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Primary Knee

Advanced Varus Deformity Associated With Medial Knee Osteoarthritis Is a Potential Predictor of Anterior Cruciate Ligament Tear and Risk for Suitable Unicompartmental Knee Arthroplasty

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ABSTRACT

Background: Previous clinical studies suggest that preserving the anterior cruciate ligament (ACL) is crucial for stable knee motion and long-term longevity of the reconstructed knee. The ACL damage or loss often occurs in advanced medial osteoarthritis (OA). This study aimed to investigate the correlation between ACL damage and varus deformity progression as a risk factor for ACL tears in knee OA.

Methods: A retrospective study was conducted on medial knee OA patients who have various degrees of varus deformity treated with unicompartmental knee arthroplasty (n = 165), where ACLs had no or mild damage. Another group with ACL tears or loss and poor range of motion underwent total knee arthroplasty (n = 184). Surgeries were performed between November 2016 and March 2023. Preoperative varus angles were measured using the hip-knee-ankle angle (HKA) on standing radiographs. The ACL damage was graded using the Oxford system, and the correlation between preoperative HKA and ACL damage was analyzed.

Results: A significant correlation was found between preoperative varus angle and ACL damage. Severe damage was more frequent in knees with higher varus angles. The cut-off varus angle for a high risk of ACL tear was identified as 11.3°, with HKA above 15° indicating substantial ACL tears.

Conclusions: Medial knee OA with advanced varus deformity is associated with severe ACL tears. A unicompartmental knee arthroplasty may be preferable for medial knee OA before the varus angle reaches more than 15°.

Osteoarthritis (OA) of the knee is a prevalent orthopaedic condition, causing knee pain in older adults and burdening health care systems, especially with an aging population [1–3]. Among knee OA types, anteromedial or medial OA with varus deformity is the most common, with joint damage confined to the medial facet [4]. Unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA) are common treatments for end-stage knee OA, improving patients' quality of life [5,6].

A UKA is recommended to restore knee function with normal anatomy and physiological range of motion. Preoperative evaluation of medial OA, including anterior cruciate ligament (ACL) dysfunction, is critical for selecting patients for UKA or TKA. An ACL dysfunction can cause posterior rollback and posterior meniscal damage, progressing to OA or varus deformity of the medial compartment [7–10]. Before conventional UKA, three prerequisites for a successful UKA are: 1) preserved normal ACL, 2) correctable varus deformity by valgus stress, and 3) preserved normal range of motion of the affected knee. Some argue that ACL function is essential for stable knee motion and preventing OA progression [11,12]. In classic indications for mobile UKA, synovial damage or

Data Availability Statement: Data supporting the findings of this study are available on request from the corresponding authors. The data are not publicly available due to privacy and ethical restrictions.

Ethics Approval Statement: This study was approved by the ethical review board of Nishinomiya Watanabe Hospital (approval number: 202317) and was conducted in compliance with the Declaration of Helsinki.

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longitudinal splits around the ACL are not exclusion criteria [12]. However, the indication in cases of ACL dysfunction remains debated. Reports indicate stable clinical outcomes for mobile UKA in ACL-deficient knees over a short-term period of five years, but long-term results are not yet available [13]. Consequently, the suitability of this procedure for ACL-deficient cases remains uncertain.

In early-stage medial OA, the ACL is visible on magnetic resonance imaging (MRI); however, in advanced stages, the ACL is often torn or degraded. Degeneration of the ACL is highly prevalent in knees with cartilage defects [14], leading to a need for TKA in some cases.

To our knowledge, current reports lack sufficient data on intraoperative ACL damage severity in relation to medial knee OA. This study investigated risk factors for ACL tears in medial OA and the correlation between varus angle and ACL damage/tear to help prevent conversion to TKA.

Methods

Ethics Approval Statement

This study was approved by the ethical review board of Nishinomiya Watanabe Hospital (approval number 202317) and conducted in compliance with the Declaration of Helsinki. We disclosed this information to the participants and provided them with the opportunity to refuse consent.

