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The Risk Factor Analysis of Femorotibial Joint Morphometrics Associated with Severity of Anterior Cruciate Ligament Tear Using MRI Examination: Study in Indonesia

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Abstract

BACKGROUND: Anterior cruciate ligament (ACL) tear is a condition that has been linked to both short-term and long-term clinical outcomes and has an anatomical risk factor known as femorotibial joint morphometrics. There are three grades of this condition, which are sometimes difficult to detect through imaging.

AIM: This study aimed to analyze the prevalent ratio (PR) of femorotibial joint morphometrics to ACL tear grades using magnetic resonance imaging (MRI).

METHODS: An observational approach along with a cross-sectional design was employed. The ACL tear grade and measurement of bi-intercondylar width (BCW), North width (NW), NW index (NWI), tibial plateau slope (TPS), tibial plateau depth (TPD), tibial eminence width (EW), and tibial EW index (EWI) were retrospectively evaluated in 48 patients using knee MRI with new non-contact ACL tear aged above 18 years. The Chi-square test was the statistical analysis used to measure PR.

RESULTS: The number of subjects presented with ACL tear grade I-II and III was 16 and 32, respectively. The PR value of lateral TPS to ACL tear grades and the lowest 95% confidence interval (CI) were both greater than one, and hence, significant. However, the PR values of BCW, NW, NWI, and medial TPS to ACL tear grades were greater than one, but the lowest 95% CI was less than one, and hence, not significant. Finally, the PR values of TPD, EW, and EWI could not be determined in this study.

CONCLUSION: The lateral TPS had a PR value greater than one, indicating that it is considered a risk factor for ACL tear grade III.

Introduction

The most frequently affected knee ligament injury is the anterior cruciate ligament (ACL). Furthermore, there is an occurrence of approximately 15,000 ACL tears in France and 175,000 ACL reconstructions in the United States each year [1], [2]. Women are four to eight times more likely to suffer an ACL tear than men [3], [4]. They are also associated with long-term clinical implications, such as repeated instability, chondromalacia, osteoarthritis, and high morbidity, particularly in athletes [3], [5], [6]. Therefore, it is essential to identify risk factors for ACL tears to prevent this injury [7].

Femorotibial joint morphometrics is one of the anatomical risk factors that can be evaluated radiologically, even though these factors are highly questionable. According to Khodair *et al*., patients with lower North width (NW) and NW index (NWI) are more likely to sustain ACL injuries. However, there was no statistically significant difference in bi-intercondylar width (BCW) in males [8]. This is consistent with Shaw *et al*. showing that the NWI in the ACL-injured group was lower than in the control group of immature patients [9]. According to the results of Xiao *et al*., decreased eminence width (EW) and EW index (EWI) were associated with an increased risk of non-contact ACL injury [10]. Ghandour *et al*. also discovered statistically significant increases in lateral TPS (LTPS) in ACL-injured patients when compared to the control group. There was no significant difference in medial TPS (MTPS) and medial TPD (MTPD) between both groups [6].

The measurement of femorotibial joint morphometrics using magnetic resonance imaging (MRI) is more accurate than radiographs, with more than 90% accuracy, sensitivity, and specificity in diagnosing ACL tears [11]. Imaging is used to differentiate between ACL tear grades but can be difficult. Consequently, this study was conducted to analyze the factors influencing ACL tear grade, specifically distal femoral and proximal tibia morphometrics. It also aimed to compare the prevalent ratios (PR) of distal femoral (BCW, NW, and NWI) and proximal tibial (tibial plateau slope [TPS], tibial plateau depth [TPD], EW, and EWI) morphometrics to ACL tear grades using MRI.

Methods

This study was an observational analytical study with a cross-sectional design. Medical records of patients diagnosed with ACL tears using knee MRI in the Radiology Department RSUP, Dr. Kariadi, Semarang, Indonesia, were assessed between September 2014 and September 2016 based on MRI data availability. The location of this study was selected due to its significance and the Ethical Committee of Universitas Diponegoro in Semarang approved it after discovering no ethical issues. The ethical clearance number was given as No. 961/EC/FK-RSDK/IX/2016. Furthermore, patients over the age of 18 years with a new non-contact ACL tear were included. Those with knee osteoarthritis, lower extremity disability, and lower extremity bone fracture were excluded. Eleven patients with osteoarthritis and 55 with distal femoral or proximal tibia fracture were excluded from this study.

