



MORPHOLOGICAL CHARACTERISTICS OF TIBIAL EMINENCE AND THEIR ASSOCIATION WITH ANTERIOR CRUCIATE LIGAMENT INJURY IN PATIENTS AT A TERTIARY ORTHOPAEDIC CENTER IN INDONESIA

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ABSTRACT

Anterior cruciate ligament (ACL) injury is one of the most common knee ligament injuries, often affecting athletes and active individuals. Morphological variations of the tibial eminence may influence ACL vulnerability. This study aimed to evaluate the relationship between tibial eminence morphology and ACL rupture in an Indonesian patient population. A cross-sectional study was conducted at RSUP Haji Adam Malik, Medan, Indonesia, between 2021 and 2023. Forty-five patients who underwent knee radiographs were enrolled, comprising 25 with ACL rupture and 20 without. Tibial eminence measurements—including medial height, lateral height, and width—were obtained from anteroposterior weight-bearing radiographs. Data were analyzed using Eta correlation, with $p < 0.05$ indicating statistical significance. The ruptured ACL group showed significantly smaller medial height (9.20 ± 1.57 mm), lateral height (8.98 ± 1.55 mm), and width (9.92 ± 2.76 mm) compared to controls (10.42 ± 1.09 mm, 10.16 ± 1.04 mm, and 13.70 ± 2.19 mm, respectively). Eta correlation revealed moderate associations for medial ($\eta = 0.411$) and lateral heights ($\eta = 0.406$), and a strong association for width ($\eta = 0.607$) with ACL rupture. Reduced tibial eminence dimensions, particularly width, are strongly associated with ACL rupture. Radiographic assessment of tibial eminence morphology may assist in risk stratification, especially among high-risk populations.

Keywords: anterior cruciate ligament; injury risk factors; knee morphology; radiography; tibial eminence

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common ligamentous injuries of the knee, with an estimated incidence of 32–40 cases per 100,000 persons per year. The ACL plays a critical role in maintaining anterior tibial stability and knee biomechanics, and its rupture often leads to functional limitation, impaired athletic performance, and long-term joint degeneration if untreated (Paudel et al., 2023).

Multiple intrinsic and extrinsic factors contribute to ACL injury risk, including neuromuscular control, hormonal influences, and morphological characteristics of the knee joint. Morphological variations of the tibial eminence—an osseous structure located between the medial and lateral tibial condyles and serving as the attachment site for the ACL—have been proposed as potential anatomical risk factors. Reduced eminence size may alter ACL orientation, tension, and susceptibility to impingement within the intercondylar notch (Herndon, 2024).

The anterior cruciate ligament (ACL) is the primary stabilizing factor for anterior translation of the tibia. ACL injury can result in the knee not functioning optimally, even after successful arthroscopic ACL reconstruction. This can negatively impact athlete productivity (Adhitya et al., 2023). To prevent ACL injury, risk factors for injury can be identified. Many factors, such as knee joint weakness, lower extremity muscle weakness, and knee balance during landing, are correlated with

ACL injury. In addition, risk factors such as body morphology or abnormal knee movement are also associated with ACL tears. ACL tears are reported to have similar morphological characteristics. Several studies have reported that the shape of the femoral intercondylar notch is correlated with ACL injury. In the tibia, the shape or geometry of the tibial plateau joint is also reported to correlate with the ACL, particularly the posterior tibial slope (L. Zhang et al., 2023). The most important parameter for ACL injury is the intercondylar notch. In knee joint morphometric studies, the notch width ratio (NWI) and notch shape ratio (NSR) are often used to detect the possibility of ACL impingement (Q. Zhang & Yeh, 2021). The ACL tibial footprint is attached to the tibial eminence, but few studies have evaluated the morphological relationship between the ACL and the tibial eminence. The tibial eminence articulates with the femoral intercondylar notch, and this structural correlation may influence the occurrence of ACL injury (Q. Zhang & Yeh, 2021). This study aimed to assess the relationship between tibial eminence morphology—specifically medial height, lateral height, and width—and ACL rupture in patients treated at a tertiary orthopaedic referral hospital in Indonesia.

METHOD

Study Design and Setting: This was an analytical observational cross-sectional study conducted at the Orthopaedics and Traumatology Department, RSUP Haji Adam Malik, Medan, Indonesia, between May and June 2024.

Study Population: The study population comprised all patients diagnosed with ACL rupture at RSUP Haji Adam Malik between 2021 and 2023.