Participants

This retrospective study included 349 knees that underwent either primary TKA or UKA for medial knee OA between January 1, 2016, and March 31, 2023, meeting specific inclusion and exclusion criteria. Exclusion criteria were: (1) spontaneous osteonecrosis; (2) inflammatory diseases like rheumatoid arthritis; (3) history of traumatic ACL tear; and (4) pain limited to walking or standing, with rest pain at night excluded. Preoperative standardized anteroposterior (AP) radiographs from the hip to ankle were taken, defining the medial knee as defined as hip-knee-ankle angle (HKA) $\leq 0^\circ$ and femoro-tibial angle $\geq 176^\circ$. Physical examination, X-ray, or MRI assessed anteromedial OA, mobile UKA indication, and ACL integrity were analyzed. Intraoperative ACL findings were classified by the surgeon according to the Oxford classification (Figure 1).

Radiographic Assessment

Radiography and MRI

An AP-standing lower-extremity radiograph from the hip to the ankle was obtained in a standardized manner in strict accordance with institutional protocols requiring the patella to be placed anteriorly without leg rotation (Supplemental Figure 1). All UKA procedures were performed according to the Oxford UKA indications and were only for patients who had antero-medial OA. The UKA cases underwent preoperative MRI using a 1.5 T clinical scanner (Fujifilm, Tokyo, Japan). This is because high sensitivity and specificity have been reported for evaluating ACL with a 1.5 T MRI [15]. Moreover, medial layer cartilage defects are verified at 1.5 T or higher with high confidence [16]. The patient was positioned supine with the knee extended for MRI.

Radiographic Evaluation and Variables

Radiographic and MRI Studies, as Well as Intraoperative ACL Classification

Lower-extremity alignment was assessed using lower-extremity radiographs in an AP-standing position from the hip to the ankle [17]. The HKA was measured as the angle between the mechanical axis of the femur (from the center of the femoral head to the center of the femoral intercondylar notch) and the tibia (from the center of the tibial spine tip to the center of the talus) [18,19]. The x-ray evaluations were performed by two assistant surgeons, in addition to the primary surgeon. Negative values indicated that the line drawn at the tibial plateau was more medial than the line drawn at the femoral condyle. AP-standing knee radiographs were graded for OA severity using the Kellgren–Lawrence (KL) grading scale [20]. Varus angles were divided into 5° increments, and HKA was classified into five grades: grade 0 (0 to 5°), grade 1 (5 to 10°), grade 2 (10 to 15°), grade 3 (15 to 20°), and grade 4 (>20°).

An MRI was used to assess the structural integrity of the ACL. The ACLs are often graded as intact, with degenerative changes, or as having total tears [21]. The ACLs with degenerative changes include thinning, scarring, ganglion formation, mucous degeneration, and partial tears, as previously reported [22]. The three physicians attending the surgery evaluate the preoperative MRI during a conference. For the decision to perform UKA surgery, the ACL was considered intact, and the final intraoperative Oxford classification was grades 1 to 3. According to our hospital protocol, patients who have medial knee OA who are potential candidates for UKA based on physical findings undergo MRI. However, MRI is not performed on radiographs in patients who have obvious flexion contracture or uncorrectable knee valgus, as these patients are indicated for TKA. Nevertheless, ACL tears in these patients are still evaluated intraoperatively.

Surgery and intraoperative ACL Classification

A UKA surgery for antero-medial OA is performed using the Oxford UKA (mobile-bearing) system, following these inclusion criteria: (1) medial bone-on-bone, (2) functionally intact ACL, (3) full-thickness lateral cartilage, (4) functionally normal medial collateral ligament, and (5) acceptable patellofemoral joint [12]. A TKA is performed for cases not meeting UKA criteria, with cruciate-retaining type for ACL dysfunction and cruciate-substituting type for ACL and posterior cruciate ligament dysfunction. Arthroplasty is performed by a lead surgeon and two orthopaedic assistants, two of whom are board-certified and have more than 15 years of experience, and the third is an orthopaedic surgeon who had less than six years of experience. Intraoperative ACL assessment, conducted postincision, classified ACLs per Oxford's five-stages: Stage 1, normal; Stage 2, synovial covering loss; Stage 3, longitudinal splits in the substance of the exposed ligament; Stage 4, friable/fragmented with collagen weakening; Stage 5, absent/ruptured [12]. The ACLs were grouped as nontear (Oxford Stages 1 to 3), partial tear (Oxford Stage 4), and total tear (Oxford Stage 5) (Figure 2).