All patients underwent 1,5-Tesla MRI scans of the knee (Signa Excite, GE Medical Systems, Milwaukee, WI, USA). Subsequently, there was an evaluation of two sagittal planes and one coronal plane from a proton density-weighted image (PD) (TR/TE: 1798–15.2 ms, matrix size: 256 × 256, FOV: 20 × 20 cm, slice thickness: 3 mm, and spacing 1 mm) and fat saturation proton density-weighted image (PD FatSat) (TR/TE: 2517–15.3 ms, matrix size: 256 × 256, FOV: 20 × 20 cm, slice thickness: 3 mm and spacing 1 mm). An MRI multimodality image review workstation measured distal femoral and proximal tibia morphometrics (AW VolumeShare 7, GE Medical Systems, Milwaukee, WI, USA).

The femorotibial joint consists of the distal femoral and proximal tibia components. The distal femoral morphometrics includes intercondylar NW, femoral bicondylar width (BCW), and intercondylar NWI, whereas the proximal tibia morphometrics includes posterior tibial slope angle (TPS), TPD, tibial EW, and tibial EWI [7], [9], [10], [12].

The measurements of distal femoral morphometrics were based on Shaw *et al*.'s method and occurred in the coronal and sagittal planes [9]. The image selected for measurement was taken at the ACL's mid-substance and the point of decussation between the ACL and the posterior cruciate ligament (PCL) [8]. Subsequently, a line was drawn through the anatomical axis of the femur at the popliteal groove, parallel to a line drawn across the inferior border of both condyles. NW is the distance between the medial aspect of the lateral condyle and the lateral aspect of the medial condyle measured along this line, whereas BCW is the distance between the femoral condyle's outermost part and this line. The NWI is the ratio of NW to BCW [9], [10], [12] (Figure 1).

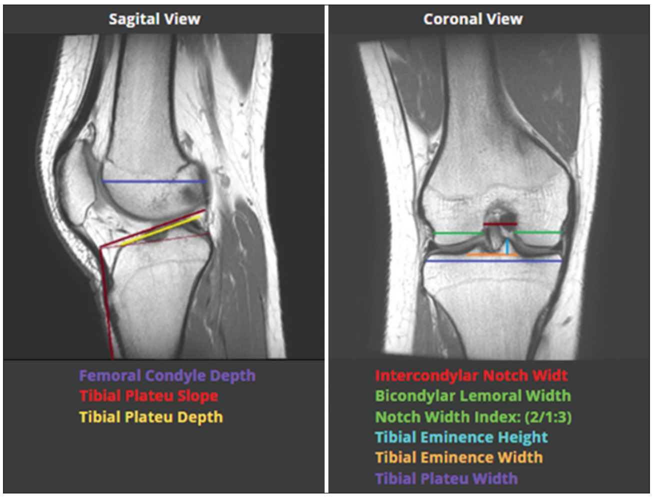

Figure 1: The sagittal sections (for tibial plateau slope and tibial plateau depth) and coronal sections (bicondylar femoral width, intercondylar notch width, notch width index, tibial eminence height, and tibial eminence width) for measurement technique

The measurements of proximal tibia morphometrics were also based on Shaw *et al*. method and occurred in the sagittal and coronal planes [9]. The sagittal plane was used to evaluate TPS and TPD, whereas the coronal plane was used to evaluate EW and EWI. TPS is defined as the angle between a line perpendicular to the tibia's longitudinal axis and a line representing the posterior inclination of the tibial plateau, whereas TPD is the depth of the tibial plateau's concavity. TPS and TPD were both measured at the medial and lateral tibial plateaus. Furthermore, EW is the width of the tibial eminence, measured from the medial to the lateral aspect, whereas EWI is the ratio of EW to the distance between the two outermost parts of the tibial condyles [9] (Figure 1).

The longitudinal tibial axis was drawn with the following steps: the first was an identification of the midline sagittal image in which the tibial attachment of the PCL, the intercondylar eminence, and concave-shaped anterior and posterior tibial plateau were done. Second, on this midsagittal section of the tibia, mark the midpoint of the anterior to the posterior diameter of the tibia at two points situated approximately 4–5 cm apart rearly. These two midpoints when connected represented the longitudinal axis of the tibia. This axis was positioned as an overlay and remained in a fixed position on the sagittal image series [13] (Figure 2).

