a significant group difference in the distribution of ΔPTSA ($F = 0.00010$, Fig. 5). Outliers with a ΔPTSA $> 3°$ were identified in one case in the angle rod group (2.4%) compared to 27 cases in the control group (54%; Fig. 5). A post hoc power analysis (effect size, 0.5) revealed that the group comparison had a statistical power of 0.66.

The intra-class correlation coefficient (ICC) of the radiographic parameters is shown in Table 2. In all measurements, the ICCs were categorized as excellent.

Table 2 Intra-class correlation coefficient (ICC) of radiographic parameters

%	Intra-observer	Inter-observer
WBL%	0.98	0.95
HKA angle (°)	0.99	0.98
MPTA (°)	0.99	0.89
WIA (°)	0.95	0.94
PTSA (°)	0.92	0.90
Opening gap height (mm)	0.98	0.96

WBL weight-bearing line, *HKA* hip–knee–ankle, *MPTA* medial proximal tibial angle, *PTSA* posterior tibial slope angle

Discussion

The most important finding in the present study was that the unintentional decrease in the PTSA was less with the use of a bone spreader angle rod compared to that with conventional techniques. An adjustment in the direction of the wedge spacer with the assistance of a bone spreader angle rod exactly controlled the change in the PTSA, based on the
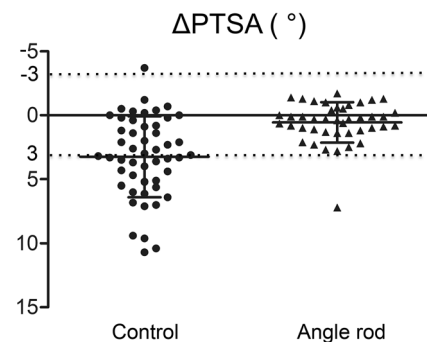
high correlation between the ΔPTSA and WIA as previously reported [19].

Previous studies have reported unintentional PTSA increases of 2.9–7.0° in OWHTO [4, 30, 31]. In the current study, a bone spreader angle rod assisted surgeons in inserting the wedge spacers more horizontally, resulting in less change in the native PTSA compared to that for conventional procedures without an angle rod. Previous studies have reported that an approximately 15° WIA is identical to a direct horizontal insertion of wedge spacers and preserves the native PTSA [19], which explains the ability of a bone spreader angle rod to assist surgeons in the exact direct horizontal insertion of the wedge spacers. With regard to the accuracy of the angle rod assistance, a 1-cm lateral shift of the tip of the 25-cm angle rod is indicative of an approximately 2.3° in the inclination of the bone spreader in the projection from the viewpoint of patients' feet (Fig. 1c). If the wedge spacer is inserted along the bone spreader within this 2.3° inclination, the change in the PTSA corresponds to an approximately 0.7°, according to a previously validated formula [19].

A close connection between the PTSA and loading on the ACL has been reported [14, 16]. Webb et al. reported the risk for ACL injury to be highest for a posterior tibial slope ≥ 12° [12, 14]. Because an increase in the PTSA can lead to an anterior translation of the tibial plateau and consequent overload on the ACL [12–17] and posterior tibial plateau [32–34], the native PTSA should be maintained to prevent OWHTO-related ACL injuries. Dejour et al. [15] reported satisfactory results for second-revision ACL reconstruction combined with a tibial deflexion osteotomy. The authors recommended correction of the tibial slope if it exceeds 12°, to reduce the risks of retearing the ACL graft. Thus, preserving the PTSA during OWHTO, particularly in cases with combined ACL reconstruction, is critical to reduce the risk of ACL re-injury. However, there are no established methods to accurately control the PTSA during OWHTO. The present findings confirm the utility of our bone spreader angle rod in this regard, with an increase in the PTSA of 0.7° for every 1-cm lateral inclination in the position of the tip of the rod, and a decrease in the PTSA of 0.7° for every 1-cm medial inclination of the rod (Fig. 1c, d). Therefore, the angle rod would also be useful for accurate control of intentional changes in the PTSA based on the native slope of the tibial plateau, balancing the sagittal plane of the knee, as well as the loading on the ACL and posterior cruciate ligament.

There are several limitations in the present study to acknowledge. (1) This was not a randomized control study and the follow-up period was short. It is unclear how a change in the PTSA after OWHTO influences long-term knee function, stability, range of motion, and mechanical strain on the cruciate ligaments. Thus, the long-term effects

of a change in the PTSA should be clarified. (2) The number of patients was relatively small, and the statistical power was 0.66. Thus, a randomized control study with a larger cohort of patients should be performed. (3) The reliability in the confirmation of the angle rod inclination is limited. However, confirmation of the angle rod inclination from the viewpoint of the patients' feet by two surgeons was shown to be adequate for the direct horizontal insertion of the wedge spacers. (4) The change in the PTSA may affect the correction angle in the coronal plane as well; therefore, the effect of the WIA on the coronal alignment of the lower extremity needs to be elucidated. (5) Although the direct horizontal insertion of the wedge spacers maintained the native PTSA in the present study, the relationship between different WIAs and the PTSA needs to be further clarified. (6) We only evaluated the PTSA in lateral radiographs. Thus, a three-dimensional analysis of the PTSA, using weight-bearing magnetic resonance imaging [35] is necessary.

Conclusion

OWHTO involves a risk of an increase in the PTSA due to inadequate surgical procedures, which may result in the degradation of the articular cartilage and progression of knee OA [8, 11]. The present results suggest that the direct horizontal insertion of wedge spacers, with the assistance of a bone spreader angle rod, maintains the native PTSA better than conventional methods.

Compliance with ethical standards

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