Correlation of tibial tuberosity–trochlear groove distance, anterolateral ligament injury, and the type of trochlear dysplasia with the grade of anterior cruciate ligaments tear

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Abstract

Background The anterior cruciate ligament (ACL) is the most frequently injured ligament. The grade of ACL tear on magnetic resonance imaging (MRI) can help determine the ACL injury treatment. Lateralization of the tibial tubercle is indicated by an increase in the distance of the tibial tuberosity–trochlear groove (TT-TG). Anterolateral ligament (ALL) injury affects a high degree of pivot shift in the knee joint with ACL deficiency. Trochlear dysplasia (TD) is a congenital morphological deformity of the femoral trochlea. An increase in the TT-TG distance, as well as the presence of ALL injuries and TD, can elevate the likelihood of experiencing ACL injuries. This study aims to analyze the correlation of TT-TG distance, ALL injury, and type of TD with the grade of ACL tear through MRI.

Methods This analytical cross-sectional study was conducted from November 2021 to June 2022 at RSUP Dr. Kariadi Hospital, Semarang. The ACL tear was divided into three degrees. The Schoettle or the Nizić method was used to measure the TT-TG distance. ALL injuries were evaluated by looking at the integrity of the ligament. TD assessment was according to the Dejour classification.

Results A total of 50 subjects participated in the study. The TT-TG distance for grade I ACL tears was 5.90–14.6 mm (22%), 1.69–18.30 mm (44%) for grade II, and 1.01–14.10 mm (34%) for grade III. The ANOVA test showed no significant relationship between the TT-TG distance and the degree of ACL tear ($p = 0.146$). ALL injuries were found in six study subjects: One subject (16.7%) had grade I ACL tear, three subjects (50%) had grade II, and two subjects (33.3%) had grade III. The Chi-square test showed no significant correlation between ALL injuries and the degree of ACL tear ($p = 0.930$). Most subjects did not experience TD (78%), while 20% experienced TD type A and 2% experienced TD type B. In type A TD, 50% of ACL tears were grade I, 30% grade II, and 20% grade III. Among all subjects with TD type B, only one was found to have a grade III ACL tear. Based on the Chi-square test, there was no significant correlation between TD type and the degree of ACL tear ($p = 0.110$).

Conclusions There is no significant correlation between the tibial tuberosity–trochlear groove distance, ALL injury, and type of trochlear dysplasia with the grade of ACL tear.

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Background

The anterior cruciate ligament (ACL) injury is typically caused by a traumatic mechanism, such as the knee being externally rotated, hyperextended (non-pivoting injury), or a sudden contraction of the quadriceps femoris muscle. Awan et al. study shows that of 66 cases with ACL injuries, 28 had a complete rupture, while 38 had a partial rupture. The degree of tear in ACL injury, as revealed by magnetic resonance imaging (MRI), can aid in the process of determining ACL reconstruction surgery. ACL tears can be classified into three grades: grade I, where the ligament fibers are stretched with no tear; grade II, involving partial or incomplete rupture of ligament fibers with bleeding; and grade III, complete ligament rupture. Reconstructive surgery for partial ACL injuries is not always a required course of action. Therefore, using MRI imaging to classify the degree of an ACL tear can be extremely beneficial [1–5].

Biomechanical factors related to the quadriceps and patellar tendons, as well as tibial translation and rotation, are important components of ACL injuries. During sports activities, the lateralization of the tibial tubercle, indicated by the greater tibial tuberosity–trochlear groove (TT-TG) distance, increases the rotational shift of the tibia elicited by contraction of the quadriceps when the limb is positioned in a provocative manner. These tibiofemoral kinematic changes can increase ACL tension, making it more susceptible to injury. Several studies have indicated a potential correlation between the TT-TG distance and ACL injury. Saper et al. stated that there was a significant difference in the TT-TG distance between the control group and those with ACL disorders. Yigman and Toprak found a positive correlation between ACL-mucoid degeneration and TT-TG distance [6, 7].

