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ORIGINAL ARTICLE

# Morphometric risk factors effects on anterior cruciate ligament injury

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## ABSTRACT

**Objectives:** This study aims to compare the morphometric differences between patients with and without an anterior cruciate ligament (ACL) injury and to investigate the anatomical risk factors associated with ACL injury.

**Patients and methods:** Between February 2020 and February 2022, a total of 100 patients (57 males, 43 females; mean age: 36.2±6.8 years; range, 18 to 45 years) who were operated for isolated non-contact ACL tear as the patient group and a total of 100 healthy individuals (58 males, 42 females; mean age: 35.0±6.9 years; range, 18 to 45 years) without an ACL tear as the control group were included. Magnetic resonance imaging scans of the knee joint were included in the study. Morphological variables of the ACL, distal femur, proximal tibia, and menisci were measured.

**Results:** The mean ACL inclination angle and medial meniscus bone angle were 37.7±3.8 and 20.2±2.9 in the patient group and 48.1±3.3 and 25.0±2.9 in the control group. According to the results of multivariate analysis, those with small ACL inclination angle and medial meniscus bone angle were more likely to have ACL tear (odds ratio: 0.128, intraclass correlation coefficient: 0.038-0.430, p=0.001).

**Conclusion:** Small ACL inclination angle and medial meniscus bone angle can be a risk factor for ACL tear.

***Keywords:*** Anatomical risk factors; anterior cruciate ligament; knee injury; knee morphology, magnetic resonance imaging.

Anterior cruciate ligament (ACL) injury is a common injury, particularly in young active individuals, with an increasing incidence.[1] Individuals undergoing ACL reconstruction can return to their former activity level only in the long term and with great effort.[2] Although the rate of return to sports after ACL reconstruction seems to be high, particularly sports requiring pivot movement, patterns increase the risk of graft and contralateral ACL rupture in individuals undergoing ACL reconstruction, while the risk of osteoarthritis in the long term is high in these individuals.[3,4] Preventive measures should be focused on before the development of ACL injury.[5]

The results from a recent research have shown that several intrinsic and extrinsic factors are responsible for ACL injuries.[6] Morphometric features such as the tibial slope,[7,8] notch width (NW),[9] notch shape,[10] NW index (NWI),[11] and the tibial tubercle-trochlear groove (TT-TG) distance[12] have been studied individually to identify whether they are predisposing factors in ACL injury. Although there is evidence that some morphometric features such as a decreased intercondylar NW

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may cause ACL injury, a clear link between ACL injury risk and the morphometric parameters of the knee has not been fully established, yet.[13] To date, the majority of studies have focused on the relationship between a single morphometric feature and ACL injury. However, it has been reported that not a single, but numerous morphometric features contribute to the ACL injury mechanism and that further studies are warranted.[14] Thus, recent studies have focused on more than one morphometric feature and reported that the TT-TG distance, medial posterior slope, NW, and NWI are associated with ACL injuries.[15,16]

Since it is not fully known which morphometric features play a role together, the current study was designed to investigate the role of these features in ACL injury and contribute to the literature regarding this subject. In the present study, we, therefore, aimed to measure the morphological parameters and identify the potential morphological risk factors associated with ACL injury, to compare the morphological differences between individuals with and without ACL injury, and to discuss the anatomical risk factors using magnetic resonance imaging (MRI).

## PATIENTS AND METHODS

This single-center, retrospective, case-control study was conducted at Konya City Hospital, Department of Radiology between February 2020 and February 2022. The study groups were selected from patients aged between 20 and 40 years who were operated for isolated non-contact ACL tear (patient group) and healthy individuals without an ACL tear (control group). The sample size was selected from a group of 400 controls and 100 cases using the propensity score matching method to include 100 homogeneous participants in each group. The homogeneity of the age, sex, body mass index (BMI), and side variables was ensured also with propensity score matching. Patients with previous knee surgeries, previous knee fractures in or around the knee, rheumatologic diseases, previous infections in the knee joint, knee pathologies affecting the intra-knee structures (such as osteoarthritis), and patients with multiple ligament injuries in the knee were excluded from the study. Finally, the patient group included a total of 100 patients (57 males, 43 females; mean age: 36.2±6.8 years; range, 18 to 45 years) and the control group included a total of 100 healthy individuals (58 males, 42 females; mean age: 35.0±6.9 years; range, 18 to 45 years).