Data Analyses

Excellent intraobserver and interobserver reliabilities were obtained for the measurement of HKA on AP-standing lower-extremity radiographs from the hip to the ankle and for the classification of the medial compartment according to the KL grade.

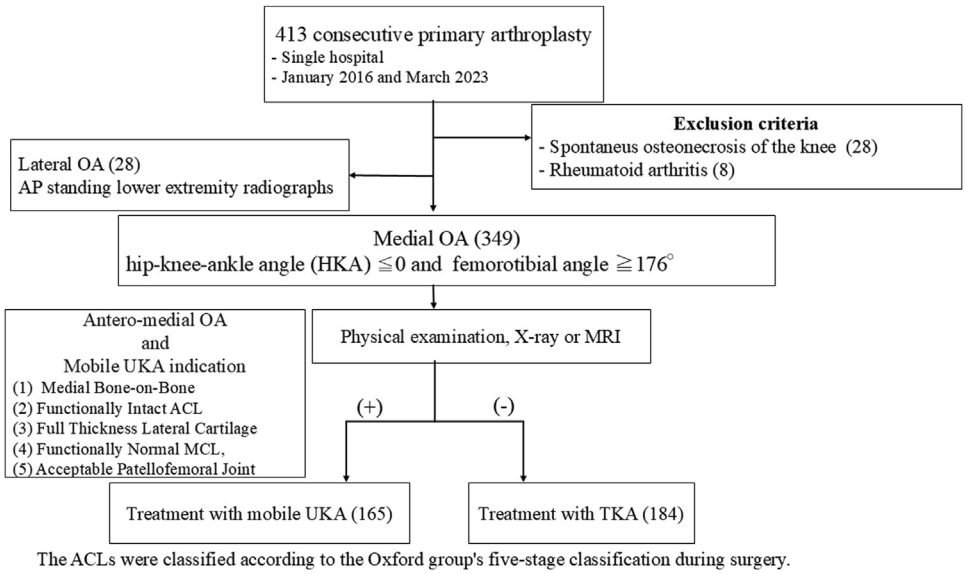


Figure 1. Flowchart of study patients. OA, osteoarthritis; AP, antero-posterior; MCL, medial collateral ligament; ACL, anterior cruciate ligament; UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty.

Randomly selected radiographs were evaluated to assess inter- and intraobserver reliabilities for HKA measurement. Univariate analyses were performed to compare the three groups using one-way analyses of variance (ANOVA).

Considering multicollinearity, Pearson's and Spearman's rank correlation coefficients were calculated to describe the associations between the evaluation items. We selected the following factors that are important when considering ACL degradation and damage: 1) patient background such as age, sex, and body mass index (BMI); 2) quantify the degree of osteoarthritis, such as KL grade; and 3) alignment of the knee. Multivariate logistic regression analyses were performed after analyzing the Pearson and Spearman correlation coefficients. A logistic regression model was used to calculate the adjusted odds ratio (OR) with a 95% confidence interval (CI) for the risk of perforated appendicitis in evaluable patients. A multivariate logistic regression model was used to adjust for all the potential confounding factors.

For causally related variables identified with significant differences using logistic regression analysis, receiver operating characteristic curves were constructed to calculate the cut-off values, sensitivity, specificity, and area under the curve (AUC). Analyses were performed using the EZR software (Jichi Medical University

