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Original article

Effect of increased posterior tibial slope on the anterior cruciate ligament status in medial open wedge high tibial osteotomy in an uninjured ACL population

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ABSTRACT

Purpose: The purpose of this study was to clarify the relationship between posterior tibial slope angle (PTSA) and anterior cruciate ligament (ACL) status in medial open wedge high tibial osteotomy (OWHTO). Our hypothesis was that even though OWHTO may improve anteroposterior laxity of the knee, an increase in PTSA after OWHTO would be associated with ACL degeneration.

Methods: Seventy-five patients treated with OWHTO were retrospectively analyzed. PTSA were evaluated radiographically pre- and postoperatively. The ACL was evaluated during the index arthroscopy at the time of OWHTO and a second-look arthroscopy during the plate removal, and scored from 1 (normal ACL) to 4 (complete tear). An anterior tibial translation (ATT) test was performed.

Results: The mean time period from the index to second-look arthroscopy was 15.0 ± 4.4 months. PTSA significantly increased from 5.3 ± 3.4° preoperatively to 7.5 ± 4.0° postoperatively ($p < 0.001$). The average ACL score significantly increased from 1.9 ± 0.5 at the index arthroscopy to 2.2 ± 0.5 at the second-look arthroscopy ($p = 0.0025$). The average ATT on the operated side significantly decreased from 7.1 ± 2.6 mm preoperatively to 5.3 ± 2.3 mm at the second-look arthroscopy ($p < 0.0001$). There was a significant positive correlation between the increase in PTSA and the change of ACL grade [correlation coefficient (r) = 0.221, $p < 0.05$].

Conclusion: Even though OWHTO reduces anteroposterior knee laxity, an increase in PTSA is associated with ACL degeneration. It is important for the surgeon to avoid an increase in PTSA during the intervention to prevent ACL degeneration after OWHTO.

Level of evidence: IV, therapeutic retrospective case series.

1. Introduction

The principle of medial open wedge high tibial osteotomy (OWHTO) involves the realignment of the lower extremity to shift the load distribution from the medial to the lateral compartment, thus decreasing symptoms of medial compartment knee osteoarthritis. However, this correction may unintentionally alter the posterior tibial slope angle (PTSA) [1]. Various studies report that the PTSA increases after OWHTO [2–6]. El-Azab et al. [7] reported that the PTSA increased after OWHTO because of the geometry of the proximal tibia. Rubino et al. [8] reported that larger axis corrections and anterior placement of the plate increased postoperative PTSA, whereas Ozalay et al. [9] demonstrated that PTSA increased in 50% of patients, decreased in 21%, and remained unchanged in 29%. During weight-bearing, every 10° increase in PTSA is associated with a 6 mm increase in anterior tibial translation [10]; thus, an unintentional increase in the PTSA during OWHTO could lead to an anterior translation of the tibial plateau [11–14] and consequently to increased strain on the anterior cruciate ligament (ACL), resulting in ACL degeneration. Various imaging-based studies of patients with non-contact ACL rupture versus control subjects have identified a high posterior tibial slope as a risk factor [15,16]. Thus, an increase in PTSA after OWHTO is believed to lead to an increased risk of ACL injury [13,17], and accurate control of the PTSA when performing OWHTO is recommended [2–4,7–9]. However, direct evidence about the exact relationship between OWHTO and ACL condition and function is scarce.

The purpose of this study was to perform an arthroscopic ACL evaluation, to measure anterior tibial translation and to radiographically assess PTSA before and after OWHTO to clarify the

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Table 1
Patient data ($n = 75$).

Parameter	Mean (range) or number ($n = 75$)
Age (years)	63.5 ± 7.8 (37–80)
Sex (female/male)	49/18
BMI	26.1 ± 4.0 (15.9–41.6)
Mean period from the index to second-look arthroscopy (months)	15.0 ± 4.4 (8–29)

BMI: body mass index; OWHTO: open wedge high tibial osteotomy.

relationship between PTSA and ACL condition and function. We hypothesized that even though OWHTO may improve anteroposterior laxity of the knee, an increase in PTSA after OWHTO would be associated with ACL degeneration.