A musculoskeletal radiologist with more than 10 years of experience in sports surgery examined the MRI scans of the patients, and the morphological parameters were measured using the standard techniques previously described in the literature.[17-25] The physician who performed the measurements was blinded to the patient records. All measurements were made once by a single physician. Whether the ACL was intact in both the control group and the patient group was determined by MRI scans, and no arthroscopic confirmation was performed. Uninjured contralateral knee MRI were used for measurement in the patient group. Knee MRI, in which the control group had no complaints, were used for measurements.

All MRIs were taken with a 1.5-T scanner (MAGNETOM Symphony; Siemens AG, Erlangen, Germany) with a 3-mm section thickness. Individual radiological measurements were performed virtually using the INFINITT PACS System (INFINITT Healthcare Co., Seoul, South Korea) with an accuracy of 0.1 mm for linear measurements and 0.1° for angular measurements.

In all patients, the following values were measured using the standard measurement techniques in the literature: ACL length (ACLL),[17] ACL width (ACLW),[18] ACL inclination angle (ACLIA),[19] Insall-Salvati index (ISI),[20] Blumensaat angle (BA), anterior tibial translation (ATT),[21] medial tibia plateau slope (MTPS), lateral tibia plateau slope (LTPS),[22] medial femoral condylar width (MFCW), lateral femoral condylar width (LFCW), medial femoral condylar depth (MFCD), lateral femoral condylar depth (LFCD), NWI, distal femoral width (DFW),[23] intercondylar femoral width (IFW),[24] medial meniscus bone angle (MMBA), and lateral meniscus bone angle (LMBA).[25] We divided the BMI groups into two to include the patients with a BMI of <30 kg/m$^2$ and a BMI of ≥30 kg/m$^2$ and the age groups into two to include the patients who were in their third decade and fourth decade of life (Figures 1-5). All measurements were performed by a musculoskeletal radiologist with more than 10 years of experience using the following standard measurement techniques.

### Statistical analysis

Statistical analysis was performed using the IBM SPSS version 28.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The normality of the variables was checked using the Kolmogorov-Smirnov test. The Mann-Whitney U test was used for the comparison of the quantitative data,


**FIGURE 1.** Magnetic resonance imaging measurement techniques of ISI, ACLL, and ACLW.
ISI: Insall-Salvati index; ACLL: Anterior cruciate ligament length; ACLW: Anterior cruciate ligament width.


**FIGURE 2.** Magnetic resonance imaging measurement techniques of ACLIA, BA, and MMBA.
ACLIA: Anterior cruciate ligament inclination angle; BA: Blumensaat angle; MMBA: Medial meniscus bone angle.


**FIGURE 3.** Magnetic resonance imaging measurement techniques of LMBA, LTPS, and ATT.
LMBA: Lateral meniscus bone angle; LTPS: Lateral tibia plateau slope; ATT: Anterior tibial translation.


**FIGURE 4.** Magnetic resonance imaging measurement techniques of MTPS, IFW, MFCW, and LFCW.
MTPS: Medial tibia plateau slope; IFW: Intercondylar femoral width; MFCW: Medial femoral condylar width; LFCW: Lateral femoral condylar width.

while the chi-square test was used for the comparison of the qualitative data. Univariate and multivariate logistic regression analyses and receiver operating characteristic (ROC) curves were used to show the effect level. A *p* value of <0.05 was considered statistically significant.


**FIGURE 5.** Magnetic resonance imaging measurement techniques of MFCD and LFCD.
MFCD: Medial femoral condylar depth; LFCD: Lateral femoral condylar depth.

## RESULTS

The patient and the control group were homogeneous in terms of demographic characteristics (p>0.05, Table I).

The patients with an ACL tear had significantly higher ACLW, BA, ATT, LTPS, MFCW, LFCW, MFCD, LFCD, DFW, and IFW values than the control group, but significantly lower ACLL, ACLIA, NWI, MMBA, and LMBA values (p<0.05). The ISI and MTPS did not significantly differ between the two groups (Table II).

The results of the univariate model confirmed the significant effect of the ACLL, ACLW, ACLIA, ATT, LTPS, MFCW, LFCW, MFCD, LFCD, NWI, DFW, IFW, MMBA, and LMBA values in the differentiation of the patients with and without an ACL tear (p<0.05) (Table III).

The multivariate regression model confirmed the significant independent effect of the ACLIA and MMBA values in the differentiation of the patients with and without an ACL tear (p<0.05) (Table III).

