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Relationship between intercondylar notch angle and anterior cruciate ligament injury: a magnetic resonance imaging analysis

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Abstract

Objectives: This study was performed to compare the intercondylar notch angle (INA) and tibial slope in patients with and without anterior cruciate ligament (ACL) injury and determine the risk factors and influence of these anatomic variations on ACL injury.

Methods: Participants with and without non-contact ACL injuries were included in the patient and control groups, respectively. The INA (formed by the femoral axis and Blumensaat line), lateral tibial slope (LTS), and medial tibial slope (MTS) were measured on magnetic resonance images. Comparisons were performed between the two groups. A binary logistic regression model was used to determine the influence of the variables on ACL injury.

Results: Fifty-two participants were included in each group. The INA was significantly smaller and the LTS was significantly greater in the patients than in the controls. No difference was found in the MTS between the two groups. The area under the receiver operating characteristic curve for the combination of the INA and LTS was 0.776 (95% confidence interval, 0.688–0.864).

Conclusions: The INA was smaller and the LTS was greater in patients with than without ACL tears. The INA in combination with the LTS could be used to predict ACL injury.

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Introduction

Injuries of the anterior cruciate ligament (ACL) are common in competitive sports and induce a functional deficiency of the knees. The mechanisms of ACL injuries are not entirely clear. Many studies have been performed to identify risk factors associated with ACL tears. ACL ruptures are well known to be induced by anatomical, hormonal, genetic, and biomechanical factors.[1–5] Anatomic structures are considered to be intrinsic causes of ACL rupture. A narrow intercondylar notch, stenotic type A notch, and steep tibial slope are frequently reported risk factors for ACL injury.[6–9] A higher tibial slope can increase the anterior tibial shift, resulting in stretching of the ACL.[10] However, some controversy exists because of the use of different measurement and imaging techniques.[4,6] Although one study showed that the angle formed by the femoral axis and Blumensaat line was associated with ACL injury,[11] another study demonstrated that this angle was not a risk factor for ACL injury.[12]

We performed the present study to identify the associations between this angle and ACL injury and thus clarify its role in ACL injury. In this study, the angle formed by the femoral axis and Blumensaat line was defined as the intercondylar notch angle (INA). We measured the INA and tibial slope on both the medial and lateral sides on magnetic resonance (MR) images to determine whether differences exist between patients with and without ACL injury and between sexes. We also compared the influences of these two anatomic variations on ACL injury.

Material and methods

This retrospective case-control study involved patients with and without ACL injury from January 2014 to April 2017. All patients' injuries occurred during sports training and were non-contact in nature. The subjects in the patient group had acute ACL rupture as diagnosed by MR images and confirmed by arthroscopy, and the participants in the control group were healthy volunteers without knee disorders. Patients with a previous ligamentous injury to the knee, knee surgery, knee deformity, femoral or tibial fracture, or osteoarthritis were excluded from the study. Age, sex, affected knee, and body mass index were recorded for all participants in both groups. This study was approved by the ethics committee of our hospital. Informed consent was obtained from all individual participants included in the study.

All MR images were obtained using a 1.5T MR imaging system (AllTech, Chengdu, China). The knee was slightly flexed at 10°, and the foot was naturally flexed with 5° external rotation. A routine knee imaging protocol was used to visualize the ligaments of each knee. Axial, coronal, and sagittal scout sequences were used to visualize the ligaments and skeletal structure of each knee. The slice thickness was 3 mm, and the interslice gap was 0.5 mm. All MR images and lateral radiographs of the tibia containing the knee joint were obtained from a picture archiving and communication system with automatic computer calculation.

On the sagittal MR image, a slice in which the roof of the femoral intercondylar notch was entirely displayed was chosen. The Blumensaat line was drawn along the cortex of the roof of the intercondylar notch on the sagittal plane. The INA was measured as described by Bouras et al.[12] (Figure 1). The tibial slope was divided into the lateral tibial slope (LTS) and medial tibial slope (MTS). Measurements of the LTS and MTS were implemented as described by Stijak et al.[4] On the lateral and medial central slices (the slices with the shortest femorotibial distance on the medial and lateral plateaus), the LTS and MTS were measured between the lines of the tibial condyles and the lines perpendicular to the long axis of the tibia, respectively (Figures 2 and 3). Before the measurement was carried out, two orthopedic surgeons were trained by a senior radiologist to determine the Blumensaat line, tibial slope, femoral axis, and tibial axis. A random sample of patients was measured by the two surgeons twice independently to determine the interobserver and intraobserver reliability. All measurements were completed without any knowledge of the patient demographics.