2. Materials and methods

2.1. Study design

This retrospective study was approved by the institutional review board of our university (Gifu University, Graduate School of Medicine, Approval number: 27-100). Informed consent for the use of medical data was obtained from all patients. The study design and cohort were similar to a previously published paper [18]. All patients who had undergone OWHTO in our institution between October 2014 and August 2016 were eligible for study inclusion. The inclusion criteria were as follows: medial compartment knee osteoarthritis or spontaneous knee osteonecrosis with a non injured ACL, diagnosed via radiography and magnetic resonance imaging; impaired activities of daily living due to persistent knee pain despite after at least three months of conservative treatment; center of deformity at the proximal tibia; < 15° of flexion contracture; preoperatively calculated bony correction angle requirement of < 20°. The exclusion criteria were simultaneous ACL reconstruction at the time of OWHTO and no second-look arthroscopy at the time of plate removal.

A total of 79 consecutive patients underwent OWHTO during the study period. Based on the above criteria, three patients were excluded because of concomitant ACL reconstruction during OWHTO ($n = 3$) and one because no second-look arthroscopy was performed during plate removal ($n = 1$). Consequently, 75 knees of 67 patients were analyzed in this study. Patients' age, gender, body mass index, and the mean period from the index to second-look arthroscopy, are summarized in Table 1. The follow-up rate was 100%. At the time of plate removal, ACL degeneration, if present, was not treated.

2.2. Surgical technique and postoperative rehabilitation

The surgical technique and preoperative planning have been described previously [18]. In brief, the targeted mechanical tibiofemoral angle was 2°–3° of valgus. Prior to OWHTO, arthroscopic microfracture was performed in degenerated cartilage lesions. Thereafter, a biplanar medial open wedge high tibial osteotomy was performed, and the osteotomy was medially fixed with either a TOMOFIX plate (DePuy Synthes, Switzerland) or a Tris Medial HTO Plate System (Olympus Terumo Biomaterials Corp., Tokyo, Japan) using two beta-tricalcium phosphate wedge spacers (OSferion60, Olympus Terumo Biomaterials Corp., Tokyo, Japan). The plate was placed on the posteromedial aspect of the tibia. Patients were allowed partial weight-bearing at seven days postoperatively and full weight-bearing after 14 days.

2.3. Radiographic evaluation

Radiographic parameters, including the percentage of weight-bearing line (%WBL) [19], PTSA, and Kellgren-Lawrence (K-L) grades [20] were evaluated preoperatively and at the latest follow-up (Fig. 1). A true lateral radiograph was obtained for an accurate and reliable measurement of PTSA. The knee was placed in 45° flexion with the femoral condyles superimposed. PTSA was defined as the angle between a line tangential to the posterior cortex of the tibia and the joint line of the proximal tibia [21].

2.4. Arthroscopic ACL assessment

The ACL was arthroscopically graded on two occasions according to previous studies [18,22,23]: during the index arthroscopy at OWHTO and during the second-look arthroscopy at the time of plate removal. ACL condition was classified and scored as follows:

- normal ACL (nearly complete synovial coverage, 1 point);
- abnormal ACL (thinner than normal or sclerotic showing partial or absent synovial coverage, 2 points);
- partial tear (3 points);
- complete tear (4 points, Fig. 2).

If there was any increase in the ACL score from the index to the second-look arthroscopy, the cases were included in the progression group; if there was no progression, the cases were included in the steady group. We further differentiated patients into ACL low-grade group (normal and abnormal ACL) and ACL high-grade group (partial and complete tear). All surgeries were in video for ACL grading. Radiographic measurements and ACL grading were performed twice with a time interval of more than 24 hours, and the mean value of the two measurements was calculated. This was performed by two independent orthopaedic surgeons, and the mean value of the mean values obtained by the two surgeons was used as the final value.

2.5. Anterior tibial translation (ATT) test

The ATT test was performed with a KS Measure Arthrometer (SIGMAX MEDICAL, Tokyo, Japan) under general anesthesia in both knees at the index- and second-look arthroscopy according to a previously validated method [24]. The relative movement (in mm) between the patella and tibial tubercle sensor pads was recorded with 30 pounds at 30° knee flexion, which was confirmed with a goniometer. The same observer performed all tests to eliminate interobserver variability. Measurements were performed thrice, and the mean value of the three measurements was calculated. This was performed by two orthopaedic surgeons, and the mean values of the mean values obtained by the two surgeons was used as the final value.