The classification of the femorotibial morphometrics was based on a cutoff value in previous studies. NW was classified as <20 mm and ≥20 mm, whereas BCW was classified as <70 mm and ≥70 mm [8]. NWI was classified as <0.25 and ≥0.2, whereas MTPS and LTPS were classified as >7° and ≤7° [9], [14]. MTPD and LTPD were classified as <4 mm and ≥4 mm, whereas EW was classified as <11 mm and ≥11 mm [6]. EWI was classified as <0.16 and ≥0.16 [10], whereas ACL tear grading was classified into two groups, grade I-II and grade III for statistical purposes. The MR findings of ACL tear grade I-II were focal hyperintensity intraligamentous, ACL thickening, and partial tear,

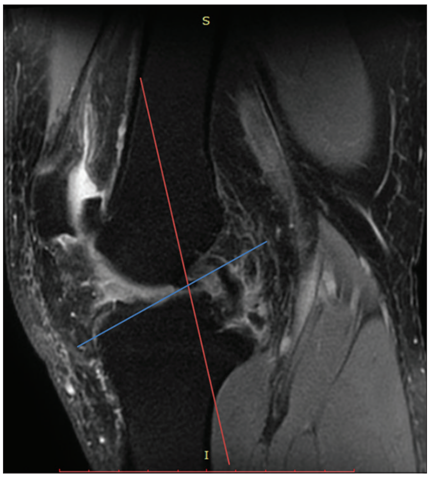

Figure 2: Longitudinal tibial axis in the mid-sagittal plane

whereas grade III findings were complete tear of ACL, non-visualized ACL, horizontalization of distal fragment ACL, wavy contour, or unclearly seen of ACL fiber with thickening of ACL.

Two radiologists used the Kappa test with $p < 0.05$ to assess the distal femoral and proximal tibia morphometrics measurements. Subsequently, one of the measurement data points was selected, and descriptive statistics were used to summarize all the demographic and radiological features of the patients. The Chi-square test (continuity correction) was used to assess the relationships between two or more qualitative variables. The results were presented along with the associated 95% confidence interval and PR value. A $p < 0.05$ was considered statistically significant.

Results

Subject general characteristics

This study consisted of 48 patients, including 30 males and 18 females, representing 63% and 37%, respectively. The age group ranged from 18 to 57 years, and 18 patients were between 21 and 30. In addition, 16 of the 48 knee MRI evaluations had ACL tear grade I-II, whereas 32 had ACL tear grade III, as shown in Table 1.

Table 1: Subject general characteristic

Characteristics	Amount	Percentage
Age (year)		
≤20	16	33.33
21–30	18	37.50
31–40	7	14.58
41–50	4	8.33
>50	3	6.25
Sex		
Male	30	63
Female	18	37
ACL tear grade		
Grade I-II	16	33.33
Grade III	32	66.67

Distal femoral and proximal tibia morphometrics measurement

There were 7 and 41 patients with a BCW of <70 mm and ≥70 mm, respectively. There were also 41 and 7 patients with a NW of <20 mm and ≥20 mm, respectively. In addition, there were 46 and 2 patients with a NWI of <0.25 mm and ≥0.25 mm, respectively, as well as 8 and 40 patients with a MTPS of >7° and ≤7°, respectively. Two sets of 24 patients each had a LTPS of >7° and ≤7°, respectively. Finally, all patients had a MTPD and LTPD of <4 mm, EW of ≥11 mm, and EWI of ≥0.16, as shown in Table 2.

Table 2: Distal femoral and proximal tibia morphometrics in relation to sex

Femorotibial joint morphometrics	Males	Females	Frequency (%)
Distal femoral morphometrics			
BCW			
<70 mm	0	7	7 (14.6)
≥70 mm	30	11	41 (85.4)
NW			
<20 mm	23	18	41 (85.4)
≥20 mm	7	0	7 (14.6)
NWI			
<25 mm	28	18	46 (95.8)
≥25 mm	2	0	2 (4.2)
Proximal tibia morphometrics			
MTPS			
>7°	4	4	8 (16.7)
≤7°	26	14	40 (83.3)
LTPS			
>7°	13	11	24 (50)
≤7°	17	7	24 (50)
MTPD			
<4 mm	30	18	48 (100)
≥4 mm	0	0	0 (0)
LTPD			
<4 mm	30	18	48 (100)
≥4 mm	0	0	0 (0)
EW			
<11 mm	0	0	0 (0)
≥11 mm	30	18	48 (100)
EWI			
<0.16	0	0	0 (0)
≥0.16	30	18	48 (100)

BCW: Femoral bicondylar width, NW: Intercondylar notch width, NWI: Intercondylar notch width index, MTPS: Medial posterior tibial slope angle, LTPS: Lateral posterior tibial slope angle, MTPD: Medial tibial plateau depth, LTPD: Lateral tibial plateau depth, EW: Tibial eminence width, EWI: Tibial eminence width index.