The data were analyzed using the statistical software SPSS 13.0 (SPSS Inc., Chicago, IL, USA). Student's t-test or the chi-square test was used to compare the data between the two groups. Binary logistic regression analysis was performed to determine the influence of the LTS, MTS, and INA on ACL rupture. The dependent variable was defined as the "ACL status" (0, injured; 1, uninjured). A receiver operating characteristic (ROC) curve was used to determine the sensitivity of variations. Interobserver and intraobserver reliabilities

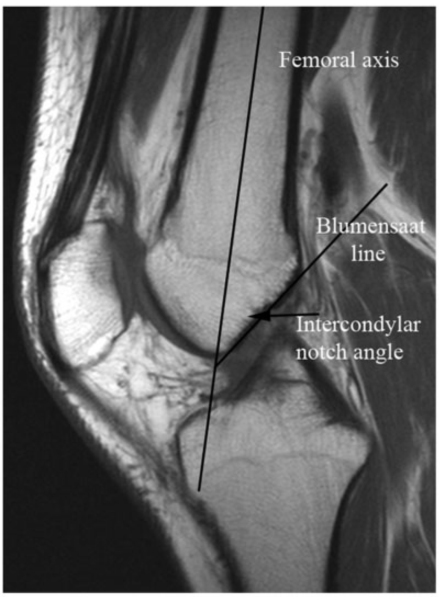

Figure 1. Sagittal T1-weighted image showing INA measurement (angle formed by the Blumensaat line and femoral axis). INA, intercondylar notch angle.

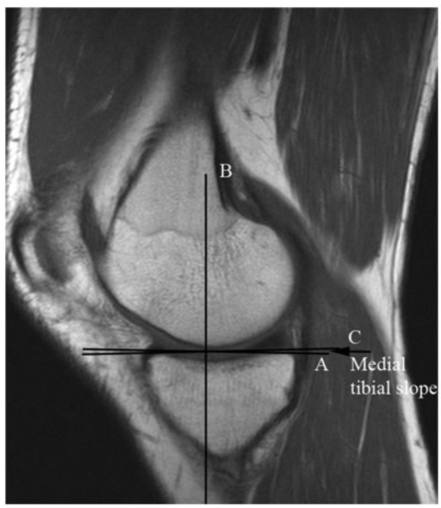

Figure 2. Sagittal T1-weighted image showing MTS measurement [angle formed by the line (line C) perpendicular to the tibial axis (line B) and the line running along the tibial slope of the medial tibial condyle (line A)]. MTS, medial tibial slope.

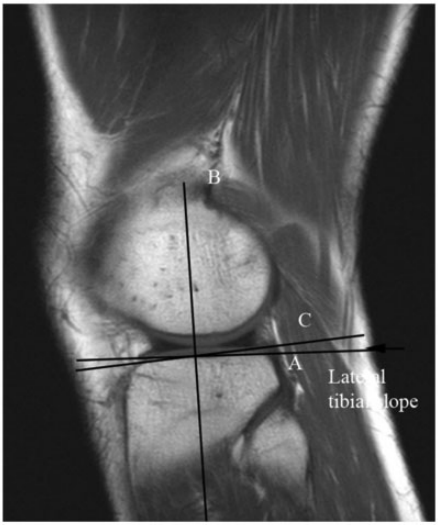

Figure 3. Sagittal T1-weighted image showing LTS measurement [angle formed by the line (line C) perpendicular to the tibial axis (line B) and the line running along the tibial slope of the lateral tibial condyle (line A)]. LTS, lateral tibial slope.

of the MR imaging measurements were calculated using the intraclass correlation coefficient. A P-value of <0.05 was considered statistically significant.