2.6. Statistical analysis

Two independent observers performed all radiographic measurements and ACL grading in a blinded manner. The intra- and interobserver reliability of radiographic parameters and ACL grading were expressed as intra-class correlation coefficients (ICC; two-way mixed effects model) that varied from 0 (no agreement at all) to 1 (total agreement). Statistical comparisons were performed using SPSS (version 13.0; SPSS Inc., Chicago, IL). Student's *t*-test and Wilcoxon signed-rank test were used to analyze parametric and nonparametric data, respectively. Spearman's correlation analysis was used to assess the correlation between PTSA, the change in ACL grade from pre- to postoperatively, and ATT. A post-hoc power analysis for correlation analysis was performed to determine

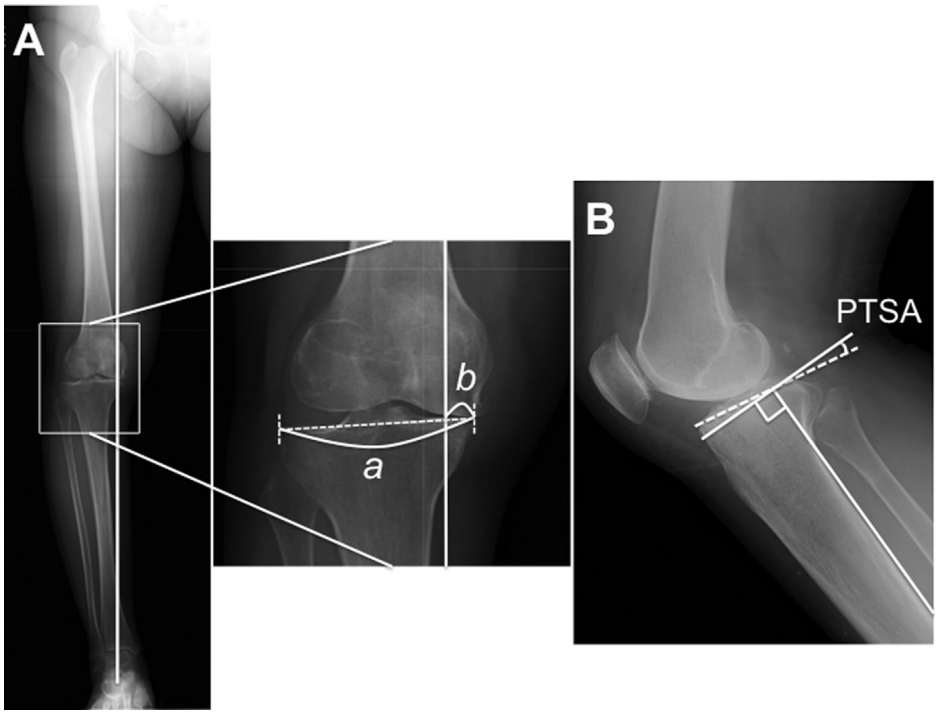

Fig. 1. Radiographic assessments. A. Percentage weight-bearing line (%WBL): %WBL is a percentage calculated by the formula of b/a × 100% on full-length standing antero-posterior radiographs of the lower extremity: a: width of the tibial plateau; b: horizontal distance from the WBL to the medial edge of the tibial plateau. B. Posterior tibial slope angle (PTSA): PTSA is defined as the angle between the line perpendicular to the posterior cortex of the tibia and the posterior inclination of the tibial plateau.

