

Posterior tibial slope measurement on lateral knee radiographs as a risk factor of anterior cruciate ligament injury: A cross-sectional study

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ABSTRACT

Introduction: The posterior tibial slope (PTS) is believed to be a risk factor for anterior cruciate ligament (ACL) injury. The aim of this study was to reveal the differences in terms of PTS measurements on lateral knee radiographs between ruptured and non-injured cases as well as between males and females in regard to ACL alignment.

Methods: The study cohort included 92 patients (61 males and 31 females) with ACL rupture and 101 individuals (59 males and 42 females) who visited the Orthopedics Department but had no ACL injury. PTS measurements on lateral knee radiographs were compared by two blinded reviewers. The results were analyzed in terms of ACL injury and sex differences. The intraclass correlation coefficient was used to calculate interobserver agreements.

Results: Notably, there was an excellent agreement between the reviewers with regard to PTS measurements. In addition, although a statistically significant difference existed in terms of PTS measurements between the patient and control groups ($p < 0.0001$), a significant difference was not observed between males and females ($p = 0.179$).

Conclusion: Lateral knee radiographs are useful for PTS measurements to estimate the risk of ACL injury.

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Introduction

Anterior cruciate ligament (ACL), the main stabilizer of the knee joint,¹ is the most commonly injured ligament of the knee.² Although recent studies have focused on the prevention of ACL rupture, increasingly more research has been devoted to understanding the underlying causes of ACL injury, resulting in the identification of several structural risk factors of ACL,³ including intercondylar notch width, notch width index, femoral condylar

width, posterior tibial slope (PTS), Q angle, alpha angle, and medial condyle depth.⁴

As a possible risk factor of ACL rupture,^{5–9} the shape of the tibial plateau, or the PTS, is believed to have a direct influence on the biomechanics of the tibiofemoral joint.¹⁰ The PTS is formed by the different heights of the anterior and posterior elevations of the tibial plateau. When a large compressive joint reaction force occurs, such as during weight-bearing activities, the PTS causes a corresponding anteriorly directed translation of the tibia as a result of an anteriorly directed shear force.^{11–15} If the magnitude of this anteriorly directed shear force exceeds the failure strength of the ligament, an ACL injury occurs.¹⁰ Therefore, a steeper PTS is expected to increase the magnitude of an anteriorly directed shear force caused by compressive joint force on the tibia.^{13,16,17}

Herein the researchers measured the angle between “the line perpendicular to the longitudinal axis of the tibia” and “the line passing through the highest anterior and posterior points of the tibial plateau” which forms the PTS, on lateral radiographs. The aim of this investigation was to reveal the differences in terms of the PTS values as risk factors of ACL rupture by measurements on

Abbreviations: ACL, Anterior cruciate ligament; ATC, Anterior tibial cortex; AUC, Area under the ROC curve; ICC, Interclass correlation coefficient; LAT, Longitudinal axis of the tibia; MPA, Mean of PTA and ATC; MR, Magnetic resonance; PTC, Posterior tibial cortex; PTS, Posterior tibial slope; ROC, Receiver operating characteristic.

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lateral radiographs of the knee between patients with ACL injuries and non-injured controls as well as between males and females.

Methods

Study approval

The study protocol was approved by the institutional ethics committee. The requirement of informed patient consent was waived due to the retrospective design of the study.

Patient selection

Patient selection was conducted by consensus of two radiologists (a musculoskeletal radiologist with 12-year experience and a general radiologist with 20-year experience), who independently conducted PTS measurements.

The study cohort was limited to 18–50-year-old patients with available radiographs for PTS measurements to avoid bias due to degenerative joint disease. Those without useful radiographs due to inappropriate positioning, tibial fractures, or metallic fixation materials positioned on (or very near to) the tibial plateau, and those clearly showing severe degenerative joint disease (defined as Kellgren–Lawrence grade ≥ 3) or high tibial osteotomy were excluded from the study.

Of 83 patients who underwent ACL reconstruction surgery because of non-contact trauma between January 2014 and February 2018, 10 who were evaluated by magnetic resonance (MR) imaging only and with no available lateral knee radiographs and seven others with lateral radiographs that were insufficient for PTS measurements due to inappropriate positioning were excluded from the study. Of 47 patients who were examined by lateral knee radiographs between July 2017 and December 2017, and had no obvious ACL rupture on MR images, 21 were excluded due to

inappropriate positioning. Thus, the ACL rupture group (patient group) included a total of 92 patients.