The anterolateral ligament (ALL) originates from the lateral femoral epicondyle with insertion on the proximal aspect of the anterolateral tibia. This ligament plays an important role in stabilizing the internal rotation of the knee. The pivot shift consists of multiple anterior tibial subluxations and excessive internal tibial rotation. This suggests that ALL injuries affect the high degree of pivot shift in the knee joint with ACL deficiency. MRI examination showed that ALL injuries were seen in 32.6% to 78.7% of knees with ACL injuries [8, 9].

The trochlear groove forms the femoral articular portion of the patellofemoral joint. Trochlear shape and depth affect the stability of the patellofemoral joint in flexion and extension. Trochlear dysplasia (TD) is a congenital morphological abnormality characterized by a shallow trochlear angle and depth. As a result, patients with TD are more susceptible to experiencing ACL injuries [7, 10].

The diagnosis of ACL injury is clinically made on a positive Lachman test and MRI examination. MRI examination has a 92–96% sensitivity and a 92–99% specificity in detecting ACL injuries. Several studies have indicated a potential correlation between the TT-TG distance, ALL injuries, and TD type on the incidence of ACL injuries with variative results [11]. Therefore, using MRI examination, this study aims to analyze the correlation between TT-TG distance, ALL injury, and TD type on the degree of ACL tear.

Methods

This cross-sectional retrospective study was conducted at the Radiology Installation of RSUP Dr. Kariadi Hospital, Semarang. This study has obtained ethical permission from the Health Research Ethics Commission at RSUP Dr. Kariadi Hospital, Semarang. From November 2021 to June 2022, a musculoskeletal radiologist reviewed MRI results of 50 subjects diagnosed with ACL knee joint injuries. This study involves patients aged ≥ 18 years with an indirect trauma-type mechanism of injury. Patients who have had previous ACL injury or limb malalignment, as well as those with a history of tumors and infections, were excluded from the study. The independent variable includes the TT-TG distance, ALL injury, and TD type, while the dependent variable is the degree of the ACL tear.

The MRI examination used a 1.5-Tesla (T) General Electric (GE) Signa Voyager. It was performed by installing a knee coil on the affected knee, and the subject was positioned supine and extended with a slice thickness of 3.0 mm and slice spacing of 0.6 mm. The MRI protocol used was axial T1-weighted/T1w (TR 565, TE min full); coronal T2-weighted/T2w (TR 5005, TE 85); axial proton density/PD (TR 2848, TE 55); coronal PD (TR 2415, TE 50); sagittal PD (TR 2455, TE 55); axial proton density with fat saturation/PDFatSat (TR 3384, TE 55); coronal PDFatSat (TR 1599, TE 50), and sagittal PDFatSat (TR 1636, TE 55).

ACL injury

The degree of the ACL tear was classified into grades I, II, and III by looking at the multiplanar MRI imaging on the T2w sequence. MRI assessment on grade I of ACL tear showed ACL thickening and no ligament rupture; grade II of ACL tear showed partial discontinuity of the

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ACL ligament, with an anteromedial bundle (AMB) and/or posterolateral bundle (PLB) rupture; and grade III of ACL tear showed complete discontinuity with abnormalities in focal or diffuse signal intensity [4, 12].

In addition to the degree of ACL tear assessment, the ACL injury location was also assessed based on the Van der List et al. classification. In this classification system, five locations of rupture were determined: type I (proximal avulsion rupture, located > 90% of the distal–proximal length); type II (proximal rupture, located 75–90% of the distal–proximal length); type III (mid-substance rupture, located 25–75% of the distal–proximal length); type IV (distal rupture, located 10–25% of the distal–proximal length); and type V (distal avulsion rupture, located < 10% of the distal–proximal length). For types I and V, the rupture was classified as either a soft tissue or bone avulsion rupture [13].