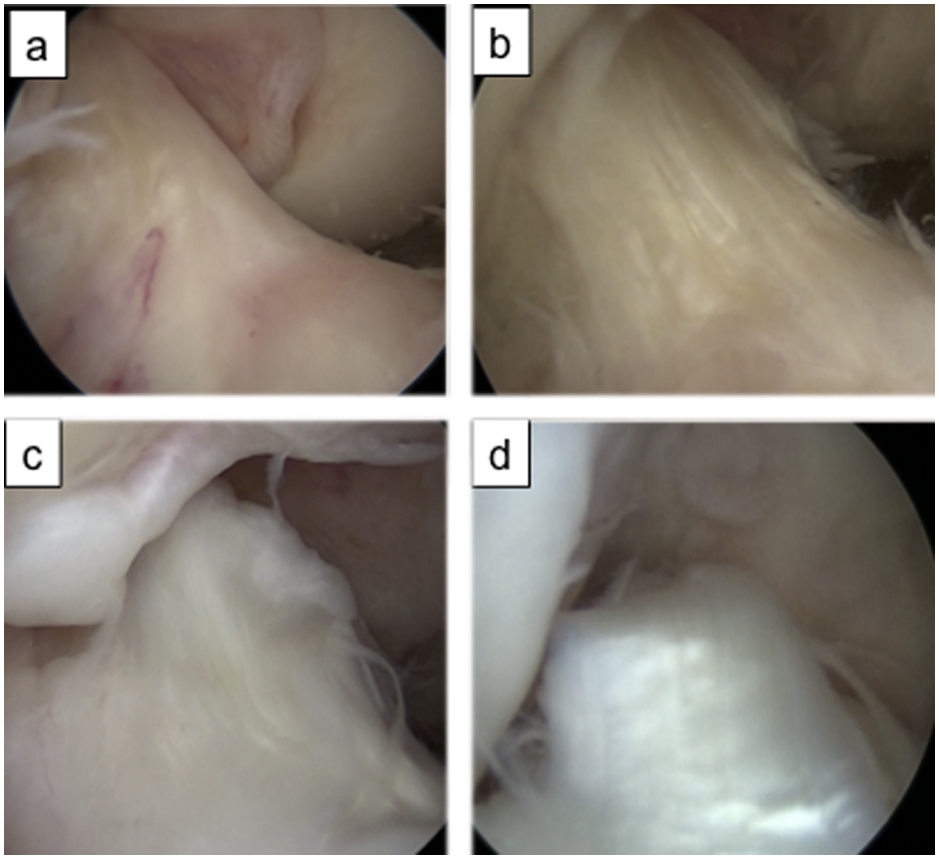

Fig. 2. Anterior cruciate ligament (ACL) staging score: a: normal ACL (nearly complete synovial coverage, 1 point); b: abnormal ACL (thinner than normal or sclerotic showing partial or absent synovial coverage, 2 points); c: partial tear (3 points); d: complete tear (4 points).