Of 155 patients who were examined by lateral knee radiographs between October 2017 and December 2017 and had no history of arthroscopy or no suspicion of ACL rupture on physical examination or MR imaging, 54 were excluded because of the inability to conduct PTS measurements. Thus, 101 patients were included in the non-ruptured (control) group.

All patient exclusions were determined on the basis of the consensus of two radiologists. There might be other factors that may possibly influence the results and the accuracy of the measurements such as neoplasms, bony changes due to severe septic arthritis or rheumatologic joint diseases on the tibial surface but there was no patient excluded from the study due to such conditions or a history related to these pathologies.

All lateral knee radiographies were handled by an automatic exposure device with a film focus distance of 115 cm. A tube voltage of 63 kV and current of 20 mAs were average values for capturing radiographic images.

Radiographic measurements

PTS measurements were made on lateral knee radiographs that met the inclusion criteria. Patients with a lateral knee radiograph showing the femoral condyles were perfectly superimposed, or the posterior condyle borders within maximum 5-mm of distance, were included in the study. After patient selection was carried out on the basis of the consensus of the two reviewers, the tibial slope measurements were handled independently. To begin, the longitudinal axis of the tibia (LAT) was drawn as a line passing through two points located in the center of the anterior–posterior width of the tibia at 6 and 10 cm apart on the proximal diaphysis. The angle formed between the line perpendicular to the LAT and the line passing through the highest anterior and posterior points of the

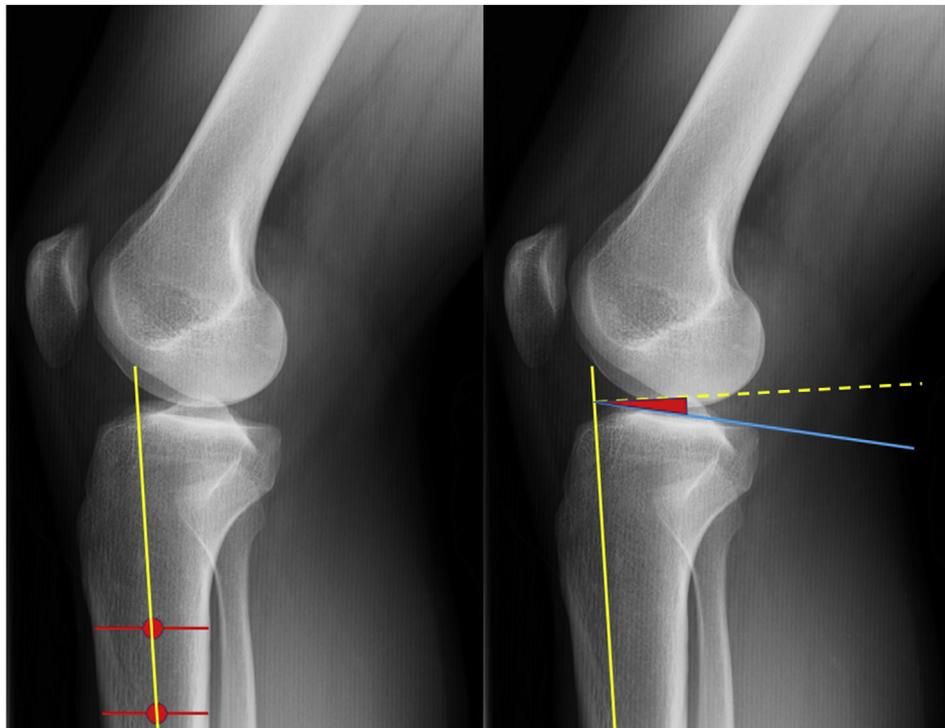


Figure 1. The yellow line that is drawn between the midpoints of the anteroposterior diameters represents the longitudinal axis of the tibia (LAT). The angle (shown in red color) that is formed between the line perpendicular to LAT (dashed yellow line) and the line passed through the anterior and posterior peak points of the tibial plateau represented the PTS.

tibial plateau represent the PTS (Fig. 1). The slope was accepted as positive if the line passing through the highest posterior point of the tibial plateau was below the perpendicular line. Each measurement was performed three times by two reviewers, and the arithmetic mean value was accepted as the final result for each patient.