TT-TG distance
The TT-TG distance is the lateral distance between the deepest point of the trochlear groove and the center point of insertion of the patellar tendon on the tibial tuberosity. The Schoettle method measured the TT-TG distance for subjects with TD type A or without TD abnormalities. For TD type B, the Nizić method was employed [6, 14].

ALL injury
The ALL evaluation was performed on a T2w coronal section, which was visualized as a low-intensity structure originating from the lateral epicondyle of the distal femur and running slightly obliquely toward the anterolateral border of the proximal tibia. ALL injuries were shown in MRI imaging as disrupted ligaments, irregular contours, intra- or peri-ligamentous edema, or a combination of these findings [8].

Trochlear dysplasia
Trochlear dysplasia was characterized by morphological abnormalities of the trochlea and shallow indentation. Based on the Dejour classification, TD characteristics assessed on MRI include: (1) type A, shallow trochlea with a sulcus angle > 145° on the axial section or fairly shallow trochlea; (2) type B, flat trochlea; (3) type C, lateral aspect of trochlea dominant and convex; and (4) type D, absence of the medial aspect of the trochlea. The most proximal section to the intact trochlea cartilage is used to identify medial and lateral trochlea structures on axial MRI imaging sections [14].

Statistical analysis
Data analysis included descriptive analysis using frequency tables (%). The results of the Kolmogorov–Smirnov test for data normality indicated normal distribution for the TT-TG distance and degree of ACL tear, as well as for the TD type and degree of ACL tear ($p > 0.05$). After confirming normal data distribution, a parametric ANOVA test was performed using numerical data for TT-TG distance. As for the categorical data (TD type), a nonparametric Chi-square test was performed. Also, the Chi-square test was used to analyze the ALL injury variable.

Results
Based on the inclusion and exclusion criteria, a sample of 50 subjects was obtained with the characteristics shown in Table 1. The average age was 36 years, with the youngest age being 18 years and the oldest being 77 years. In addition, the study subjects comprised 66% males and 34% females. During the ACL tear degree assessment, 22% of study subjects were found to have a grade I tear, while 44% had a grade II tear. The remaining 34% of subjects had a grade III ACL tear, as shown in Fig. 1.

The results of knee MRI measurements and assessments in patients with ACL injuries showed an average

Table 1 Characteristics of the study sample based on age, gender, degree and location of ACL tear, TT-TG distance, TD type, and ALL injury

Characteristics	*n*	%	Mean:median (min–max)
Age (years)			36:31:00
			(18–77)
Gender			
Male	33	66	
Female	17	34	
ACL tear degree			
Grade I	11	22	
Grade II	22	44	
Grade III	17	34	
ACL injury location			
Type I	2	4	
Type II	13	26	
Type III	20	40	
Type IV	14	28	
Type V	1	2	
TT-TG distance (mm)			7.72: 7.36
			(1.01–18.30)
Trochlear dysplasia type			
Normal	39	78	
Type A	10	20	
Type B	1	2	
Type C	0	0	
Type D	0	0	
ALL injury	6	12	