In addition, BA, ACLIA, LMBA, ACLW, MMBA, ATT, MFCD, MFCW, IFW, LTPS, LFCD, NWI, LFCW, DFW, and ACLL could predict ACL injury. The ISI and MTPS values did not have a significant prediction power in the differentiation of patients with and without an ACL injury. Table III shows the predictive levels of measured parameters from highest to lowest (Table IV).

**TABLE I**
Demographic data of the participants

| | ACL tear group | | | | Control group | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | n | % | Mean±SD | Median | n | % | Mean±SD | Median | *p* |
| Age (year) | | | 36.2±6.8 | 39 | | | 35.0±6.9 | 38 | 0.285* |
| Age range (year) | | | | | | | | | 0.179† |
| ≤30 | 19 | 19.0 | | | 27 | 27.0 | | | |
| >30 | 81 | 81.0 | | | 73 | 73.0 | | | |
| Sex | | | | | | | | | 0.886† |
| Male | 57 | 57.0 | | | 58 | 58.0 | | | |
| Female | 43 | 43.0 | | | 42 | 42.0 | | | |
| Height (cm) | | | 167.8±10.0 | 167.0 | | | 167.4±10.0 | 166.5 | 0.902* |
| Weight (kg) | | | 80.6±14.2 | 77.0 | | | 78.3±14.0 | 79.5 | 0.515* |
| Body mass index (kg/m²) | | | 28.7±5.2 | 27.3 | | | 27.9±4.3 | 27.5 | 0.648* |
| Body mass index (kg/m²) | | | | | | | | | 1.000† |
| <30 | 69 | 69.0 | | | 69 | 69.0 | | | |
| ≥30 | 31 | 31.0 | | | 31 | 31.0 | | | |
| Side | | | | | | | | | 0.203† |
| Right | 55 | 55.0 | | | 46 | 46.0 | | | |
| Left | 45 | 45.0 | | | 54 | 54.0 | | | |

ACL: Anterior cruciate ligament; SD: Standard deviation; * Mann-Whitney U test, † chi-square test.

**TABLE II**
Distribution of the demographic data and measurement parameters by group

| | ACL tear group | | Control group | | |
|---|---|---|---|---|---|
| | Mean±SD | Median | Mean±SD | Median | *p** |
| Anterior cruciate ligament length (mm) | 35.4±3.2 | 36.0 | 36.5±3.1 | 36.0 | **0.030** |
| Anterior cruciate ligament width (mm) | 11.5±2.1 | 11.0 | 8.6±1.4 | 8.0 | **0.000** |
| Anterior cruciate ligament inclination angle (degree) | 37.7±3.8 | 38.5 | 48.1±3.3 | 48.0 | **0.000** |
| Insall-Salvati index | 1.0±0.1 | 1.00 | 1.0±0.1 | 1.00 | 0.057 |
| Blumensaat angle (degree) | 19.2±2.8 | 19.0 | 6.8±2.1 | 7.0 | **0.000** |
| Anterior tibial translation (mm) | 5.9±4.3 | 6.0 | 1.9±1.6 | 2.0 | **0.000** |
| Medial tibia plateau slope (degree) | 8.4±2.7 | 8.0 | 8.4±3.1 | 8.0 | 0.822 |
| Lateral tibia plateau slope (degree) | 8.1±2.6 | 7.5 | 6.7±2.5 | 6.0 | **0.000** |
| Medial femoral condylar width (mm) | 28.2±2.8 | 28.0 | 26.6±2.3 | 26.0 | **0.000** |
| Lateral femoral condylar width (mm) | 31.7±2.9 | 31.5 | 30.3±2.8 | 30.0 | **0.004** |
| Medial femoral condylar depth (mm) | 6.2±1.1 | 6.0 | 5.1±1.0 | 5.0 | **0.000** |
| Lateral femoral condylar depth (mm) | 5.7±1.1 | 6.0 | 5.1±1.1 | 5.0 | **0.000** |
| Notch width index | 3.9±0.4 | 3.9 | 4.0±0.4 | 4.0 | **0.001** |
| Distal femoral width (mm) | 78.9±6.3 | 78.0 | 76.7±5.9 | 76.0 | **0.022** |
| Intercondylar femoral width (mm) | 20.6±2.5 | 20.5 | 19.2±2.5 | 19.0 | **0.000** |
| Medial meniscus bone angle (degree) | 20.2±2.9 | 20.0 | 25.0±2.9 | 25.0 | **0.000** |
| Lateral meniscus bone angle (degree) | 19.7±2.7 | 19.5 | 25.4±3.6 | 25.0 | **0.000** |

SD: Standard deviation; * Mann-Whitney U test; Significant *p* values are written in bold.