Statistical analysis

All statistical analysis was performed using MedCalc software (<https://www.medcalc.org/>). According to the power analysis results, if the type 1 error was accepted as 0.05, and the power of the test was accepted as 80%, ≥ 34 individuals were needed in both the patient and control groups for analysis to determine the statistical significance of differences. The homogeneity of data distribution was determined using the Kolmogorov–Smirnov test. Homogeneously distributed data are presented as the mean \pm standard deviation and non-homogeneously distributed data as the median, minimum, and maximum values. The interclass correlation coefficient (ICC) was used to assess interobserver agreements. An ICC value of <0.20 was considered as a poor agreement, 0.20 – 0.40 as fair, 0.41 – 0.60 as moderate, 0.61 – 0.80 as good, and 0.81 – 1.00 as very good. The independent sample *t*-test and Mann–Whitney *U*-test were used to identify differences in PTS values between the patient and control groups as well as between males and females. Receiver operating characteristic (ROC) curves were used to identify associations between PTS values and ACL injury. A probability (*p*) value of <0.05 was considered statistically significant.

Results

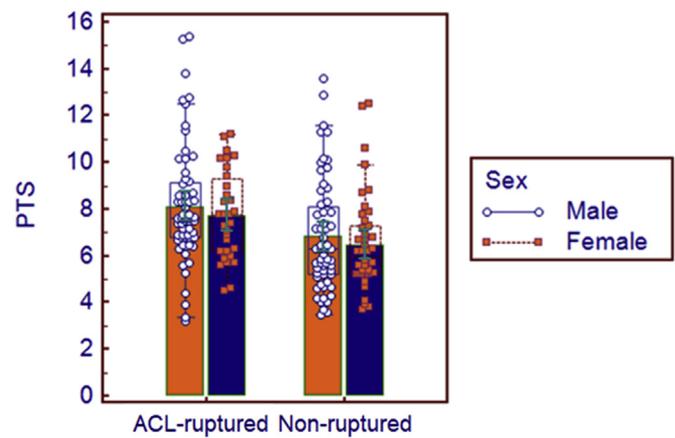
The number of patients with regard to age and sex are shown in Table 1. There were no significant differences in the median ages of patients vs. controls (27 vs. 28 years, respectively) or between males and females (28 vs. 28 years, respectively). Box-plot analyzes were used to reveal the data distributions with regard to PTS measurements between the patients and controls, as well as between the males and females (Graphic 1). According to the data distribution of measurement results, the ACL ruptured group had higher values of PTS for the total of patients, for males and for females as well. Maximum and minimum values of PTS were measured in the ACL ruptured group of males.

The non-homogeneously distributed PTS measurements are presented as the median, minimum, and maximum values. The PTS measurements of all males vs. all females were homogeneously distributed. The ICC values indicated very good agreement between the patient and control groups, and between the male and female groups (Table 2). When sex differences were taken into consideration, there was no statistically significant difference in PTS measurements between the male and female groups ($p = 0.210$ and 0.179 , as determined by reviewers 1 and 2, respectively; Table 2). However, there were statistically significant differences in PTS measurements between the patient and control groups

Table 1
The distribution of patients with regard to age and sex differences.

Patient/Control	Age [median (min; max)]	Male (n)	Female (n)	Total (n)
ACL-Ruptured	27 (18; 44)	61	31	92
Non-Ruptured	28 (18; 49)	59	42	101
Age [median (min; max)]	28 (18; 49)	28 (18; 49)	28 (18; 45)	193

ACL: Anterior cruciate ligament, SD: Standard deviation, min: minimum value, max: maximum value.



Graphic 1. The data distribution of ACL ruptured and non-ruptured group with regard to sexes.

($p < 0.0001$), as well as the male and female groups in regard to ACL injury ($p < 0.05$; Table 3).

If the cutoff value of PTS measurements was accepted at >5.9 , sensitivity was 88% and specificity was 50.5%, whereas the area under the ROC curve (AUC) was 0.710 (Graphic 2).

Discussion

The results of this study indicated significant differences in terms of PTS values between the patient and control groups, and between the male and female groups. PTS measurement on lateral knee radiographs was confirmed as a possible risk factor of ACL rupture.