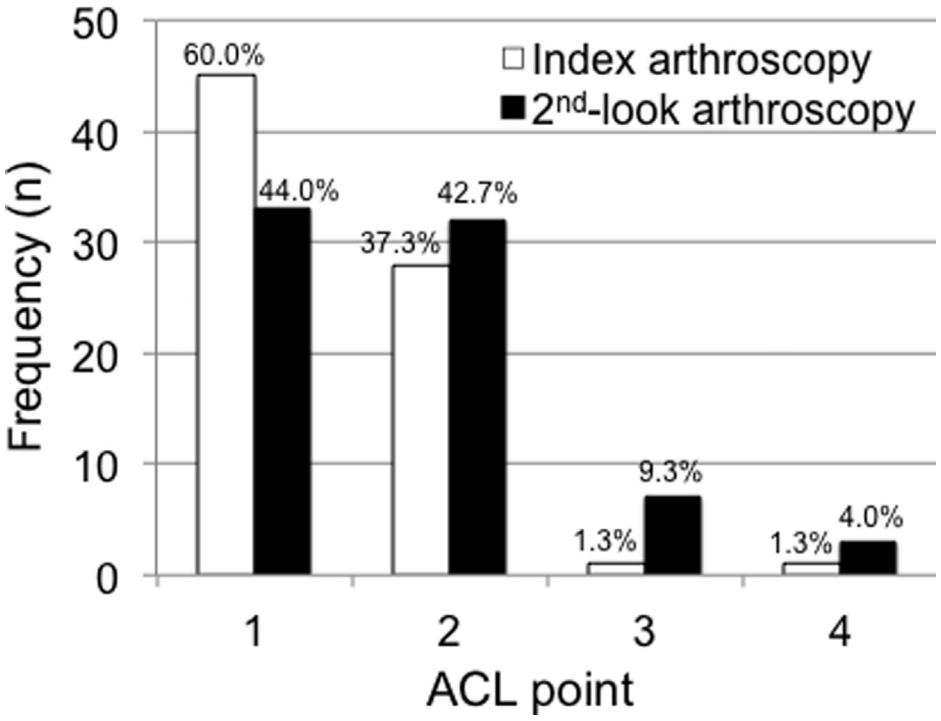

Fig. 3. Distribution of the anterior cruciate ligament (ACL) grade at the index and second-look arthroscopy (1 + 2 = low-grade: $n = 65$; 3 + 4 = high-grade: $n = 10$).

the statistical power using G*Power (version 3.0.3). The statistical power for the correlation analysis between ACL grade (points) and the radiographic parameters was 0.85 with an effect size of 0.3, alpha of 0.05, and sample size of 75. The significance level was set to $p < 0.05$ for all analyses.

3. Results

3.1. Radiographic evaluation

We obtained an inter- and intra-observer reliability greater than 0.92 and 0.90, respectively, for each radiographic measurement.

%WBL changed from 13.1 ± 18.7 (−45.0 to 50.0) preoperatively to 60.9 ± 7.8 (48.0–78.0) postoperatively ($p < 0.0001$).

PTSA significantly increased from 5.3 ± 3.4 (−3.4 to 10.8) preoperatively to 7.5 ± 4.0 (−2 to 14.8) postoperatively ($p < 0.001$).

3.2. Arthroscopic assessment of the ACL and ATT test

The inter- and intra-observer reliability for ACL grading was 0.98 and 0.97, respectively. The average ACL score significantly increased from 1.9 ± 0.5 at the index arthroscopy to 2.2 ± 0.5 at the second-look arthroscopy ($p = 0.0025$). Partial or complete ACL tear (3 or 4 points) were found in 10 cases (13.3%) (high-grade group) at the second-look arthroscopy as compared with two cases (2.7%) (low-grade group) at the index arthroscopy (Fig. 3).

To investigate the relationship between the increase in ACL grade from the index arthroscopy to the second-look arthroscopy and PTSA, the steady and progression groups were compared. The change in PTSA was significantly larger in the progression group than in the steady group ($p = 0.013$, Table 2). The average postoperative PTSA and the change in PTSA were significantly higher in the ACL high-grade group at the second-look arthroscopy than in the low-grade group ($p < 0.001$ for both, Table 3). The average ATT on the operated side significantly decreased from 7.1 ± 2.6 mm preoperatively to 5.3 ± 2.3 mm at the time of plate removal ($p < 0.0001$, Table 4). There was no significant difference in the extent of the change in ATT between the steady and the progression groups (Table 2). The average ATT was significantly higher in the ACL high-grade group at the second-look arthroscopy than in the low-grade group ($p < 0.05$, Table 3).

3.3. Correlation between the changes in PTSA and ACL grade

Spearman's correlation analysis showed a significant positive correlation between the change in PTSA after OWHTO and the change in ACL grade [correlation coefficient (r) = 0.221, $p < 0.05$, Fig. 4], but not with the change in ATT.

4. Discussion

The most important finding of the study was that an increase in PTSA was significantly correlated with ACL degeneration, even though OWHTO significantly improved anterior knee laxity, independently of PTSA. This finding confirmed our hypothesis.

Although several studies suggest a close relationship between increased PTSA and ACL degeneration, few studies have reported that increased PTSA induces ACL degeneration after OWHTO. In the current study, statistical analysis showed a significant positive correlation between an increase in PTSA and ACL degeneration. In addition, postoperative PTSA and the change in PTSA were significantly higher in the ACL high-grade group (partial and complete tear) than in the ACL low-grade group (normal and abnormal ACL). A biomechanical study by Giffin et al. showed that an increase in tibial slope results in an anteriorized tibial resting position [12], implying that a steeper PTSA after OWHTO increases the strain on the ACL due to anterior tibial translation. On the other hand, the average ATT in our study was significantly decreased after OWHTO and the change of ATT was not correlated to the increase in PTSA, which is consistent with a previous study showing OWHTO without ACL reconstruction improves knee laxity measured with an arthrometer similar to the one we used [25]. At the same time, postoperative ATT in our study was significantly higher in the ACL high-grade group than in the ACL low-grade group. Taken together,

Table 2
Comparison of the change in PTSA between the steady and progression groups of ACL grading.