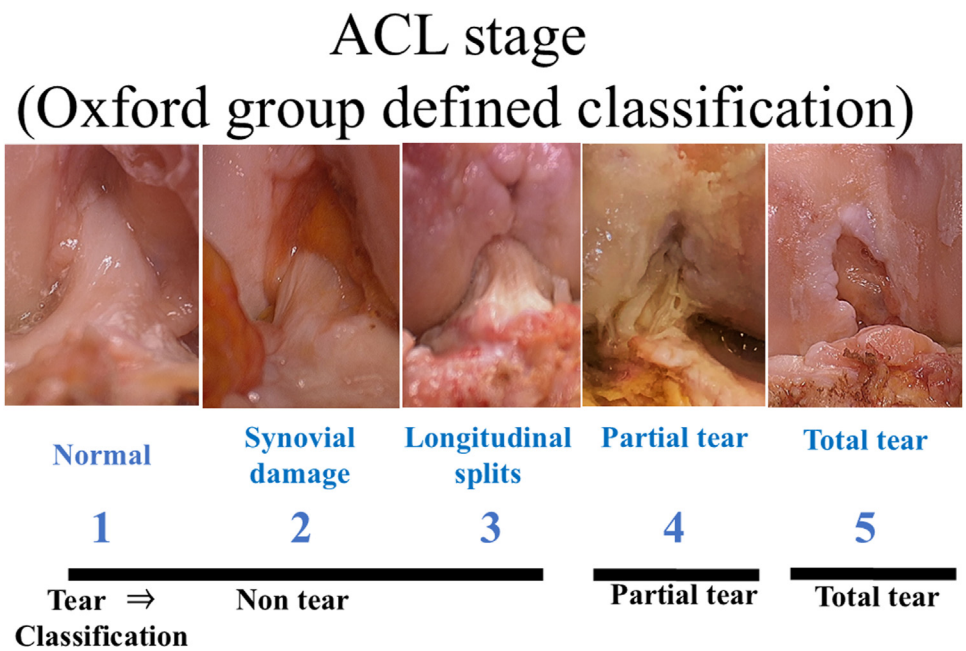


Figure 2. Intraoperative evaluation of the ACL according to the Oxford grading system. Tear findings were classified into the following three groups based on the Oxford group-defined classification: nontear: Oxford Stages 1 to 3, partial tear: Stage 4, and total tear: Stage 5. ACL: anterior cruciate ligament.

Table 1
Patient Characteristics.

Characteristic	Mean ± SD or *n* (%)
Age (year)	77 ± 6 (56 to 94)
Sex, men:women (%)	71 (20.4): 278 (79.6)
Height (cm)	154.8 ± 7.9 (137 to 180)
Weight (kg)	59.7 ± 11.1 (38 to 105)
BMI	24.8 ± 3.7 (16.6 to 40.0)
Operation (*n*)	UKA *n* = 164 (47.0%) TKA *n* = 185 (53.0%)

BMI, body mass index; UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty.

Saitama Medical Center, Saitama, Japan) for Windows. Data are presented as mean ± SEM. The level of significance was set at < 5%.

Results

Participant Characteristics

The retrospective study consisted of 71 men (20.4%) and 298 women (79.6%) who had a mean age of 77 years (range, 56 to 94) and a mean BMI of 24.8 (range, 16.6 to 40.0). Owing to the presence of medial OA, all patients were considered potential candidates for UKA. However, at our hospital, the indication for UKA was anteromedial OA, and only patients who met the medial bone-to-bone criteria underwent UKA. Those who did not meet the UKA criteria underwent TKA (UKA, n = 164; TKA, n = 185) (Table 1).

Correlation Between ACL Damage and Knee Varus

The 349 patients who underwent surgery for knee OA were classified according to the intraoperative ACL Oxford group–defined classification as follows: stage 1, n = 1; stage 2, n = 124; stage 3, n = 78; stage 4, n = 91; and stage 5, n = 55.

In this study, we investigated the relationship between the varus knee and the ACL in knee OA.

A significant correlation was observed between Oxford ACL classification findings and HKA (correlation coefficient = −0.37; $P < 0.001$) (Figure 3). A weak correlation was observed between age and HKA (correlation coefficient = −0.12; $P < 0.05$), ACL classification and KL classification (correlation coefficient = 0.18; $P < 0.001$), or HKA or KL classification (correlation coefficient = −0.35; $P < 0.001$). However, no significant correlation was found between ACL classification and age, ACL classification and BMI, etc. (Supplemental Table 1).

