



ACL degeneration after an excessive increase in the medial proximal tibial angle with medial open wedge high tibial osteotomy

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Abstract

Purpose This study examined the influence of the mechanical medial proximal tibial angle (MPTA) on anterior cruciate ligament (ACL) degeneration following open wedge high tibial osteotomy (OWHTO). It was hypothesised that an excessive increase in MPTA would be associated with ACL degeneration following OWHTO.

Methods Seventy-four knees treated with OWHTO were retrospectively examined. Arthroscopic ACL grading [0 (intact) to 4 (complete rupture)], anterior tibial translation (ATT) test at the time of OWHTO with the index arthroscopy and at plate removal with the second-look arthroscopy, clinical assessments using the Knee Society Score (KSS), and radiographic evaluations of MPTA were performed. The relationship between MPTA and the ACL condition was analysed using Spearman's correlation.

Results The time from the index arthroscopy to the second-look arthroscopy was 15.0 ± 4.4 months; the total follow-up was 31.0 ± 6.5 months. ACL grade significantly increased from 0.6 ± 0.8 (index arthroscopy) to 1.1 ± 1.2 (second-look arthroscopy) ($p < 0.0018$). 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 ($p < 0.001$). No significant difference was observed in KSS for ACL grades in the steady and progression groups. Changes in MPTA from the preoperative to postoperative period were significantly higher in the progression group ($p = 0.0155$). Changes in ACL grades were significantly correlated with preoperative MPTA and changes in MPTA ($r = -0.365$ and 0.343 , respectively; $p < 0.01$).

Conclusions Excessively increased MPTA led to ACL degeneration following OWHTO. ACL degeneration was not associated with short-term clinical outcomes. Excessive correction of MPTA should be avoided to prevent ACL degeneration following OWHTO.

Level of evidence Therapeutic case series, Level IV.

Keywords Medial proximal tibial angle · Anterior cruciate ligament · High tibial osteotomy · Knee Society Score · Anterior tibial translation

Introduction

Medial open wedge high tibial osteotomy (OWHTO) is associated with an unintentional increase in the posterior tibial slope angle (PTSA) [6, 13, 19, 20, 22, 25]. An

unintentional increase in PTSA could lead to the anterior translation of the tibial plateau [1, 10, 15, 27]. This could increase the strain on the anterior cruciate ligament (ACL), resulting in ACL degeneration. Because ACL dysfunction is considered to be one of the risk factors for knee osteoarthritis [7], appropriate control of the PTSA could be important for the long-term success of OWHTO. However, recently, it has been reported that OWHTO reduces coronal tibiofemoral subluxation, which is lateral subluxation of the proximal tibia relative to the distal femur during progression of knee osteoarthritis, and that coronal tibiofemoral subluxation is correlated with the mechanical medial proximal tibial angle (MPTA) [4, 24]. When reducing the lateral coronal tibiofemoral subluxation in

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OWHTO, the distance between the origin and the insertion of the ACL increases in the coronal plane; consequently, the medial–lateral component of the strain on the ACL might increase, resulting in ACL degeneration. However, the influence of MPTA on ACL degeneration following OWHTO has not been investigated. Therefore, this study was designed to analyse the relationship between MPTA and ACL conditions following OWHTO. This clarification could provide knowledge about a permissible range of MPTA in OWHTO from the point of view of the ACL condition. It was hypothesised that an excessive increase in MPTA would be associated with ACL degeneration following OWHTO.

Materials and methods

This retrospective study was approved by the institutional review board of Gifu University Graduate School of Medicine (No. 27–100). Written informed consent for participation in the study was obtained from all patients. Patients who had undergone OWHTO at our institution between October 2014 and August 2016 were eligible for study inclusion. The surgical indications were as follows: medial compartment knee osteoarthritis or spontaneous osteonecrosis of the knee diagnosed via radiography and magnetic resonance imaging; impaired performance of activities of daily living due to persistent knee pain after at least 3 months of conservative treatment; presence of the centre of the deformity around the proximal tibia; $< 15^\circ$ of flexion contracture; and a bony correction angle requirement of $< 15^\circ$, as calculated preoperatively. The exclusion criteria were complete rupture of the ACL at the index arthroscopy and a lack of second-look arthroscopy evaluations.