The tibial slope is an important factor influencing the biomechanics of the knee.¹⁸ It is known that slope alterations affect the kinematics and stability of the knee.^{11,19–21} The tibial slope is not static and changes from birth until skeletal maturity.^{18,22} Past studies have reported that the PTS ranges from 0° to 20° , and the average value varies among populations.^{21–27}

A steeper tibial plateau with axial loading generates greater anterior translation of the tibia, which is stabilized by the ACL, but causes overtightening. Biomechanical studies revealed the association of PTS with various aspects of knee biomechanics. For example, Takai et al.²⁸ showed that the anteromedial and posterolateral bundles of the ACL were equally loaded in full extension with an anterior tibial translation of 100 N, even though the anteromedial bundle is the primary load bearer at knee flexion of $>45^\circ$. A study on the effect of ACL resection on anteroposterior shear forces conducted by Singerman et al.²⁹ showed that ACL resection resulted in anteriorization of force vectors. Li et al.³⁰ studied the effects of dynamic muscle forces on compressive loading and forces on the cruciate ligaments. In that study, quadriceps loading at 200 N and co-contraction of hamstring muscles with 80 N using cadaveric knee specimens indicated reductions in *in situ* forces to the ACL at 15° , 30° , and 60° of knee flexion by 30%, 43%, and 44% respectively. Imran and O'Connor³¹ used a mathematical model to analyze the influence of the tibial surface geometry on forces to the cruciate ligaments of the knee using a simulated anteroposterior laxity test. The results showed that the contact and ligament forces had increased with a posterior tilt of the tibial plateau.³¹ A possible reason for the change in joint compression with tibial slope alterations with this model is shifting either anteriorly or posteriorly. A study by Chan and Seedhom³² showed that the curvature of the tibial surface modifies the tension along either cruciate ligament, and in the absence of an axial

Table 2The mean values of PTS measurements, interobserver agreements of the interpreters and the *p* value of sex difference.

PTS (degrees)	R1 (mean ± SD)	R2 (mean ± SD)	ICC	<i>p</i> value (R1; R2)
PTS (for total)	6,9 (3,2; 15,4) Median (min; max)	7,3 ± 2,4	0,96	
PTS (for all males)	7,4 ± 2,5	7,4 ± 2,6	0,97	0,210; 0,179
PTS (for all females)	7,0 ± 2,0	6,9 ± 2,1	0,94	

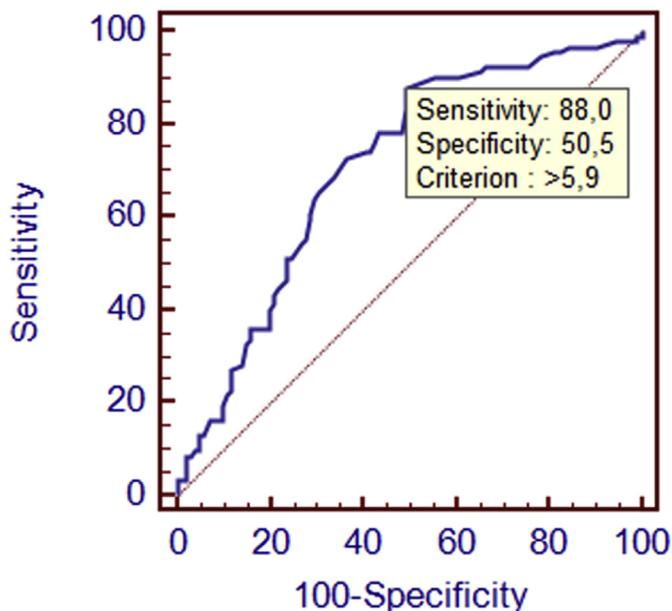
PTS: Posterior tibial slope angle, MTS: Medial posterior tibial slope, LTS: Lateral posterior tibial slope, ICC: Interclass correlation coefficient, SD: Standard deviation, R1: Reviewer 1, R2: Reviewer 2.

Table 3The mean values of PTS measurements, and the *p* values for differences between patient and control groups.

PTS (degrees)		Reviewer 1 (R1) Median (min; max)	Reviewer 2 (R2) (mean ± SD)	<i>p</i> value (R1; R2)
Total	PTS (patient)	7,6 (3,2; 15,4)	8,1 ± 2,4	<0.0001
	PTS (control)	6,2 (3,5; 13,6)	6,5 ± 2,2	
Males	PTS (patient)	8,1 ± 2,5 (mean ± SD)	8,2 ± 2,5	0.0022; 0.0011
	PTS (control)	6,7 ± 2,4 (mean ± SD)	6,7 ± 2,4	
Females	PTS (patient)	7,7 ± 1,9 (mean ± SD)	7,8 ± 2,1	0.0092; 0.0025
	PTS (control)	6,4 ± 2,0 (mean ± SD)	6,3 ± 1,9	

PTS: Posterior tibial slope angle, SD: Standard deviation.