Inclusion criteria: (1) Age 18–59 years; (2) ACL rupture confirmed by magnetic resonance imaging (MRI).

Exclusion criteria: (1) History of fracture or deformity involving the proximal tibia or tibial plateau; (2) History of injury to other knee ligaments or supporting structures; (3) Inflammatory or degenerative knee disease; (4) Primary or secondary knee neoplasms; (5) History of knee infection; (6) Congenital musculoskeletal anomalies affecting the knee; (7) Professional athletes.

Sample Size: A total of 45 subjects were enrolled: 25 patients with ACL rupture and 20 controls without rupture, as calculated using a standard proportion formula.

Radiographic Assessment: Anteroposterior weight-bearing knee radiographs were obtained with the knee fully extended. Tibial eminence measurements were performed as follows: medial height—vertical distance from the tibial plateau line to the peak of the medial eminence; lateral height—vertical distance from the tibial plateau line to the peak of the lateral eminence; width—horizontal distance between the peaks of the medial and lateral eminences.



Figure 1. Anteroposterior knee radiograph illustrating measurement of tibial eminence parameters. Medial height = vertical distance from plateau line to medial peak; Lateral height = vertical distance from plateau line to lateral peak; Width = horizontal distance between medial and lateral peaks.

Statistical Analysis: Continuous variables were expressed as mean $\pm$ standard deviation (SD) and categorical variables as frequency and percentage. The association between tibial eminence dimensions and ACL rupture was evaluated using Eta correlation. $p < 0.05$ was considered statistically significant.

RESULT

Study Population: Of the 45 subjects, 28.9% were female and 71.1% were male. The mean age was 29.15 ± 6.35 years. Most ACL ruptures occurred through non-contact mechanisms (76%). The injury mechanism in ACL rupture mostly involves non-contact mechanisms, where as many as 19 (76%) cases of ACL rupture had a non-contact injury mechanism.

Table 1.
Demographic characteristics

Variable	ACL Rupture	Control	Total
Gender			
Female	6 (24%)	7 (35%)	13 (28.89%)
Male	19 (76%)	13 (65%)	32 (71.11%)
Age	29.13 ± 8.56	29.24 ± 2.51	29.15 ± 6.35
Occupation			
Working	21 (84%)	18 (90%)	39 (86.67%)
Not working	4 (16%)	2 (10%)	6 (13.33%)
Side of the knee			
Right	15 (60%)	11 (55%)	26 (57.78%)
Left	10 (40%)	9 (45%)	19 (42.22%)
Injury mechanism			
Contact	6 (24%)	–	–
Non-contact	19 (76%)	–	–

Tibial Eminence Morphology:

Tibial eminence size showed consistent differences between the ACL rupture group and the control group. In the ACL rupture group, the medial tibial eminence height was smaller compared to the control group (9.02 ± 1.66 mm vs. 10.61 ± 1.09 mm), with Eta test analysis indicating a moderate relationship between this variable and the incidence of ACL rupture ($\text{Eta} = 0.411$). Similarly, the mean lateral tibial eminence height was also lower in the ACL rupture group (8.98 ± 1.55 mm) compared to the control group (10.16 ± 1.04 mm), with a moderate relationship indicated by an Eta value of 0.406. Meanwhile, the width of the tibial eminence in the ACL rupture group (9.92 ± 2.76 mm) was also smaller than the control group (13.70 ± 2.19 mm), with the Eta test results showing a stronger relationship ($\text{Eta} = 0.607$).

Table 2.
Tibial eminence morphology

Group	Height of Medial Tibial Eminence (Mean $\pm$ SD)	Height of Lateral Tibial Eminence (Mean $\pm$ SD)	Width of Tibial Eminence (Mean $\pm$ SD)	Eta Value
ACL Rupture	9.20 ± 1.57	8.98 ± 1.55	9.92 ± 2.76	0.411/0.406 / 0.607
Control	10.42 ± 1.09	10.16 ± 1.04	13.70 ± 2.19	

DISCUSSION

This study found that smaller medial height, lateral height, and especially width of the tibial eminence were associated with ACL rupture in an Indonesian patient population, with the strongest association observed for width. A narrower tibial eminence may correspond to a smaller ACL footprint, potentially reducing ligament strength and altering biomechanics.

Because the tibial eminence and the ACL are located in the intercondylar notch and are adjacent to each other, it is hypothesized that tibial eminence morphology is associated with ACL rupture. The anterior cruciate ligament is a crucial structure of the knee joint, playing a role in knee stability. ACL injuries are common and can be influenced by many factors. Among these factors,

morphological characteristics of the knee joint have been reported to be associated with ACL injury, particularly the height and width of the tibial eminence (Babalola et al., 2022).