Surgical technique and postoperative rehabilitation

The surgical technique and preoperative planning used in the present study were described previously [23]. The postoperative mechanical axis was designed to pass across the knee at the Fujisawa point (a point at 62.5% of the cross-sectional diameter of the tibial plateau) according to Miniaci's method [9, 18]. Before the OWHTO, arthroscopic microfracture surgery of the knee was used to treat articular cartilage lesions in all patients. The biplanar OWHTO was internally fixed with a TomoFix osteotomy system (DePuy Synthes, Zuchwil, Switzerland) or Tris medial HTO plate system (Olympus Terumo Biomaterials, Tokyo, Japan) with two β -tricalcium phosphate wedge spacers (Osferion60, Olympus Terumo Biomaterials) [14,

30, 31]. The length of the posterior aspect of the medial gap was recorded.

Patients were allowed partial and full weight-bearing on postoperative days 7 and 14, respectively.

Clinical evaluation

Preoperative patient data, including age, sex, and Body Mass Index (BMI), were recorded. Clinical outcomes were evaluated using the Knee Society Score (KSS; total knee score, and total function score) preoperatively and at the latest follow-up examination.

Arthroscopic assessment of ACL

The ACL was arthroscopically graded according to the original ACL grading system created by the authors that ranged from 0 to 4 points (Fig. 1) during the index arthroscopy at OWHTO and during the second-look arthroscopy at the time of plate removal.

Anterior tibial translation test

The anterior tibial translation (ATT) test was performed with a KS Measure Arthrometer (Sigmax Medical, Tokyo, Japan) under general anaesthesia during the index arthroscopy and second-look arthroscopy according to a previously validated method [17]. The relative movement between the patella and tibial tubercle sensor pads was recorded with 30 pounds at 30° of flexion, which was confirmed with a goniometer. One observer performed all of the tests to eliminate interobserver variation. Measurements were performed three times, and the mean value of the three measurements was used.

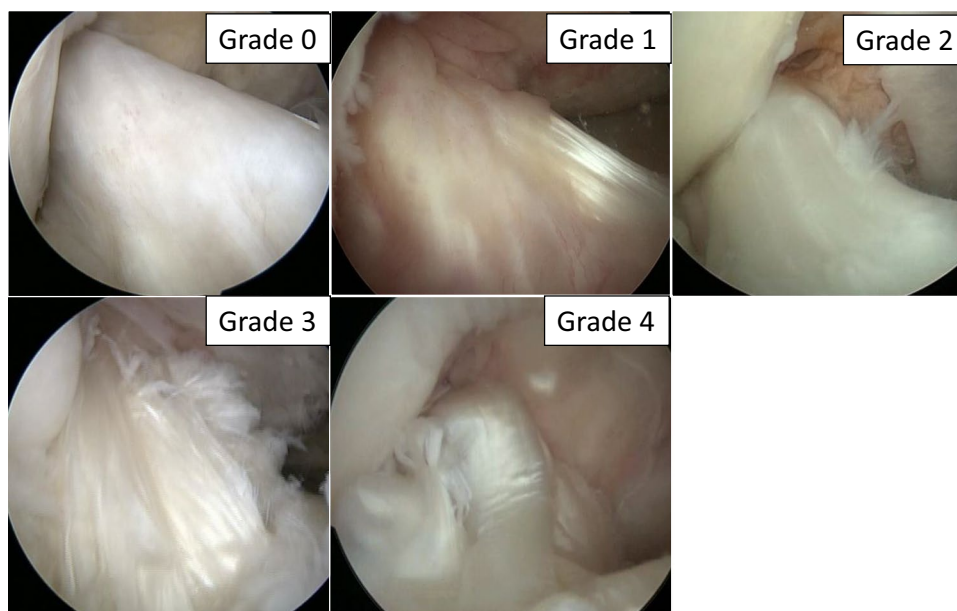
Radiographic evaluation

Radiographic parameters, including the percentage of the weight-bearing line (%WBL) [9], MPTA, and Kellgren–Lawrence (K-L) grades [12], were evaluated preoperatively and at the latest follow-up (Fig. 2).

Statistical analysis

Two independent observers performed all radiographic measurements twice with an interval of more than 1 day in a blinded manner. The intra-rater and inter-rater reliabilities for determining the radiographic parameters, ACL grade, and ATT test results were expressed as intraclass correlation coefficients (ICC; two-way mixed effects model) that varied from 0 (no agreement) to 1 (total agreement). Statistical comparisons were performed using SPSS version 13.0 (SPSS Inc., Chicago, IL). Tests to determine normality and distribution were performed using the Kolmogorov–Smirnov