The *p* values showing statistically significant differences were indicated in bold.

**Graphic 2.** The ROC analysis of PTS and ACL injury relationship.

compressive load on the knee joint, small changes in the geometry of the tibial plateau causes an increase or decrease in tension. Furthermore, a study on the influence of PTS on anterior translation of the tibia in ACL-deficient and normal knees conducted by Dejour et al.³³ showed a 6-mm increase in anterior tibial translation for every 10° increase in PTS.

Previous studies have also demonstrated the effect of the tibial plateau on ACL injuries in light of the biomechanical background. For example, a case control study of 146 patients conducted by Zeng et al.³⁴ suggested that an increase in PTS was associated with a greater risk of non-contact ACL injury. Notably, in that Chinese population-based study, the inter- and intra-rater reliabilities with regard to PTS measurement on lateral knee radiographs were higher than in the present study.³⁴ Webb et al. used lateral knee radiographs in a prospective study of 200 patients who underwent

ACL reconstruction. Two reviewers interpreted the lateral knee radiographs of these patients and proposed that an increase in PTS is associated with a greater risk of further ACL injury after surgery.³⁵ A study of 32 skeletally immature patients with lateral knee radiographs conducted by O'Malley et al.³⁶ concluded that a moderate association may exist between PTS and ACL injury. Bisicchia et al.³⁷ investigated the influences of ethnicity and sex on PTS measurements and found differences among ethnic groups, but observations between sexes were conflicting, suggesting that the difference is too small to have any clinical implication. In the current study, there was a significant difference in PTS measurements between the patients and controls, but not between males and females.

Both radiographic and MR images are often used for PTS measurement. As a cross-sectional imaging method, MR imaging has the advantage of obtaining lateral and medial measurements of the tibial slope independently. Some MR imaging studies have suggested that the tibial slope is a possible risk factor of ACL injury, as an increase in either medial^{6–9} or lateral^{5,6} PTS values have been associated with ACL injury.

Aside from the positive results of the possible effect of PTS on ACL injury, the negative opinions of some authors should also be mentioned. For example, Hudek et al.³⁸ reported no relationship between lateral or medial PTS measurements with MR images and ACL injury. Moreover, a prospective cohort study by Beynon et al.³⁹ concluded that medial PTS was not associated with the risk of ACL injury regardless of sex and lateral PTS was correlated with ACL injury only in females.

In the present study, knee radiographs were used for PTS measurements because this imaging method is routinely performed before knee arthroscopy and further radiographs would result in unnecessary radiographic exposure. The PTS on a lateral radiograph is defined as the angle formed between the tangent of the medial and lateral tibial plateaus and a line perpendicular to the longitudinal mechanical axis.^{13,24,26,40,41} Various tibial axes have been reported in the literature.^{26,40,42–44} For instance, a study by Uzsneider et al.⁴⁵ of 14 cadaveric knees found that the PTS measurements using lateral radiographs varied depending on the applied method. The mean of the anterior tibial cortex (ATC) line and posterior tibial cortex (PTC) line, which was defined as the MPA (the mean of PTA and ATC), demonstrated the best correlation to a

computed tomographic scan, even on short knee radiographs, and concluded that short lateral radiographs using the MPA was a reliable method to measure the PTS.⁴⁵ Faschingbauer et al.⁴⁶ studied three axes to measure the PTS on lateral radiographs with the field of view including the complete tibia. The diaphyseal axis formed by a mid-diaphyseal line at 6 and 16 cm below the tibial plateau (axis 1), a mid-diaphyseal line at 6 and 10 cm below the tibial plateau (axis 2), and a mid-diaphyseal line at 16 and 20 cm below the tibial plateau (axis 3) were measured in comparison with the true lateral tibial axis. The correlation between the PTS in relation to the true lateral tibial axis was best with axis 3, which was formed by a mid-diaphyseal line more distal to the maximum cut off line on lateral knee radiographs. The authors concluded that PTS can only be estimated on short knee radiographs and the results would be increased by approximately 3°. In the current study, the center points of the anterior–posterior width of the tibia, which were drawn at a distance of 6 and 10 cm from the tibial plateau, formed the tibial axis for PTS measurements.