Results

In total, 104 participants were included in this study. The patient group comprised 31 male and 21 female patients (mean age, 25.48 years; range, 16–40 years), and the control group comprised 32 male and 20 female participants (mean age, 24.46 years; range, 17–42 years). There were no baseline differences in age, sex, affected knee, or body mass index between the patients and controls (Table 1). However, statistically significant differences were found in the INA and LTS between the patients and controls ($p = 0.000$ and $p = 0.002$, respectively). The MTS was not significantly different between the two groups (Table 2). There were no significant differences in the INA, MTS, or LTS between males and females (Table 3).

The effect of each factor on ACL injuries was analyzed using a binary logistic

Table 1. Demographic comparison of patient and control groups.

Demographics	Patients	Controls	P-value
Age, years	25.48 ± 5.04	24.46 ± 5.05	0.306
Sex			0.841
Male	31	32	
Female	21	20	
Affected knee			0.327
Left	29	24	
Right	23	28	
BMI, kg/m^2	22.86 ± 3.24	23.37 ± 3.21	0.422

Data are presented as mean ± standard deviation or number of patients.
BMI, body mass index.

Table 2. Comparisons of INA, MTS, and LTS in patient and control groups.

	Patients (n = 52)	Controls (n = 52)	P-value
INA	38.46 ± 3.72	41.12 ± 2.99	0.000*
MTS	6.89 ± 2.70	6.36 ± 2.09	0.267
LTS	7.15 ± 3.01	5.42 ± 2.58	0.002*

Data are presented as mean ± standard deviation.
INA, intercondylar notch angle; MTS, medial tibial slope; LTS, lateral tibial slope.

Table 3. Comparisons of INA, MTS, and LTS between sexes.

	Male (n = 63)	Female (n = 41)	P-value
INA	39.64 ± 3.29	40.02 ± 4.09	0.603
MTS	6.95 ± 2.31	6.12 ± 2.51	0.089
LTS	6.44 ± 2.92	6.02 ± 2.93	0.482

Data are presented as mean ± standard deviation.
*$P < 0.05$, statistically significant difference.
INA, intercondylar notch angle; MTS, medial tibial slope; LTS, lateral tibial slope.

regression model. Both the INA and LTS were significant risk factors for ACL rupture (correlation coefficient = 0.291, $p = 0.000$ and correlation coefficient = −0.260, $p = 0.004$, respectively). The area under the curve (AUC) was 0.694 in the ROC curve of the INA [95% confidence interval (CI), 0.594–0.794] and 0.677 in the ROC curve of the LTS (95% CI, 0.573–0.780). An ROC curve constructed with the INA, LTS, and combined predictor values was used to show the effects on ACL injury. The AUC of the combined ROC curve was larger than that of both the INA and LTS (AUC = 0.776; 95% CI, 0.688–0.864) (Figure 4).

A random sample of 40 patients from among the 104 patients was selected for determination of the interobserver and intraobserver reliability. The average intraclass correlation coefficient was 0.96 for interobserver reliability and 0.95 for intraobserver reliability.

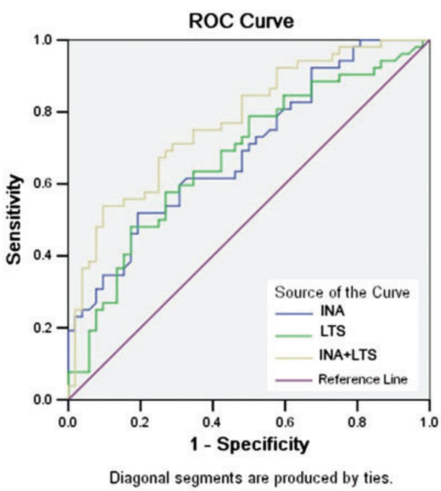

Figure 4. Receiver operating characteristic curve demonstrated the effects of the INA, LTS, and their combination on ACL injury. INA, intercondylar notch angle; LTS, lateral tibial slope; ACL, anterior cruciate ligament.