Fig. 1 The anterior cruciate ligament (ACL) grading system. The condition of ACL consists of 5 grades from 0 to 4. Grade 0: intact ACL, Grade 1: partial loss of synovial coverage, Grade 2: complete loss of synovial coverage, Grade 3: partial substance rupture, Grade 4: complete substance rupture



Grade	ACL condition
0	Intact
1	Partial loss of synovial coverage
2	Complete loss of synovial coverage
3	Partial rupture of the substance
4	Complete rupture of the substance

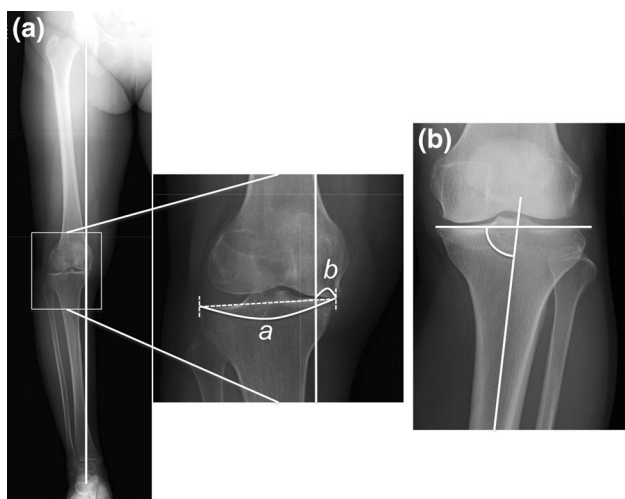


Fig. 2 Radiographic assessments. %Weight-bearing line (%WBL): %WBL is a percentage calculated by the formula $b/a \times 100\%$ on full-length standing anteroposterior radiographs of the lower extremity (a). a: width of the tibial plateau, b: horizontal distance from WBL to the medial edge of the tibial plateau. Mechanical medial proximal tibial angle (MPTA): MPTA is defined as the angle between the tibial plateau and the tibial mechanical axis (b)

test. Student's *t* test was used to analyse parametric data. Spearman's correlation analysis was used to assess the correlation between MPTA and the changes in the ACL grade and ATT. A post hoc power analysis for correlation was performed using G*Power version 3.0.3 to determine the statistical power. The statistical power for the correlation analysis between the ACL grade and the radiographic parameters was 0.85, with an effect size of 0.3, an alpha of 0.05, and a sample size of 75. The significance level was set at $p < 0.05$ for all analyses.

Results

Of 79 consecutive OWHTO from October 2014 to August 2016, 5 were excluded because of complete rupture of the ACL at the index arthroscopy ($n = 4$) and the absence of plate removal concomitant with second-look arthroscopy ($n = 1$). Consequently, 74 knees of 67 patients were analysed during this study. The mean period from the index arthroscopy to the second-look arthroscopy was 14.9 ± 4.5 months (range 8–29 months), and the mean total follow-up period was 30.0 ± 6.5 months (range 20–46 months). Age, sex,

Table 1 Patient data (n = 74)

Parameter	Mean ± SD (range)
Age (years)	63.5 ± 7.8 (37–80)
Sex (female/male)	53/21
BMI (kg/m ²)	26.2 ± 4.1 (15.9–41.6)
Opening gap at the osteotomy site (mm)	11.6 ± 2.7 (6–17.4)

BMI Body Mass Index, SD standard deviation

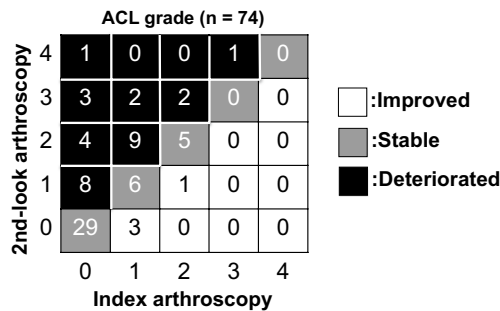


Fig. 3 Distribution of the anterior cruciate ligament (ACL) grade at the index and second-look arthroscopies

BMI, and opening gap at the osteotomy site of the patients are summarised in Table 1.