Subsequently, based on the Oxford group–defined classification, the tear findings were classified into three groups and compared. The number of patients in the nontear group (Oxford Stages 1 to 3) was n = 125, the partial tear group (Stage 4) was n = 91, and the complete tear group (Stage 5) was n = 55. Significant differences were observed in HKA between the three ACL tear groups (nontear group: −10.0° ± 4.4°; partial tear group: −12.7° ± 5.1°, complete tear group: −15.2° ± 5.3°). One-way ANOVA followed by the Bonferroni test yielded F2,346 = 29.8, $P < 0.001$; nontear versus partial tear group; $P < 0.001$, $P < 0.001$; nontear versus complete tear group: $P < 0.001$; partial tear versus complete tear group: $P = 0.010$) (Figure 4).

Furthermore, receiver operating characteristic curves were constructed to calculate the HKA cut-off values, sensitivity, specificity, and AUC for partial and total tears. The HKA cut-off values were as follows: cut-off value, −11.3°; sensitivity, 0.685; specificity, 0.674; and AUC, 0.7 (Figure 5).

In addition, comparisons were made by dividing the varus angles into 5° increments, and the HKAs were classified into five grades: grade 0 for HKA 0 to 5°, grade 1 for HKA 5 to 10°, grade 2 for HKA 10 to 15°, grade 3 for HKA 15 to 20°, and grade 4 for HKA >20°. We examined the ratio for nontear ACL in the HKA grades and compared it with each other group. Grades 3 and 4 for HKA showed a clear and significant difference when compared to classes 1 to 3 (grade 1 group: 71.4 ± 8.6%, grade 2 group: 72.5 ± 4.2%, grade 3 group: 62.6 ± 4.3%, grade 4 group: 30.7 ± 5.7%, grade 5 group: 20.0 ± 9.1%). A one-way ANOVA followed by the Bonferroni test yielded F4,344 = 12.6, $P < 0.001$. The *P*-value is shown in Figure 5,

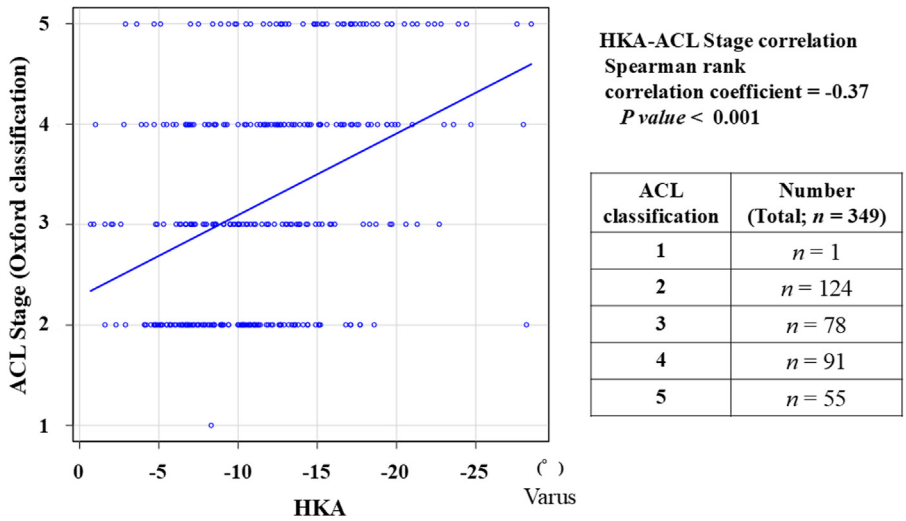


Figure 3. Correlation between HKA and ACL stage (Oxford group–defined classification) in patients who have medial knee osteoarthritis. HKA, hip-knee-ankle angle; ACL, anterior cruciate ligament.