	Steady group ($n = 45$)	Progression group ($n = 30$)	p-value*
ΔPTSA (°)	1.2 ± 3.8 (−1.7 to 9.4)	1.8 ± 2.4 (−3.7 to 10.4)	0.013
ΔATT at operated side (mm)	−1.8 ± 2.6 (−6.0 to 2.0)	−2.1 ± 2.5 (−8.0 to 2.0)	n.s.

ACL: anterior cruciate ligament; PTSA: posterior tibial slope angle; ATT: anterior tibial translation; Δ: the change from preoperative to postoperative values; n.s.: not significant.
* Paired *t*-test.

Table 3
Comparison of PTSA and ATT between ACL low- and high-grade groups at the second-look arthroscopy.

	ACL grade group at the second-look arthroscopy		p-value*
	Low ($n = 65$)	High ($n = 10$)	
Postoperative PTSA (°)	7.0 ± 3.8 (1.0–13.6)	10.9 ± 3.5 (3.3–16.0)	< 0.01
ΔPTSA (°)	1.8 ± 2.7 (−3.7 to 10.4)	4.6 ± 3.1 (−0.6 to 9.6)	< 0.01
Postoperative ATT at operated side (mm)	5.1 ± 2.1 (2.0–11.0)	6.6 ± 2.5 (3.0–13.0)	< 0.05

ACL: anterior cruciate ligament; PTSA: posterior tibial slope angle; ATT: anterior tibial translation; Δ: the change from preoperative to postoperative values; n.s.: not significant.
* Student's *t*-test comparing preoperative and postoperative values.

Table 4
Anterior tibial translation test at the index and second-look arthroscopy ($n = 75$).

	Index	Second-look	p-value*
Non-operated side (mm)	6.7 ± 2.5 (2.0–14.0)	6.2 ± 2.4 (2.0–13.0)	n.s.
Operated side (mm)	7.1 ± 2.6 (3.0–13.0)	5.3 ± 2.3 (2.0–13.0)	< 0.0001

n.s.: not significant.
* Student's *t*-test comparing preoperative and postoperative values.