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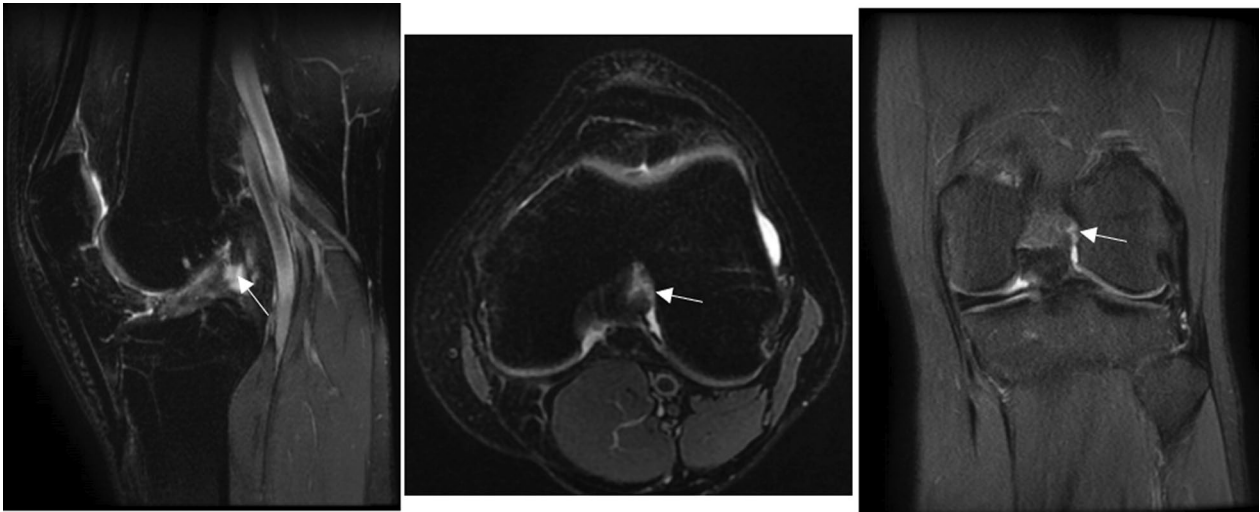
Fig. 1 ACL tear grade III axial, sagittal, and coronal MRI sections of the PDFatSat sequence show complete ACL disruption with type II location (arrows)

TT-TG distance of 7.72 mm with a minimum limit of 1.01 mm and a maximum of 18.30 mm (Figs. 2, 3). The incidence of ALL injury was observed in only 12% of study subjects, as shown in Fig. 4. Meanwhile, TD type A affected 20% of subjects (Fig. 2), and type B affected 2% (Fig. 3). The remaining 78% of subjects had no abnormalities.

For grade I ACL tears, the age range of the subjects was 20 to 69 years. For grade II, the age range was 18 to 62 years, and for grade III, it was 19 to 77 years. Then, a correlation analysis was performed to determine the relationship between the subject's age and the degree of ACL tear. Based on the Kruskal–Wallis test, there was no significant correlation between age and the degree of ACL tear ($p = 0.828$).

Among male subjects, 9.1% had grade I, 48.5% had grade II, and 42.4% had grade III ACL injuries, whereas of female subjects, 47.1% had grade I ACL injury, 35.3% had grade II, and 17.6% with grade III injury. Next, a correlation analysis was performed for gender variables with the degree of ACL tear. The Chi-square test was performed and found a noticeable distinction in the proportion of ACL injury degrees between male and female subjects. The test result showed that most ACL injuries affected male subjects ($p = 0.007$).

Grade I ACL tears were found in 22% of subjects, with a TT-TG distance of 5.90–14.6 mm, whereas grade II ACL tears were found in 44% of subjects with a TT-TG distance of 1.69–18.30 mm and grade III ACL tears were found in 34% of subjects with a TT-TG distance
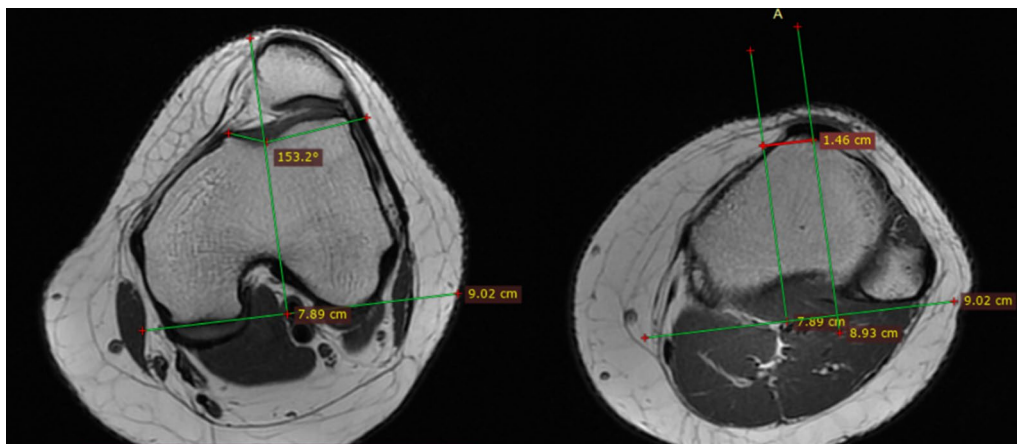
Fig. 2 ACL injury with type A TD (trochlea angle > 145°) with TT-TG distance measurement using the Schoettle method