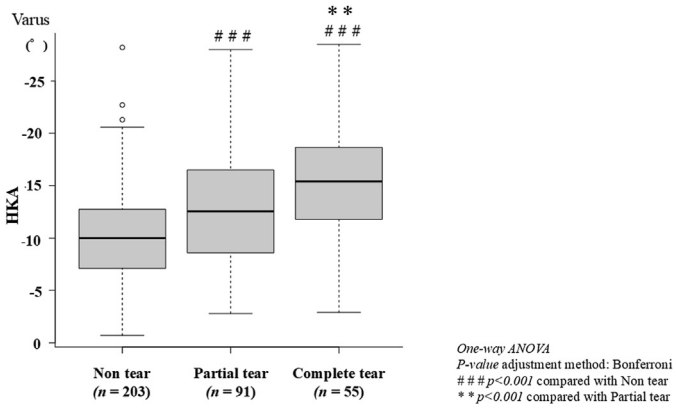


Figure 4. Relationship between the HKA and ACL tear (nontear, partial, and rotal tear) for patients who have medial knee OA. Analysis was conducted using one-way ANOVA. Note; # # #$P < 0.001$ compared with nontear, * *$P < 0.001$ compared with partial tear. HKA, hip-knee-ankle angle; ACL, anterior cruciate ligament; OA, osteoarthritis; ANOVA, analysis of variance.

comparing each group. Therefore, HKA above 15° was found to have considerably more partial and complete tears of the ACL (Figure 6).

Multivariate logistic regression analysis was performed to identify influencing factors. Considering the sample size, we selected and analyzed age, sex, BMI, KL classification, and HKA as the influencing factors. The results suggested that sex, KL classification, and HKA were independent influencing factors (Supplementary Table 2). Supplementary Table 2 shows the adjusted OR for each variable in patients who have partial and total ACL tears. Progress of OA and HKA was associated with a high risk of partial and total ACL tears, with an adjusted OR of 2.42 for OA (95% CI: 1.21 to 4.82, $P = 0.012$) and 0.87 for HKA (95% CI: 0.83 to 0.92, $P = 0.002$). However, other variables, such as age and BMI, were not associated with partial or total ACL tears. Although the progression of OA and HKA were correlated, they were mutually independent factors (Supplementary Table 2).

Discussion

In this report, we investigated the correlation between ACL damage and the severity of varus deformity as a risk factor for ACL tears in knee OA. The key finding was that intraoperative ACL tears in medial knee OA were strongly linked to increased varus deformity.

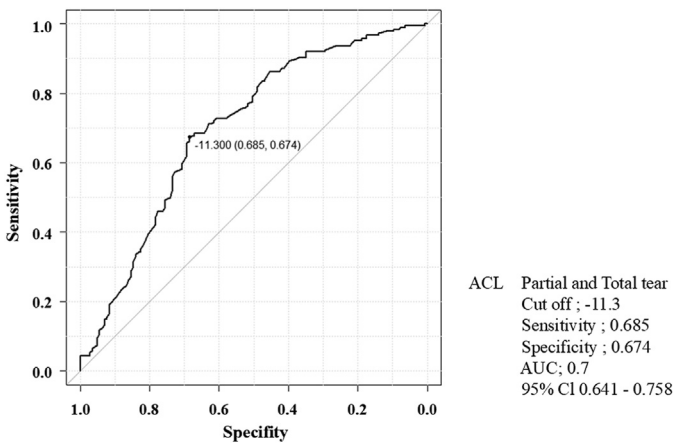


Figure 5. Receiver operating characteristic curve analysis of patient HKA for ACL partial and total tears. HKA, hip-knee-ankle angle; ACL, anterior cruciate ligament; AUC, area under the curve.