Arthroscopic assessment of the ACL and ATT test

There was no history of any trauma related to the ACL injury for all patients during the study period. The average

ACL grade significantly increased from 0.6 ± 0.8 at the index arthroscopy to 1.1 ± 1.2 at the second-look arthroscopy (p = 0.0018). Severe grades of 3 and 4 for partial or complete ACL rupture were found in 9 cases (12.2%) at the second-look arthroscopy compared to one case (1.4%) at the index arthroscopy (Fig. 3). The knees for which the ACL grade increased from the index arthroscopy to second-look arthroscopy by at least one grade (progression group) were compared with knees with no such noted increase (steady group). Although there was no significant difference in the average ACL grade at the index arthroscopy [not significant (NS)], the average ACL grade of the progression group was significantly higher than that of the steady group at the second-look arthroscopy (p < 0.0001) (Table 2). The inter-rater and intra-rater reliability for ACL grading were 0.98 and 0.97, respectively. 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); however, no such decrease was noted on the non-operated side (Table 3). There was no significant difference in the change in ATT on the operated side between the preoperative and postoperative periods (NS) or between the steady and progression groups (NS) (Table 2). The intra-rater reliability for the ATT test was 0.92.

KSS

Overall, the KSS (both total knee score and total function score) significantly improved postoperatively (p < 0.0001 for each). However, there was no significant difference in the

Table 2 Comparison of parameters of the steady group and progression group

	Steady group (n = 44) Mean ± SD (range)	Progression group (n = 30) Mean ± SD (range)	p value*
ACL grade			
Index arthroscopy	0.5 ± 0.7 (0–2)	0.6 ± 0.8 (0–3)	NS
Second-look arthroscopy	0.4 ± 0.7 (0–2)	2.1 ± 0.9 (1–4)	< 0.0001
ΔMPTA (°)	8.2 ± 3.0 (5–14.4)	10.0 ± 3.1 (5.1–16.6)	< 0.05
ΔATT on the operated side (mm)	-1.7 ± 2.2 (-6–2)	-2.2 ± 2.9 (-8–2)	NS

ACL anterior cruciate ligament, ΔMPTA change in the medial proximal tibial angle from the preoperative period to the postoperative period, ΔATT change in anterior tibial translation from the index arthroscopy to the second-look arthroscopy, NS not significant

*Paired t test

Table 3 ATT test performed at the index arthroscopy and second-look arthroscopy (n = 74)

	Index Mean ± SD (range)	Second-look Mean ± SD (range)	p value*
Non-operated side (mm)	6.6 ± 2.5 (3–14)	6.2 ± 2.4 (2–13)	NS
Operated side (mm)	7.1 ± 2.6 (2–14)	5.3 ± 2.3 (2–13)	< 0.0001

ATT anterior tibial translation, NS not significant

*Student’s t test comparing preoperative and postoperative values

Table 4 Knee society score (KSS)

	Overall ($n = 74$), Mean \pm SD (range)		p value
Total knee score (out of 100)			
Preoperative	60.0 \pm 15.8 (15–89)		
Latest follow-up	97.1 \pm 3.5 (90–100)		<0.0001*
Total function score (out of 100)			
Preoperative	64.0 \pm 20.1 (0–100)		
Latest follow-up	90.0 \pm 12.8 (40–100)		<0.0001*
	Steady group ($n = 44$) Mean \pm SD (range)	Progression group ($n = 30$) Mean \pm SD (range)	
Total knee score at the latest follow-up (out of 100)	96.8 \pm 3.5 (90–100)	97.5 \pm 3.6 (90–100)	NS**
Total function score at the latest follow-up (out of 100)	93.3 \pm 8.2 (80–100)	91.9 \pm 10.1 (70–100)	NS**

KSS values are presented as mean \pm SD

NS not significant

*Comparing the preoperative and latest follow-up values

**Comparing the steady group and progression group

Table 5 Correlation between Δ ACL grade and MPTA

	Correlation coefficient (r)	p value
Preoperative MPTA	-0.365	<0.01
Postoperative MPTA	0.008	NS
Δ MPTA	0.343	<0.01

ACL anterior cruciate ligament, Δ ACL change in ACL grade from the index arthroscopy to the second-look arthroscopy, MPTA medial proximal tibial angle, Δ MPTA change in MPTA from the preoperative value to the postoperative value, NS not significant

scores of the steady group and progression group at the latest follow-up (NS) (Table 4).

Radiographic evaluation

The %WBL significantly improved from 13.1 \pm 18.7% (range -45–48%) preoperatively to 60.9 \pm 7.8% (range 44–79%) at the latest follow-up ($p < 0.0001$). MPTA significantly increased from 84.6 \pm 2.8° (range 77.9°–91.9°) preoperatively to 93.5 \pm 3.3° (range 86.5°–100.9°) postoperatively ($p < 0.001$). Moreover, the change in MPTA from the preoperative to postoperative period (Δ MPTA) was significantly higher in the progression group than in the steady group ($p = 0.0155$) (Table 2). There was no significant difference in KL grades for the medial compartment of the knee at the index arthroscopy (3.1 \pm 0.6) and at the second-look arthroscopy (3.1 \pm 0.8) (NS). Inter-rater reliability more than 0.92 and intra-rater reliability more than 0.89 were obtained for the radiographic measurements.