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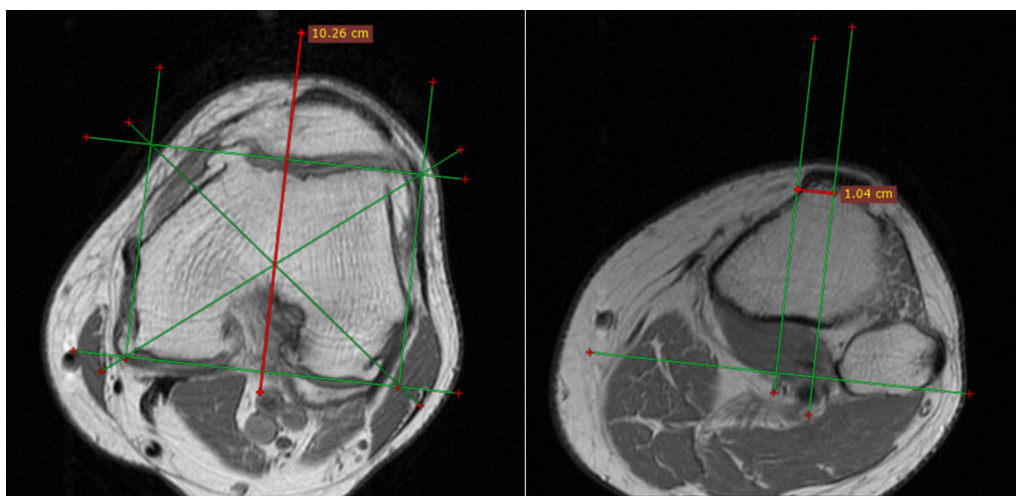
Fig. 3 ACL injury with type B TD (flat trochlea) with TT-TG distance measurement using the Nizić method

Fig. 4 Irregularity and hyperintensity on the distal aspect of ALL (arrow) indicating abnormality or injury

of 1.01–14.10 mm. Then, correlation analysis was performed to determine the difference in TT-TG distance according to the degree of ACL tear (Table 2). Based on the ANOVA test, no significant correlation was observed between the TT-TG distance and the degree of ACL tear ($p = 0.146$).

The total study subjects, 6 subjects had ALL injuries, of which 16.7% of the subject had grade I ACL injuries, 50% had grade II injuries, and 33.3% had grade III injuries. Furthermore, a correlation analysis was performed between ALL injuries and the degree of ACL tear (Table 3). Based on the Chi-square test, there was no significant correlation between ALL injury and the degree of ACL tear ($p = 0.930$).

In trochlear dysplasia type A, 50% of subjects had grade I ACL injuries, 30% with grade II injuries, and 20% with grade III injuries. In trochlear dysplasia type B, 100% of subjects had a grade III ACL injury. There were 39 subjects who did not have trochlear dysplasia. A correlation analysis was performed on the trochlear