Discussion

The most important finding of this study is the significantly smaller INA in patients with than without ACL injury. The Blumensaat line is commonly used to evaluate the graft tunnel position after ACL reconstruction surgery.[13–15] It is not affected by the position of the femur. Mahajan et al.[16] found that this line was reliable on radiographs while the knee was in external, internal, valgus, and varus rotations of <10°. Alentorn-Geli et al.[17] found that the angle between the Blumensaat line and the anterior tibial slope was significantly greater in men with ACL injury. However, the angle might vary with the position of the tibia. In contrast the angle created by the femoral axis and the Blumensaat line is comparatively stable. We found that the mean INA was 39.79° in this study, and Uozumi et al.[18] found that it was about 35° on three-dimensional computed tomography. A probable reason for the disparity is that we measured the INA on two-dimensional MR images. This angle was about 44° as measured by Bouras et al.,[12] similar to our measurement. Fernández-Jaén et al.[11] measured the α angle on MR images, which was defined as the INA in the present study, and found that it was about 57°. Surprisingly, there was a discrepancy of approximately 13° between the two studies using the same measurement technique.[11,12] This cannot be readily explained, and more studies are required.

Fernández-Jaén et al.[11] found the α angle was positively correlated with ACL injury and was a risk factor for such injury. They also found that the intercondylar notch was more sensitive than the α angle in predicting ACL injury. However, Bouras et al.[12] measured the α angle in female patients but found no significant difference between the ACL-injured and uninjured groups; therefore, they considered it a weak indicator of the prognosis of ACL injury. However, we believe that sex-related bias might have been present in their study. Moreover, the INA in the ACL-injured patients in this study was smaller than that in uninjured participants, indicating that knees with a smaller INA might be more prone to ACL injury; however, the mechanism of how the INA induces ACL rupture is unknown. The femoral axis and the Blumensaat line form a tangential face of the intercondylar notch. A small INA indicates a sharp edge of the notch outlet, and the ACL may strike the notch roof when the knee is in excessive extension. If the ACL impinges on the notch roof, it is likely to rupture in the presence of a smaller INA. People with a small INA might have a high risk of ACL rupture when they participate in competitive sports. Some precautions must be considered, such as education and injury prevention training.

One of the secondary findings of the present study was that the LTS was significantly greater in the patients than in the controls while the MTS was not significantly different between the two groups. The measurement techniques and results in this study are in agreement with those of previous research.[4] The tibial slope has long been thought to be a risk factor for ACL rupture. The anterior tibial translation was found to be greater on the lateral than medial tibial plateau during knee flexion.[10,19] Additionally, an increased LTS imparted higher stress on the ACL, inducing injury. Rahnemai-Azar et al.[20] found that an increased LTS might be an important anatomical variable predicting high-grade rotatory laxity in patients with ACL injury. Some studies have demonstrated a relationship between the LTS and the incidence of ACL rupture, but other studies have shown different results.[4,7,8,21–23] Some studies have revealed that the MTS is a risk factor for ACL injuries.[6,17,24,25] Consistent results are dependent upon use of the same measurement techniques and imaging resources. Further biomechanical experiments are also necessary.

Previous studies have shown that women might have a higher risk of ACL rupture than men.[3,21,26,27] We hypothesized that morphological differences exist between the two sexes, but our study failed to reveal any significant differences in the INA, MTS, or LTS between males and females. This might have been due to the small sample size of our study. However, our results are consistent with some previous reports.[11,23]

This study also indicated that both the INA and LTS played a significant role in increasing the risk of ACL rupture. However, the AUC values of the LTS and INA were not high enough to ensure accurate prediction of ACL injury. This indirectly indicates that ACL injury could be caused by multiple factors. When the two factors were combined, their AUC value increased to 0.776, indicating moderate accuracy in prediction of ACL injury. Consequently, it is necessary to explore more risk factors for ACL injury and take all of them into consideration rather than explore them one by one because only holistic analysis has the lowest risk of bias.

This study has two main limitations. First, our limited sample size might have affected the results. We had attempted to recruit more participants but failed because of limited availability of the imaging documents. Second, we measured the anatomic parameters only on two-dimensional MR images on which neither the tibial nor femoral shaft was entirely displayed. Therefore, we used an approximate axis of the bone shaft instead of the actual anatomical axis to develop the measurements. This method was only helpful for MR imaging studies. Measurements should be performed on three-dimensional MR images to obtain more precise results in the future.

In conclusion, the present study showed that the INA may be significantly smaller and the LTS higher in patients with ACL injury. The MTS may not significantly differ between the patients with and without ACL injury. Measurement of the LTS and INA can provide reliable results.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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