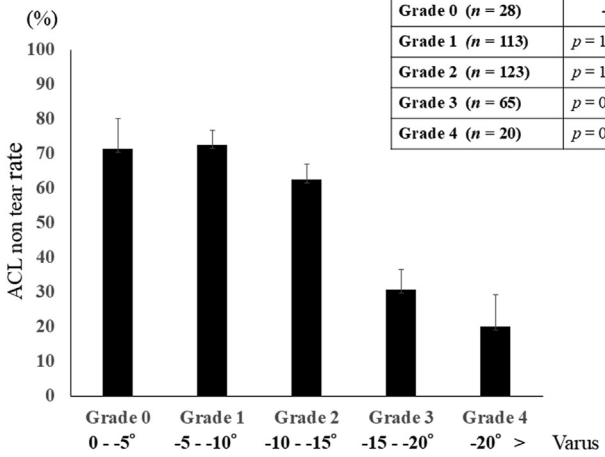
Careful patient selection and thorough preoperative evaluation are critical before UKA. Long-term studies have shown favorable outcomes for UKA in treating anteromedial OA, particularly when intact ACL and medial collateral ligament structures are preserved to maintain normal knee anatomy and correct varus deformity [11,12]. Given the ACL's role in stable knee motion, an intact or minimally damaged ACL is essential for a successful UKA [23–25]. Although ACL damage might be detectable through lateral radiographic or sagittal MRIs, as reported by Hamiton et al. and Waldstein et al., precise damage grading should be confirmed by direct observation during surgery [11,26]. In this study, a definite correlation between knee varus angles and macroscopic ACL damage observed during surgery was shown. This correlation, although weak, is considered acceptable because both variables would proceed as concomitant changes associated with OA progression. The varus deformity in medial knee OA could result from chronic erosion of medial facet cartilage and subchondral bone with progression of OA that is visible on radiographs, or may represent a pre-existing alignment in some patients. However, precise detection of ACL damage grade can be difficult even with MRI, and it was essential for direct visual observation, especially for partial ACL tears. In this study, the OA knees with partial ACL tears were referred to TKA due to the poor regenerating potential of the ACL, the possibility of progressing to a complete tear postoperatively, and the anticipated poor outcome. We cannot determine whether this decision is correct at this time point; further follow-up will be necessary to provide an answer.

We should recognize advanced varus angle as a risk factor for ACL tear and for appropriate UKA. Generally, increasing varus deformity exacerbates the pathological process of OA within the joint cavity, including ACL degradation and damage. Statistical analyses identified a cut-off varus angle (HKA = 11.3 degrees) to avoid ACL damage. However, a larger-scale study would be necessary to determine a more precise cut-off varus angle to preserve an intact ACL. Based on this study, we tentatively propose that a varus angle of more than 15° is the practical threshold to consider high suspicion of ACL damage and thus decide on TKA rather than UKA.

Regarding the pathological process that causes ACL damage or tear in the knee, OA is poorly studied. The presumptive biomechanical explanation for ACL tears associated with OA has been presented by increased tensile stress on the ACL elicited by varus deformity and external rotation of the tibial plateau [27,28]. In knee OA, osteophyte formation is also observed in the intercondylar space, possibly induced by a reduction in the width of this space [29]. Recently, the OA-associated inflammatory milieu within the joint cavity generated by proinflammatory cytokines such as interleukin-1β, interleukin-6, and tumor necrosis factor-α from synovial cells and inflammatory cells responding to those cytokines may cause degeneration of the ACL and other intra-articular ligaments, as well as cartilage and bone destruction [30–32]. This biochemical research could be beneficial and attractive in elucidating the mechanism of degeneration of the knee-stabilizing ligaments and for developing methods to protect these ligaments from the OA-associated degeneration process, thereby aiding in suitable UKA. Advancement of such research would be warranted.

Potential Limitations

This was a retrospective study. We did not observe temporal change; therefore, we could not determine whether varus knee deformity or ACL damage developed first. Since the study focused on patients who have OA and did not assess healthy participants, we did not assess ACL temporal changes over time during OA progression.



Comparison group	Grade 0	Grade 1	Grade 2	Grade 3
Grade 0 (n = 28)	-	-	-	-
Grade 1 (n = 113)	p = 1.000	-	-	-
Grade 2 (n = 123)	p = 1.000	p = 0.75	-	-
Grade 3 (n = 65)	p = 0.003	p < 0.001	p = 0.001	-
Grade 4 (n = 20)	p = 0.005	p < 0.001	p = 0.003	p = 1.0

Figure 6. Relationship between ACL nontear rate and HKA classification in patients who have medial knee osteoarthritis. Analysis was conducted using one-way ANOVA. ANOVA, analysis of variance; ACL, anterior cruciate ligament; HKA, hip-knee-ankle angle.

