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The Effect of Proximal Posterior Tibial Slope on the Incidence of Anterior Cruciate Ligament Injury

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SUMMARY
Several studies have investigated the association of posterior tibial slope (PTS) with anterior cruciate ligament (ACL) injury. However, the results have been inconclusive and even contradictory. The first goal of this study was to evaluate the association of PTS with an ACL injury. The second goal was to identify the patients' characteristics that might affect PTS and ACL injury. In a retrospective case-control study, PTS was evaluated in the MRI of the 173 patients with an ACL tear and 136 patients who underwent MRI for other knee injuries. MRI images were analyzed using imaging software (OsiriX). The role of the patient's characteristics, such as age and gender, in the association of PTS with an ACL injury was also assessed in the ACL tear group. Both medial and lateral PTS were significantly more in the ACL tear group than the ACL intact group ($p < 0.001$ for both). In patients with an ACL tear, lateral PTS, but not medial PTS, was significantly greater in females and older patients ($p = 0.23$ and < 0.001 respectively). In multivariate analysis, lateral PTS, older age, female gender, and associated injury were significant risk factors of an ACL tear. Medial PTS was not identified as a significant risk factor of the ACL tear in the multivariate model. Although PTS is a significant predictor of an ACL tear, patients' characteristics such as gender and age could be used further to characterize the association of PTS and ACL injury and identify the subjects at higher risk of ACL injury.

KEY WORDS
Anterior cruciate ligament; MRI; Posterior tibial slope; Osirix software; injury.

BACKGROUND

The anterior cruciate ligament (ACL) injuries are among the most common knee injuries, which generally occur when pivoting or landing after a jump (1, 2). Even with accelerated rehabilitation programs, recovery (rehabilitation after surgery) from ACL injuries usually lasts 6 to 8 months (3, 4). Nevertheless, a significant number of professional athletes who sustain an ACL injury do not return to top-level competition (5). Moreover, ACL injury has significant potential for the induction of early-onset osteoarthritis (6). These serious short- and long-term consequences of ACL injuries encourage further investigations on identifying predisposing factors of ACL injuries.

Several extrinsic and intrinsic factors risk factors have been suggested for ACL injury. Weather, condition of playing field, and footwear are acknowledged as the extrinsic risk factors of ACL injury (7). Many hormonal, physiologic, and genetic factors have been noticed as the intrinsic risk factors of ACL injury (8). Several anatomic characteristics have also been associated with the increased risk of ACL injury, such as decreased intercondylar femoral notch size, increased anterior-posterior knee laxity, and decreased concavity depth in the medial tibial plateau (9).

Posterior tibial slope (PTS) has been suggested as an anatomic risk factor for ACL injury. Based on biomechanical studies, PTS plays a vital role in the knees stability so that increased PTS is associated with a more extensive anterior tibial translation and a consequently higher rate of ACL injury (10, 11). The association of increased PTS with increased risk of ACL injuries has been demonstrated in several clinical studies (12-15). However, the results of studies that have examined the relationship between demonstrated injury have been inconclusive and sometimes contradictory (15-19).

Patients' characteristics such as age and gender have been suggested as factors impairing the association between PTS and ACL injury, leading to the inconclusive results of earlier investigations (19). We hypothesized that further categorization of patients according to their age and gender would shed more light on the role of PTS as a risk factor of ACL injury. Such categorization also provides more consensuses regarding the implication of PTS for screening purposes as a part of ACL injury prevention programs. This study adds to the existing literature, working toward a consensus.

This investigation aimed to evaluate the relationship between PTS and ACL injury in a case-control study. The studys secondary goal was to determine the role of patients age and sex in the association of PTS with an ACL injury.

MATERIALS AND METHODS

The study was conducted in accordance with institutional and international (Declaration of Helsinki) standards. Ethical approval was obtained from the Ethics Committee of Isfahan University of Medical Sciences (IR.MUI.MED.REC.1397.366). Before provision of written informed consent, all study participants received written and verbal information about voluntary participation and the purpose and using their information and data in the study. After the examination, all participants were informed of relevant findings. Where indicated, they were advised to contact an appropriate care provider, or they were referred for further investigation.

This study was done in Ayatollah Kashani Hospital, Isfahan, Iran, and patients provided written consent to use their medical files for publication. In a retrospective case-control study, the medical notes of patients consecutively referred to our university hospital between 2018 and 2019 and who had a knee injury were reviewed. The patients were included in the study if they had a knee MRI (magnetic resonance imaging) and age of 18-50 years. Patients with a multi-ligament knee injury or a history of knee surgery were excluded from the study. From a total of 357 patients, 309 patients were identified as eligible for the study. PTS was compared between patients with and without an ACL tear.