Univariate and bivariate analysis of distal femoral morphometrics factor to the ACL tear grades

ACL tear grade III was seen in five out of seven patients with a BCW of <70 mm, and 27 out of 41 patients with a BCW of ≥70 mm. There were also 28 out of 41 patients with a NW of <20 mm, and four out of seven patients with a NW of ≥20 mm. Furthermore, there were 31 out of 41 patients with a NWI of <0.25, and one out of two patients with a NWI of ≥0.25. There was no statistical significance ($p < 0.05$) in the case of BCW, NW, and NWI. According to the prevalence ratio, patients with a BCW of <70 mm had a 1.085 times higher chance of suffering ACL tear grade III than their counterparts. Patients with a NW of <20 mm also had a 1.195 increased chance of suffering from this condition than their counterparts, whereas those with a NWI of <0.25 had a 1.346 times higher chance than their counterparts, as shown in Table 3.

Table 3: Univariate and bivariate analysis of distal femoral morphometrics factor to the ACL tear grades

Distal femoral morphometrics	ACL tear grades		p-value*	Prevalent ratio	CI
	Grade I-II (%)	Grade III (%)			
BCW					
<70 mm	2 (28.6)	5 (71.4)	1.000	1.085	0.646–1.820
≥70 mm	14 (34.1)	27 (65.9)			
NW					
<20 mm	13 (31.7)	28 (68.3)	0.885	1.195	0.609–2.346
≥20 mm	3 (42.9)	4 (57.1)			
NWI					
<0.25	15 (32.6)	31 (67.4)	1.000	1.346	0.332–5.468
≥0.25	1 (50)	1 (50)			

*Continuity Correction, statistical significance: $p < 0.05$. BCW: Femoral bicondylar width, NW: Intercondylar notch width, NWI: Intercondylar notch width index.

Univariate and bivariate analysis of proximal tibia morphometrics factor to the ACL tear grades

ACL tear grade III was seen in seven out of eight patients with MTPS of >7° and 25 out of 40 patients with a MTPS of ≤7°. It was also seen in 20 out of 24 patients with a LTPS of >7° and 12 out of 24 patients with a LTPS of ≤7°. There was a statistical significance ($p < 0.05$) in the case of LTPS, but not in the case of MTPS. According to the prevalence ratio, patients with a MTPS of >7° had a 1.4 times higher chance of suffering an ACL tear grade III than their counterparts, whereas those with a LTPS of >7° were 1.667 times more likely to suffer from this condition than their counterparts, as shown in Table 4.

Table 4: Univariate and bivariate analysis of proximal tibia morphometrics factor to the ACL tear grades

Proximal tibia morphometrics	ACL tear grade		p-value*	Prevalent ratio	CI
	Grade I-II (%)	Grade III (%)			
MTPS					
>7°	1 (12.5)	7 (87.5)	0.338	1.400	0.981–1.997
≤7°	15 (37.5)	25 (62.5)			
LTPS					
>7°	4 (16.7)	20 (83.3)	0.032	1.667	1.075–2.583
≤7°	12 (50)	12 (50)			
MTPD					
<4 mm	16 (33.3)	32 (66.7)	-	-	-
≥4 mm	0	0			
LTPD					
<4 mm	16 (33.3)	32 (66.7)	-	-	-
≥4 mm	0	0			
EW					
<11 mm	0	0	-	-	-
≥11 mm	16 (33.3)	32 (66.7)			
EWI					
<0.16	0	0	-	-	-
≥0.16	16 (33.3)	32 (66.7)			

*Continuity Correction, statistical significance: $p < 0.05$. MTPS: Medial posterior tibial slope angle, LTPS: Lateral posterior tibial slope angle, MTPD: Medial tibial plateau depth, LTPD: Lateral tibial plateau depth, EW: Tibial eminence width, EWI: Tibial eminence width index.

ACL tear grade III was seen in 32 patients (66.7%) with MTPD of <4 mm, LTPD of <4 mm, EW of ≥11 mm, and EWI of ≥0.16, whereas ACL tear grade I-II was seen in 16 patients (33.3%). None of the patients had MTPD and LTPD >4 mm, EW <11 mm, and EWI <0.16, as shown in Table 4. However, the prevalence ratio of MTPD, LTPD, EW, and EWI to ACL tear grade could not be determined.