## DISCUSSION

The present study revealed the relationship between ACL injury and morphometric features of the knee. According to the univariate model, a smaller ACLL, ACLIA, MMBA, and LMBA and a greater ACLW, ATT, LTPS, MFCW, LFCW, MFCD, LFCD, NWI, DFW, and IFW were associated with an ACL injury. On the other hand, the results of the multivariate analysis indicated that smaller ACLIA and MMBA values were independent risk factors for ACL injury.

**TABLE III**
Univariate and multivariate analysis of variance results of all morphological measurements (forward logistic regression)

| | Univariate model | | | Multivariate model | | |
|---|---|---|---|---|---|---|
| | OR | 95% CI | *p* | OR | 95% CI | *p* |
| Anterior cruciate ligament length (mm) | 0.903 | 0.826-0987 | 0.025 | | | |
| Anterior cruciate ligament width (mm) | 2.686 | 2.047-3.526 | 0.000 | | | |
| Anterior cruciate ligament inclination angle (degree) | 0.178 | 0.085-0.373 | 0.000 | 0.128 | 0.038-0.430 | **0.001** |
| Anterior tibial translation (mm) | 1.459 | 1.298-1.640 | 0.000 | | | |
| Lateral tibia plateau slope (degree) | 1.253 | 1.110-1.414 | 0.000 | | | |
| Lateral femoral condylar width (mm) | 1.190 | 1.072-1.322 | 0.001 | | | |
| Medial femoral condylar width (mm) | 1.302 | 1.153-1.471 | 0.000 | | | |
| Medial femoral condylar depth (mm) | 2.457 | 1.783-3.384 | 0.000 | | | |
| Lateral femoral condylar depth (mm) | 1.644 | 1.254-2.156 | 0.000 | | | |
| Notch width index | 0.340 | 0.160-0.723 | 0.005 | | | |
| Distal femoral width (mm) | 1.061 | 1.013-1.112 | 0.013 | | | |
| Intercondylar femoral width (mm) | 1.269 | 1.122-1.435 | 0.000 | | | |
| Medial meniscus bone angle (degree) | 0.569 | 0.488-0.664 | 0.000 | 0.590 | 0.399-0.874 | **0.008** |
| Lateral meniscus bone angle (degree) | 0.543 | 0.458-0.644 | 0.000 | | | |

OR: Odds ratio; CI: Confidence interval; Significant *p* values are written in bold.

**TABLE IV**
Predictive powers of the morphological measurement parameters regarding ACL injury (from highest to lowest)

| | AUC | 95% CI | *p** |
|---|---|---|---|
| Blumensaat angle (degree) | 1.000 | 1.000-1.000 | **0.000** |
| Anterior cruciate ligament inclination angle (degree) | 0.996 | 0.991-1.000 | **0.000** |
| Lateral meniscus bone angle (degree) | 0.904 | 0.863-0.945 | **0.000** |
| Anterior cruciate ligament width (mm) | 0.883 | 0.837-0.928 | **0.000** |
| Medial meniscus bone angle (degree) | 0.876 | 0.829-0.922 | **0.000** |
| Anterior tibial translation (mm) | 0.779 | 0.708-0.850 | **0.000** |
| Medial femoral condylar depth (mm) | 0.746 | 0.678-0.813 | **0.000** |
| Medial femoral condylar width (mm) | 0.681 | 0.606-0.755 | **0.000** |
| Intercondylar femoral width (mm) | 0.675 | 0.601-0.749 | **0.000** |
| Lateral tibia plateau slope (degree) | 0.667 | 0.593-0.742 | **0.000** |
| Lateral femoral condylar depth (mm) | 0.649 | 0.573-0.725 | **0.000** |
| Notch width index | 0.635 | 0.558-0.713 | **0.001** |
| Lateral femoral condylar width (mm) | 0.617 | 0.540-0.695 | **0.004** |
| Distal femoral width (mm) | 0.594 | 0.515-0.672 | **0.022** |
| Anterior cruciate ligament length (mm) | 0.588 | 0.509-0.667 | **0.031** |
| Insall-Salvati index | 0.576 | 0.496-0.655 | 0.065 |
| Medial tibia plateau slope (degree) | 0.509 | 0.429-0.590 | 0.823 |

ACL: Anterior cruciate ligament; AUC: area under the curve; CI: Confidence interval; Significant *p* values are written in bold.