Correlation of change in the ACL grade and MPTA

Spearman's correlation analysis showed a significant correlation between the change in the ACL grade (Δ ACL grade) and preoperative MPTA ($r = -0.365$; $p < 0.01$) and Δ MPTA ($r = 0.343$; $p < 0.01$), but not with postoperative MPTA (NS) (Table 5).

Discussion

The most important finding in this study was that an increase in MPTA was significantly correlated with ACL degeneration following OWHTO. In addition, anteroposterior stability of the tibia significantly increased after OWHTO regardless of MPTA.

Information regarding the influence of OWHTO on ACL is limited. Some biomechanical studies showed that an increase in PTSA can be a major risk factor for ACL rupture [10, 16], suggesting the importance of avoiding an unintentional increase in PTSA during OWHTO. However, the influence of MPTA on ACL degeneration following OWHTO is unclear. OWHTO is a realignment surgery performed for the lower limb; during this surgery, MPTA is increased. Valgus MPTA not only shifts the load distribution from the medial to the lateral compartment of the knee but also reduces lateral coronal tibiofemoral subluxation [4, 24]. With this reduction, the distance between the origin and the insertion of the ACL might increase in the coronal plane; subsequently, the tension on the ACL might increase. This repeated tension effect may explain why the anterior laxity of the tibia was improved after OWHTO, as shown by the

ATT test results; furthermore, repeated tension of the ACL may increase anteroposterior stability of the tibia.

The evidence that the degree of MPTA is correlated with the reduction of lateral coronal tibiofemoral subluxation (medial shift of the tibia relative to the femur) [24] strongly implies that MPTA is also correlated with the magnitude of strain on the ACL because reduction of the subluxation directly stretches the ACL in the coronal plane. In fact, in the current study, the Δ MPTA was higher for ACL degeneration in the progression group than in the steady group (Table 2). Furthermore, the Δ ACL grade was correlated with the Δ MPTA (Table 5). MPTA increased during OWHTO; subsequently, this might induce the reduction of lateral coronal tibiofemoral subluxation and repeated tension of the ACL. Because the magnitude of the strain on the ACL depends on the degree of MPTA, an excessive increase in MPTA may lead to ACL degeneration. However, because shortening of the medial collateral structure and stretching on the lateral side occurs when a varus deformity exceeds 10° [5], OWHTO might also change the balance of the bilateral collateral ligaments by reducing varus deformity and coronal tibiofemoral subluxation, which might also affect ACL conditions. Unless the ACL ruptures due to strain beyond its limit, it is tense and stabilises the knee during OWHTO. This could be why the ATT test showed significantly stabilised knees after OWHTO; it could also be why OWHTO did not affect the approximately 2.5-year short-term clinical outcomes observed during the present study. However, because patients with an ACL injury are at significantly higher risk for a secondary meniscal tear, osteoarthritis, and total knee arthroplasty [21, 28], excessively high MPTA should be avoided to prevent ACL degeneration following OWHTO to achieve good long-term results.

The ideal postoperative alignment for OWHTO is unknown. Because there are many opinions about the indications for OWHTO [3, 11, 29], postoperative alignment must be customised to the need of the patient [8]. Some studies suggested that marked overcorrection into the valgus might not be necessary because even neutral mechanical alignment leads to decreased loading of the medial compartment [2, 26]. However, our results suggest that excessive valgus correction induces ACL degradation. An individualised decision regarding the minimum amount of valgus correction should be established based on pathology and cartilage conditions.

There were some limitations to this study that must be appreciated when interpreting the findings. First, how ACL grade 4 affects clinical outcomes remains unclear because the follow-up period was short and the number of patients with ACL grade 4 following OWHTO was small. Second, the influence of the degree of PTSA on ACL degeneration was not investigated, which may have affected the ACL conditions. Because high PTSA is a risk factor for ACL

degeneration, the effect of the relationship of MPTA and PTSA on ACL conditions should be comprehensively investigated. Third, this study was retrospective. Therefore, further prospective, randomized, clinical trials are warranted.

Conclusion

The magnitude of the MPTA change is correlated with ACL degeneration following OWHTO. However, OWHTO stabilised anterior tibial translation regardless of ACL degeneration, and this degeneration was not associated with short-term clinical outcomes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in this study.

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