Discussion

The results were consistent with those of previous studies in which the majority of ACL tears occurred in people in their third decade of life [15]. Various studies revealed that ACL damage is more likely to occur in males in terms of gender [3], [4], [15]. This study also showed that ACL tear in grade III patients was more prevalent than in grade I-II patients. According to sources, 80% of ACL injuries are complete tears that occur in the middle one-third of the ACL [11]. There is a theory that suggests that the location of the tear is determined by the degree of the injury. There is also a possibility that the ligament tears off the wall in low-energy injuries and it is more typically disturbed in the mid-substance in high-impact injuries. Another possibility is that different tear types could be associated with the mechanisms of the injury. Hyperextension injuries, for example, are more typically associated with proximal tears than valgus mechanisms [14].

The risk factor for distal femoral morphometrics of BCW <70 mm, NW <20 mm, and NWI <0.25 did not influence the grading of ACL tears. ACL-injured females had a considerably lower BCW than the control group in a previous study [8]. According to Angelo *et al*., there was no statistically significant difference in BCW values between the ACL-injured and control groups [16]. The ACL is located in the intercondylar notch, and it can impinge in certain knee postures [17]. There has also been a link between intercondylar notch stenosis and an increased risk of an ACL tear in some studies [12], [18]. A small NW indicates a smaller and weaker ligament [19], [20]. However, Bouras *et al*. found no significant differences in the mean NWI or prevalence of critical notch stenosis in patients with and without an ACL tear [21]. This suggests that distal femoral morphology is merely a risk factor for an ACL tear, not for the severity of the tear.

In addition, LTPS of >7° was found to be a risk factor for ACL tear grade III, whereas MTPS of >7° was not because LTPS >7° occurred more frequently, hence, tearing the ACL. Recent studies suggested measuring MTPS and LTPS separately because patients with ACL tear appeared to have a larger slope on the lateral condyle [15], [22]. According to Ghandour *et al*. and McKinnis, there was no statistically significant difference in MTPS between ACL-injured patients and the control group [4], [6]. ACL-injured patients displayed a higher LTPS than the control group in other studies [4], [15]. Consequently, ACL damage is more likely to occur in people with greater LTPS [12], [15], [23], [24]. Tibial plateau posterior inclination, commonly called TPS, is a bone anatomical feature that affects anteroposterior stability. This is proportional to the degree of tibial anterior translation [23], which shows that a higher TPS results in a higher tibia anterior translation [15], [25], [26]. This translation will produce overtightening and increased strain on the ACL because the ACL is the principal stabilizing structure of the movement. This implies the greater the strain on the ACL, the more probable the tear grade will increase [6], [12], [15].

The MTPD measurements were smaller in patients with an ACL tear than those without and given as 2.25 ± 0.65 mm and 2.44 ± 0.65 mm, respectively, but the difference was of no statistical significance. There was also no statistical significance in terms of age interval. The critical value below 2.12 mm showed a sensitivity and specificity of 68% and 64%, respectively. The odds ratio calculations also showed that smaller MTPD was 4.1 times more likely to occur in patients with an ACL tear [13]. Previous studies also indicated that MTPD was smaller in patients with an ACL injury, and there was no statistically significant difference in MTPD between the ACL-injured female group and the control group [6]. However, Khan *et al*. found that a greater LTPS combined with a lower MTPD resulted in tibia anterior translation, which was considered a risk factor for an ACL tear [12]. The MTPD and LTPD values in this study could not be statistically analyzed because there were no patients with MTPD or LTPD ≥4 mm. It was most likely because the threshold for determining normal and low TPD was set too high. According to Khan *et al*., the average MTPD in ACL-injured males was 2.3 mm and 1.52 mm in females [12].

Previous studies showed that a smaller EW or EWI is considered a risk factor for ACL tears [10]. According to Wang *et al*., EW and EWI could be indicators in predicting the diameter of ACL [27]. Another study also found that a tiny ligament could explain why females are more likely to sustain an ACL injury than males [7]. Furthermore, the EW and EWI values could not be statistically evaluated further because there were no patients with an EW of ≥11 mm or an EWI of ≥0.16. This was most likely due to the value used to calculate the normal and low EW or the EWI being too low.

There were some limitations in this study due to several factors, such as physical activity profile, trauma biomechanics, and ACL size. These factors could significantly affect ACL tear grade but were not accounted for. There was only one group found in the MTPD, LTPD, EW, and EWI variables. Another limitation of this study did not include other ligament injuries and bone edema and injury which may lead to bias.

Conclusion

The results showed that the lateral posterior tibial slope angle (>7°) had a PR value greater than one in ACL tear grades, which was considered a risk factor for ACL tear grades III. Furthermore, these data showed the need for additional studies into the effects of physical activity, trauma biomechanics, and ACL diameter on ACL tear grades.

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