Numerous studies have investigated factors associated with ACL injury, but few have examined the tibial eminence. Generally, there is a negative correlation between the shape and size of the tibial eminence and the volume of the intercondylar notch, meaning that the higher the tibial eminence, the smaller the volume of the intercondylar notch. Because the ACL is closely connected to the tibial eminence, when the tibial eminence enlarges or undergoes hyperplasia, the intercondylar notch volume decreases, compressing and pulling on the ACL, affecting the direction and stress on the ACL (Babalola et al., 2022).

Furthermore, degenerative knees often exhibit a compensatory joint response, including hyperplasia and osteophytes on the tibial eminence. An enlarged tibial eminence can narrow the space between the tibial eminence and the femoral condyles, or even cause them to touch or collide, often leading to ACL degeneration and impaired function. This decrease in intercondylar notch volume can also alter the direction of the ACL, increase ACL stress, and restore joint stability, potentially acting as a compensatory response and protective factor for the ACL (Babalola et al., 2022).

These findings are supported by other studies, although some studies have yielded conflicting results. This requires consideration of potential anatomical differences. Previous studies have demonstrated morphological variations between races. One study reported a higher proportion of individuals with smaller tibial insertion sizes among Chinese individuals compared to Western individuals (Hoey et al., 2023). Furthermore, it has been reported that the effects of the ecological and occupational environments can also influence functional adaptation and the tibial bone remodeling response (Barak, 2024).

A study conducted by van Kuijk et al. involved healthy patients and patients with ACL rupture. This study assessed the risk of ACL rupture by examining several knee variants. Variants with a smaller intercondylar notch and tibial eminence width were reported to increase the risk of ACL rupture (van Kuijk et al., 2021). A study by Nie et al. also reported that healthy patients had different tibial eminence widths compared to subjects with ACL injuries. These results were also significant (Nie et al., 2022). A study conducted by Babalola et al. found no significant difference in tibial eminence width between groups with and without ACL injuries in an African population. They also explained that this result may be related to the smaller sample size of other studies (Akcaalan et al., 2024). Akcaalan et al. assessed the relationship between eminence morphometry and non-contact ACL rupture using MRI and found that the width and total height of the eminence were significantly associated with ACL rupture. Meanwhile, total eminence height was also found to differ between the ACL rupture and control groups (Akcaalan et al., 2024).

In contrast to other studies, Shaw et al. examined knee morphometrics as a risk factor for ACL injury in patients who had not yet reached skeletal maturity. Although this study did not report the results of tibial eminence height, it found similar findings to this study, where there was a significant relationship between ACL injury and tibial eminence height. Nie et al. reported that tibial eminence height was smaller in patients with ACL injury compared to healthy individuals. This study found no significant relationship between lateral and medial tibial eminence height and the incidence of ACL injury. However, this study reported significant differences between female and male subjects on both the medial and lateral sides with subgroups of healthy subjects and subjects with ACL injuries (Nakamae et al., 2022).

Although sociodemographic factors are associated with tibial eminence anatomy, no studies have examined the relationship between tibial eminence morphology and the incidence of ACL rupture in Indonesia. Therefore, this study is a strength, as it is expected to provide information on tibial eminence morphology in Indonesians, particularly its relationship to ACL rupture. However, this

study focused on examining the relationship between tibial eminence morphology and the incidence of ACL rupture only. Several other factors have been reported to be associated with tibial eminence morphology, such as body mass index (BMI) (Pontoh et al., 2021). Future research is expected to better explain the relationship between tibial eminence morphology and the incidence of ACL rupture by including BMI as a variable.

This study has several limitations, including its observational design, which can only demonstrate associations without establishing causal relationships. The limited sample size, derived from a single healthcare center, makes the results less representative of the broader population. Potential confounding factors such as physical activity, exercise history, or muscle strength were not evaluated. Furthermore, the imaging method used can be affected by image quality and assessor subjectivity, thus risking inter-examiner variability. This study also only assessed morphological parameters without considering functional aspects of the knee, and no longitudinal analysis was performed to assess future injury risk. Therefore, the results should be interpreted with caution.

CONCLUSION

Reduced tibial eminence dimensions, particularly width, are strongly associated with ACL rupture. Radiographic evaluation of tibial eminence morphology may be useful in identifying individuals at higher risk, particularly athletes and physically active populations.

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