Table 2 Difference in TT-TG distance according to the degree of ACL tear

	Degree of ACL tear			*p* value
	Grade I ***n* (%)** **Mean ± SD** **Median (min–max)**	**Grade II** ***n* (%)** **Mean ± SD** **Median (min–max)**	**Grade III** ***n* (%)** **Mean ± SD** **Median (min–max)**	
TT-TG Distance (mm)	11 (22%) 9.41 ± 3.07 8.91 (5.90–14.6)	22 (44%) 7.54 ± 3.62 7.34 (1.69–18.30)	17 (34%) 6.86 ± 3.08 6.70 (1.01–14.10)	0.146

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Table 3 Correlation between ALL injury and the degree of ACL tear

ALL	Degree of ACL tear			*p* value
	Grade I *n* (%)	Grade II *n* (%)	Grade III *n* (%)	
Abnormal (n: 6)	1 (16.7%)	3 (50.0%)	2 (33.3%)	0.930
Normal (n: 44)	10 (22.7%)	19 (43.2%)	15 (34.1%)	

Table 4 Correlation between trochlear dysplasia (TD) type and the degree of ACL tear

TD type	Degree of ACL tear			*p* value
	Grade I *n* (%)	Grade II *n* (%)	Grade III *n* (%)	
Normal (n: 39)	6 (15.4%)	19 (48.7%)	14 (35.9%)	0.110
Type A (n: 10)	5 (50.0%)	3 (30.0%)	2 (20.0%)	
Type B (n: 1)	0 (0.0%)	0 (0.0%)	1 (100.0%)	

dysplasia type with the degree of ACL tear (Table 4). Based on the Chi-square test, there was no significant correlation between the trochlear dysplasia type and the degree of ACL tear ($p = 0.110$).

Grade I ACL tears have medial posterior tibial slope (MPTS) angle values of 2.20–13.60° and lateral posterior tibial slope (LPTS) of 0.70–14.70°, and grade II have MPTS angle values of 0.90–11.10° and LPTS 0.30–9.60°. In grade III ACL injury, the MPTS angle values were 0.80–14.20° and LPTS 0.20–16.20°. A correlation analysis between PTS and the degree of ACL tear was performed (Table 5). Based on the Kruskal–Wallis test, there was no significant correlation between PTS and the degree of ACL tear (MPTS $p = 0.300$; LPTS $p = 0.750$).

Discussion

Based on the inclusion criteria, a total of 50 subjects, comprised of 66% males and 34% females, participated in this study. Additionally, there was a notable variance in the degrees of ACL injury between genders, with most cases occurring in males. In addition, the average age of the study subjects was 36 years, with the youngest age being 18 years and the oldest being 77 years. The subject's gender and age characteristics in this study were comparable to the study of Moon et al., which involved 48 subjects. A higher prevalence was also observed in male subjects ($n = 40$ males and $n = 8$ females) with an average age of 32 years (age range 18–60 years) [15]. Similarly, the Indonesian population study conducted by Deviandri et al. revealed that of 106 subjects diagnosed with ACL injuries, 75 were males, indicating a clear gender disparity [16]. Chaudhari et al. also found that the most common age range for ACL injuries among 162 study subjects was 21–40 years [17].

The general MRI examination found that 22% of subjects had grade I ACL tears, 44% had grade II, and 34% had grade III. In addition, the most common ACL bundle tear in grade II ACL tears was AMB, which occurred in 40.9% of subjects. This finding was aligned with the study of Zhao et al., which found that the highest percentage of ACL injury degrees experienced by the study subjects was grade II or partial (38 out of 66 subjects with ACL injuries) [18]. A study by Awan et al. also stated that partial ACL injuries were more commonly found in study subjects than other degrees of injury [3].