Conclusions

Failure of the ACL in medial OA is strongly associated with severe varus deformity. In preoperative AP-standing lower-extremity radiographs, patients who have severe varus deformity often have partial or total ACL tears. We tentatively propose that a varus angle of 15° is a practical threshold at present to avoid substantial ACL damage in medial OA of the knee, and cases with more varus than 15° should be carefully evaluated for partial or total ACL tears. This may guide surgeons in deciding between UKA and TKA.

CRediT authorship contribution statement

Takanori Matsuura: Writing – original draft, Validation, Software, Methodology, Data curation. **Shinichi Fukuoka:** Supervision, Project administration, Methodology, Data curation. **Takeharu Sasaki:** Supervision, Project administration. **Kunio Takaoka:** Writing – review & editing, Supervision, Conceptualization.

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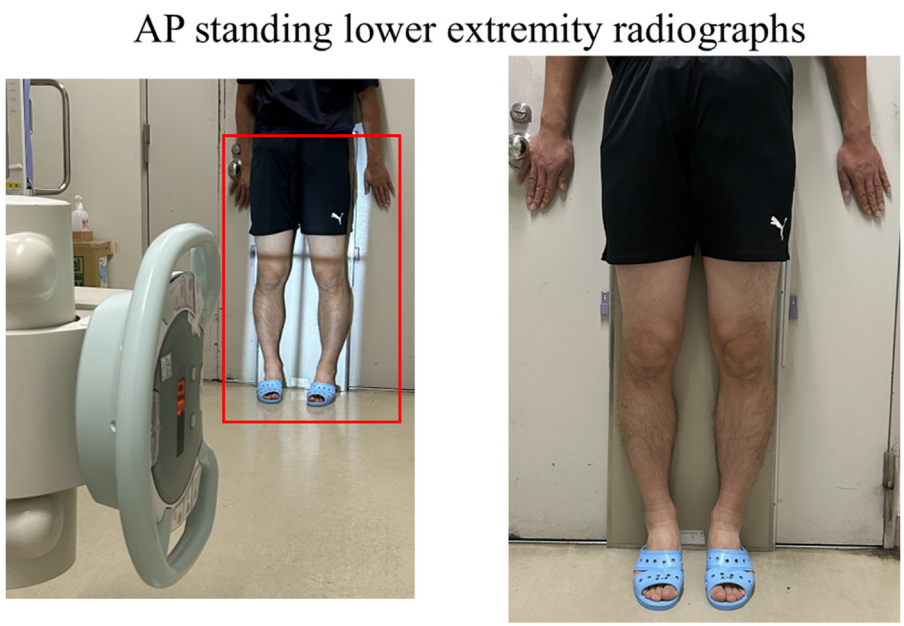
Appendix



Supplemental Figure 1. Sample of anteroposterior standing lower extremity radiographs.

Supplementary Table 1
Pearson or Spearman correlation coefficients between variable factors.

Variable	Age	BMI	KL	HKA	ACL
Age (year)	1				
BMI	−0.28***[a]	1			
KL classification	−0.01[b]	0.17[b]	1		
HKA (°)	−0.12*[a]	−0.04[a]	−0.35***[b]	1	
ACL classification	0.09[b]	0.04[b]	0.18***[b]	−0.37***[b]	1

BMI, body mass index; KL, Kellgren-Lawrence; HKA, hip-knee-ankle angle; ACL, anterior cruciate ligament.
*$P < 0.05$ and ***$P < 0.001$ are statistically significant.
[a] Spearman Correlation Analysis.
[b] Pearson Correlation Analysis.

Supplementary Table 2
Multivariate logistic regression analysis of each variable.

Variable	*P* Value	OR	Lower	Upper
Age (year)	0.12	1.03	0.99	1.07
Sex (women)	0.011*	0.44	0.24	0.83
BMI	0.94	1.00	0.93	1.07
KL classification	0.012*	2.42	1.21	4.82
HKA (°)	0.002**	0.87	0.83	0.92

BMI, body mass index; KL, Kellgren-Lawrence; HKA, hip-knee-ankle angle; ACL, anterior cruciate ligament; CI, confidence interval, OR, odds ratio.
*$P < 0.05$ and **$P < 0.01$ are statistically significant.