Several studies have shown that morphometric features of the knee may predispose to ACL injury.[7-16] Recent findings have indicated that the combination of morphometric features may be utilized in further elucidating the mechanism of ACL injury.[26] Bayer et al.[27] reported that intercondylar notch stenosis, sagittal condylar shape variations, increased tibial slope, decreased tibial eminence size, poor tibiofemoral alignment, and decreased ACL size were the risk factors for ACL injury. In a study investigating the structural predisposition for ACL injuries, Kızılgöz et al.[16] showed that NW, NWI, and medial tibial slope (MTS) were the risk factors for ACL injuries. Since our study differs from other studies in terms of design, our results are also different. The study closest in design to our study is that of Shen et al.[15] in which the authors reported the multiple variance analysis of the variables that might be anatomical risk factors for ACL injury in active individuals. The aforementioned authors reported that increased TT-TG distance, increased MTS, and decreased NWI could be independent risk factors for ACL injury in active individuals, although they provided no information about ACLL, ACLW, ACLIA, and meniscus bone angle measurements. In the current study, ACLIA and MMBA were found to be morphometric variables associated with an ACL injury.

Hudek et al.[28] reported that meniscus morphology was associated with ACL injuries, showing that the angle between the horizontal plane and the line passing through the tips of the anterior and posterior horns was associated with ACL injuries. However, the number of studies investigating the relationship between the meniscal bone angle and ACL injuries is limited. These studies mostly focus on LMBA, reporting that this morphometric feature may be a factor in ACL injuries.[26,29] On the other hand, the results of studies investigating MMBA suggest that there is no relationship between MMBA and ACL injury.[27] Contrary to the literature, our results indicate that small MMBA is a risk factor for ACL injury.

The angular relationship of the ACL with the femur and the tibia is particularly important in the anatomical placement of the graft during reconstruction and has been a subject of research on surgical techniques.[20] A limited number of studies have investigated the relationship between the angulation of the ACL with respect to the femur and the tibia and ACL injuries.[16,29] Sauer et al.[29] reported that individuals with ACL injury had a high beta angle, while the alpha angle has not been found a predisposing factor for ACL injury.[16] However, to the best of our knowledge, there is only one prospective study investigating whether ACLIA is a risk factor for ACL injuries, in which Adhikari et al.[30] found ACLIA and BA to be sensitive and specific for ACL injury. Our results suggest that one of the main risk factors for ACL injury can be small ACLIA.

Nonetheless, this study has some limitations. First, it did not confirm ACL rupture by arthroscopy in the patient group, which may have resulted in the acceptance of intact ACLs as ruptures. The second is the fact that the measurements were made by a single musculoskeletal radiologist, which may have caused the inter-observer and intra-observer bias. Another limitation is that the variables associated with ACL inclination were performed on sagittal images. However, variables associated with ACL inclination can be evaluated by measuring on both sagittal and coronal MRI sequences. This may have caused measurement errors. In addition, other intrinsic and extrinsic factors such as the activity level that are risk factors for ACL rupture could not be measured and included in the analysis. However, the effect of other intrinsic and extrinsic risk factors may limit the effectiveness of morphometric variables, which were observed to be effective in differentiating ACL injury from healthy knees as a result of the study.

In conclusion, our study results demonstrate that small ACLIA and MMBA can be considered independent factors for ACL injury in active individuals. This information can be useful in identifying individuals who may suffer an ACL injury. In addition, the consideration of ACLIA as a risk factor and the preparation of the tunnel accordingly for graft placement during reconstruction may prevent graft rupture.

**Ethics Committee Approval:** The study protocol was approved by the Necmettin Erbakan University Ethics Committee (date: 04.02.2022, no: 2022/3643). The study was conducted in accordance with the principles of the Declaration of Helsinki.

**Patient Consent for Publication:** Informed consent was not obtained from the participants due to the retrospective design of the study and the anonymous analysis of the data.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Author Contributions:** Idea/consept: M.Z.G., Y.M.D.; Design: A.Y., M.Z.G., S.A.; Data collection and/processing: M.Z.G, Z.Y.; Analysis and/or interpretation; A.Y., M.Z.G., S.A., Y.M.D.; References and fundings: M.Z.G., Y.M.D., Z.Y.; Control/supervision: A.Y., Z.Y., Y.M.D.; Literatur review: S.A., M.Z.G., Y.M.D.; Writing the article: S.A., M.Z.G.; Critical review, materials: A.Y., M.Z.G., S.A., Y.M.D., Z.Y.

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