Moreover, type I ACL injury location was found in 4% of subjects, type II in 26%, type III in 40%, type IV in 28%, and 2% in type V. The results of this study support the classification system proposed by van der List et al., which found that most ACL injuries (52%) were categorized as type III [13]. Sherman et al. categorized the location of ACL injuries into four different types in their

Table 5 Correlation between PTS and the degree of ACL tear

	Degree of ACL tear			*p* value
	Grade I	Grade II	Grade III	
	n (%)	*n* (%)	*n* (%)	
	Mean ± SD	Mean ± SD	Mean ± SD	
	Median (min–max)	Median (min–max)	Median (min–max)	
	n: 11 (22%)	n: 22 (44%)	n: 17 (34%)	
MPTS (°)	6.57 ± 3.37	5.01 ± 3.07	6.25 ± 3.74	0.3
	5.30 (2.20–13.60)	3.80 (0.90–11.10)	4.70 (0.80–14.20)	
LPTS (°)	3.62 ± 4.02	4.13 ± 2.89	4.68 ± 4.72	0.75
	2.30 (0.70–14.70)	3.40 (0.30–9.60)	2.90 (0.20–16.20)	

study. Of all 50 subjects with ACL injuries, 26% had type I injury locations, 30% had type II, and 44% had type III or IV injury locations [19]. The study by Sherman et al. showed that type III and IV injury locations were found in 44% of cases, comparable to the 40% of type III injury locations found in the present study.

The results of knee MRI measurements and assessments in patients with ACL injuries showed an average TT-TG distance of 7.72 mm with a minimum limit of 1.01 mm and a maximum of 18.30 mm. ANOVA test indicates no correlation ($p > 0.05$) between the degree of ACL tear and TT-TG distance. This finding follows Matt Davey's theory, which states no significant increase in the TT-TG distance in ACL injuries compared to the control group (ACL injury group = 12.01 mm, normal control group = 11.16 mm). Meanwhile, Saper et al. found a significant correlation between the TT-TG distance and ACL injury only in males and not female subjects [6, 20]. Alpay et al. also stated that the TT-TG distance in ACL injuries and control patients was within normal limits [21].

The TT-TG distance is an indicator in evaluating patellofemoral instability. The TT-TG distance indicates patellofemoral instability if it exceeds 20 mm, as it quantifies knee rotation and tibial tubercles. In cases where ACL injuries are accompanied by ALL injuries, there is an increase in the TT-TG distance [22]. This study found no significant increase in TT-TG distance due to only 12% of ACL injuries having ALL injuries.

Trochlear dysplasia type A was found in 20% of subjects, type B was found in 2%, and no abnormalities were found in the remaining 78% of subjects. The Chi-square test analysis showed no significant correlation ($p > 0.05$) between the TD type and the degree of ACL tear. Yigman et al. found a correlation between TD and the degree of ACL injury and had a larger sample size for TD than this study ($n = 105$ subjects) [7]. This study found that only 11 out of the 50 participants had trochlear dysplasia. In addition, it is important to compare the assessment of TD using conventional photographs of lateral projection of the knee and MRI, as recommended by Dartnell and Hui's review [23]. It should be noted that this study only evaluated TD through MRI examination.

In future studies, it is necessary to compare the group with ACL injuries to the control group. Complete research subject data should include the mechanism and onset of injury, as well as supporting examinations in the form of conventional photographs of the lateral projection of the knee.

Limitations of the study
This study's limitation involved data analysis that was not performed in the normal control group, whereas the supporting studies generally compared the group with ACL injuries and the normal group. Polat et al. and Ntagiopoulus et al. studied acute ACL injury cases (onset within 21 days post-trauma or under 6 months) [22, 24]. In contrast, in this study, the data on the mechanism of injury were unknown at the onset of events. In addition, Dejour classification was performed only via MRI without assessment of conventional photographs on the lateral projection of the knee. Another limitation of this study is the small amount of the sample.

Conclusions
Based on the study results, it can be concluded that no significant correlation is observed between the tibial tuberosity–trochlear groove (TT-TG) distance, ALL injuries, and the type of trochlear dysplasia with the degree of ACL tear. This finding is particularly relevant in cases of ACL injuries without patellofemoral instability.

Declarations

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Consent for publication

Competing interests

The authors declare that they have no competing interests.

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