PTS is not the only possible anatomical factor to influence the risk of ACL injuries. A narrow femoral notch was found to be associated with ACL rupture in the past studies.^{47–54} Some authors claimed that “a small notch houses a smaller, thus a weaker ligament” and this variance was thought to be a risk factor for ACL injury during activity.⁵⁵ More joint rotation was expected with the increase in the size of the femoral condyle. Therefore, according to some researchers, increased condyle size was expected to be another factor to increase the risk of ACL rupture.⁵⁶ The longitudinal axis of the femur and the Blumensaat line form the alpha angle. Fernandez-Jaen et al. claimed that an increased alpha angle causes a more horizontal elongation of the ACL and produces an impingement against the anterior intercondylar notch. On the other hand, less impingement would be observed with a more vertical position of the ACL, and the ligament could turn on itself with a decreased alpha angle. This situation might have led more frequent ACL injuries in individuals with increased alpha angles.⁵⁷ Some observational studies have suggested that a dynamic alignment of the lower limb characterized by a combination of adduction and internal rotation of the hip and the knee valgus might be an underlying mechanism and predictor of ACL rupture.^{58,59} Some researchers found significant differences regarding Q angle measurements between ACL-injured and non-injured groups consisting for both males and females.⁶⁰ Considering the mechanism through which an increased PTS becomes as a risk factor for ACL rupture, it can be supposed that an increased posterior-inferior-directed tibial slope combined with a shallow tibial plateau, might increase the risk of ACL injuries.^{6,10} The biomechanical explanations of injury mechanisms show that multiple risk factors seem to be responsible for ACL rupture. Even if prominent studies in literature imply the role of an increased PTS as a risk factor, other anatomical factors should also be considered. Moreover, the combined effect of PTS and other morphological factors should also be studied in order to better understand ACL injury tendencies.

In consideration of all of the cited studies, the authors of the current study propose measuring the PTS on lateral knee radiographs to estimate the risk for ACL rupture. This will encourage clinicians to reexamine the patient for a possible ACL injury and if necessary, perform further investigations, such as MR imaging. On the other hand, shorter imaging intervals might be used for control examinations of patients after ACL reconstruction surgery, as the PTS measurements on lateral radiographs were greater than expected.

There were some limitations to this study that should be addressed. First, lateral radiographs were used for PTS measurements, and the field of view was limited to the proximal diaphysis distally. The longitudinal tibial axis, which is essential for PTS measurement, was drawn on the lateral knee radiographs.

However, the use of an expanded lateral radiograph would depict a closer approximation of the LAT and PTS measurements. A perfect lateral knee radiograph to measure the PTS is very hard to obtain because of small differences in the X-ray tube angle or patient positioning. The second limitation was the effect of projection and positioning inaccuracies. Third, although the measurements were conducted by two experienced radiologists with high interobserver agreements, human error may have occurred, particularly because of the very narrow angles. The investigation of possible differences in measurement results caused by positioning inaccuracies and human error might be the subject of another study. Revealing how these variances would influence PTS measurement results and the differences between ACL-injured and non-injured individuals could add an important aspect to the research. Lastly, the effects of height, weight, body mass index, and ethnicity of the study population are important parameters that should be considered in relation to the tibial slope, but this study was limited to the investigation of tibial geometry with regard to PTS as a possible risk factor for ACL injury.

According to the results of the current study, the authors revealed an important relationship between PTS values and ACL injury, however, further investigations are needed to verify more accurate cutoff values in order to introduce the use of this parameter in routine radiology reports assessing the risk of ACL rupture.

Conclusion

PTS is a possible risk factor of ACL rupture, as demonstrated by the significant differences on lateral radiographs between the patient and control groups. On the other hand, there was no significant difference in PTS measurements between the male and female groups. PTS measurements on lateral knee radiographs might be useful to estimate the risk of ACL injury.

Author contributions

Guarantor of integrity of entire study: VK.
 Study concepts: VK, GRU, HA.
 Study design: VK, AKS, GRU.
 Data acquisition: VK, TÇ, GRU, KY.
 Data analysis: VK, TÇ, GRU, HA, KY.
 Statistical analysis: AKS, VK.
 Image Interpretations: VK, TÇ.
 Literature research: VK, KY, HA, GRU.
 Manuscript drafting: VK.
 Manuscript editing: VK, AKS, HA, KY, TÇ, GRU.

Conflict of interest

All authors declare that there is no conflict of interest regarding the publication of this paper.

Ethics

This study has been approved by ethics committee.

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