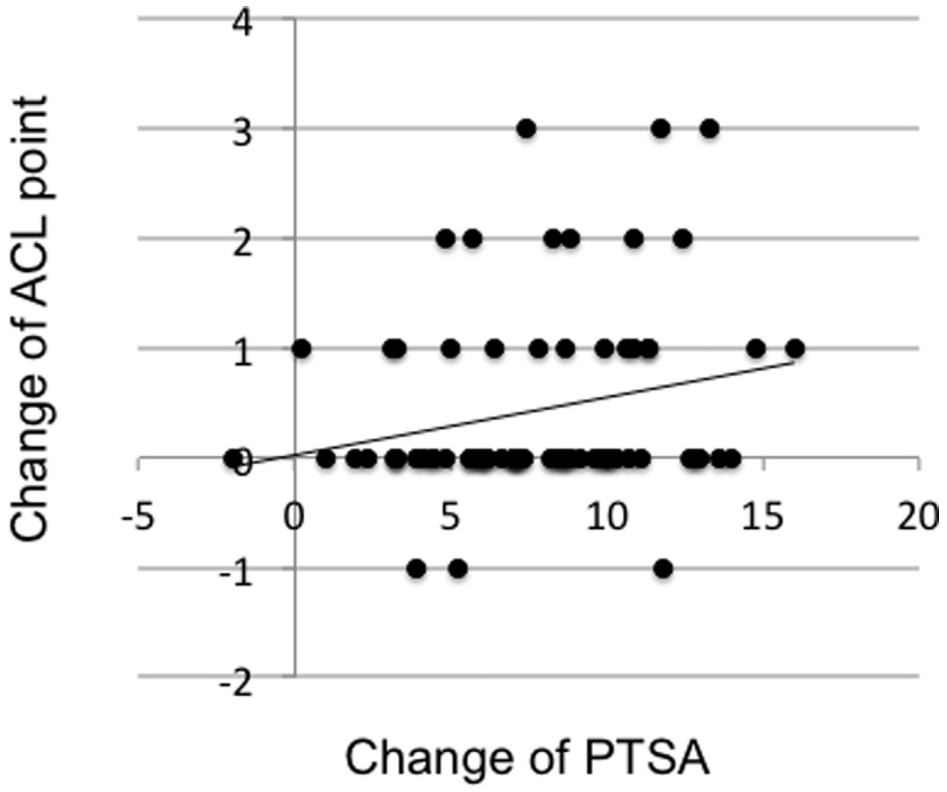

Fig. 4. Relationship between the change in anterior cruciate ligament (ACL) grade and the change in posterior tibial slope angle (PTSA) between the index and second-look arthroscopy.

it is suggested that anteroposterior knee laxity can be associated with increased PTSA caused by OWHT: however, the risk of partial or complete ACL tear increase as a result. Therefore, an increase in PTSA should be avoided in OWHTO to prevent ACL degeneration and control anteroposterior knee laxity.

It is theorized that decreasing PTSA minimizes the anteroposterior strain component on the ACL and joint contact forces. This may alleviate anterior instability symptoms in patients with chronic ACL deficiency. For this reason, OWHTO or lateral closed wedge high tibial osteotomy is an alternative option in patients with medial compartment osteoarthritis in whom ligament reconstruction does not always achieve favorable outcomes, such as the elderly and patients with low activity levels.

When assessing the effect of OWHTO on the ACL, the mediolateral component of the strain on the ACL may be as important as the anteroposterior component associated with PTSA. Recently, we reported that OWHTO reduces coronal tibiofemoral subluxation, which is a lateral subluxation of the proximal tibia relative to the distal femur seen during the progression of knee osteoarthritis, and that the reduction of coronal tibiofemoral subluxation correlates with the mechanical medial proximal tibial angle [18]. As a result of this reduction, the distance between the origin and the insertion of the ACL gets longer in the coronal plane; consequently, the mediolateral component of strain on the ACL might increase, resulting in ACL degeneration. The magnitude of change in the medial proximal tibial angle (MPTA) is correlated with ACL degeneration following OWHTO, using the same study design and patients cohort as documented in the Materials and methods section of this paper [18].

The current study shows the importance of PTSA on ACL degeneration in addition to MPTA. The exact relationship between MPTA, PTSA, and ACL degeneration warrants further investigation.

There are several limitations to this study. The study period was short; the influence of the change in PTSA and ACL status should be investigated in the long-term. The effect of ACL degeneration after OWHTO on the clinical outcome remains unclear, particularly with respect to the clinical relevance of the loss of synovial coverage, which was a prominent finding in the cases with increased PTSA. Although an ACL classification similar to the one used in this study has been published [18,22,23], it needs to be validated. The influence of meniscectomy on ACL degeneration was not investigated in this study; however, meniscectomy may be associated with ACL degeneration because medial meniscectomy increase the ACL loading [26]. The influence of meniscectomy performed during OWHTO on ACL degeneration should be investigated. In the current study, anteroposterior laxity was measured in the supine position; the measurement of anteroposterior laxity in the standing position may be clinically more important. Finally, the measurement of PTSA using plain radiography is controversial [27]; computed tomography would have been a more reliable method.

5. Conclusion

OWHTO could increase PTSA, which leads to ACL degeneration postoperatively. It is therefore important for surgeons to avoid an increase in PTSA during the procedure to prevent ACL degeneration after OWHTO. In addition, preventing an increase in PTSA may also be important to maintain anteroposterior laxity.

Disclosure of interest

The authors declare that they have no competing interest.

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No funding was received for this study.

Authors' contribution

Hiroyasu Ogawa: designing the study, collecting and analyzing the data, drafting and revising the manuscript.

Kazu Matsumoto: collecting and analyzing the data, drafting the paper.

Haruhiko Akiyama: drafting the manuscript.

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