ACL was assessed using a 4-point grading scale for ACL injuries, including intact, low-grade partial (less than 50% of ligament substance), high-grade partial (more than 50% of ligament substance), complete tear (20). Demographic characteristics of the patients, such as age, gender, and mechanism of injury, were extracted from the patients notes. MRI was analyzed using imaging software (OsiriX). The tibial slope was assessed according to the previously described method (21). For this purpose, we first identified the longitudinal axis of the tibia on the adequate MRI slice. Then, we highlighted the sagittal anatomical axis of the tibia by a line. After identifying the mediolateral center of the medial plateau, we draw a tangential line connecting the posterior cortex of the medial plateau to the uppermost superior-anterior cortex. The angle between the line orthogonal to the longitudinal axis and the line tangential to the surface of the medial plateau was regarded as the slope of the medial tibial plateau. The slope of the lateral tibial plateau was measured by identifying the mediolateral center of the lateral plateau and by repeating the steps which were described for the calculation of the medial tibial plateau (**figure 1**).

Two fellowship-trained knee surgeons did the measurements. The reliability of measurements was assessed by intraclass correlation (ICC) analysis on 20 randomly selected MRIs. In this respect, an ICC value of 0.97 and 0.98 was obtained for the lateral and medial tibial plateau, respectively, showing a strong correlation between investigators measurements.

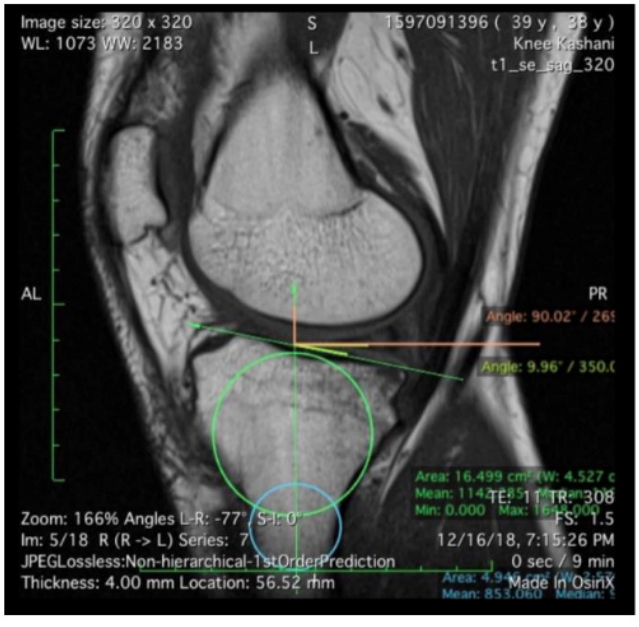

Figure 1. Posterior Tibial Slope measurement by using Osirix software.

Characteristics features of the patients

The study population included 190 (61.5%) males and 119 females (38.5%) with a mean age of 31.9 ± 8.6 years (range 18-49). Injury during non-contact sports participation was the most frequent mechanism (n = 106, 34.3%). ACL tear was detected in 173 (56%) patients, while the ACL was intact in the remaining 136 (44%) patients. The low-grade partial tear was the most common type of ACL tear (n = 88, 50.9%). The characteristic features of the patients with and without an ACL tear are demonstrated in **table I**.

Statistical analysis

SPSS for Windows, version 16 (Chicago, Illinois, USA) was used for statistical evaluations. Descriptive statistics were presented as mean ± standard deviation (SD) or number and percentage. An independent T-test was used for the comparison of mean values between the two study groups. A one-way ANOVA test was used for the comparison of mean values between more than two groups. A chi-square test was used to evaluate the association between categorical variables. Pearsons or Spearmans correlation coefficient test was used for the evaluation of potential correlations. Binary logistic regression analysis was used for the multivariate analysis.

A P-value of less than 0.05 was considered significant. It is noteworthy that the power test value was higher than 80% in all statistical tests, according to sample size.

RESULTS

The mean medial PTS was 7.62 ± 1.21° (range 2.73-12.47). The mean lateral PTS was 7.24 ± 1.16° (range 2.68-12.33). The difference between medial and lateral PTS was statistically significant (p = 0.04). However, a significant correlation was observed between the lateral and medial PTS (r = 0.880, p < 0.001). The mean medial PTS was 7.87 ± 1.21° in patients with an ACL tear (included: high grade and low grade) and 7.31 ± 1.15° in patients without ACL tear. This difference was statistically significant (p < 0.001). The mean lateral PTS was 7.47 ± 1.11° and 6.95 ± 1.17° in patients with and without ACL tear, respectively. This difference was statistically significant, as well (p < 0.001).

According to the results of the study, there was an association between PTS grade and medial (r = 0.249; p < 0.001) and lateral (r = 0.23; p < 0.001). Also, the mean medial and lateral PTS was significantly more in patients with a low-grade partial tear. The mean medial and lateral PTS was significantly more in higher age groups as well. Also, the medial and tibial PTS were significantly more in patients with asso-

Table I. Comparison of characteristic features between patients with and without an ACL tear.

Variable	With ACL tear (n = 173)	Without ACL tear (n = 136)	P-value
Age (year)	33.1 ± 8.9	30.4 ± 8.1	0.007
Sex			
Male	120 (69.4)	70 (51.6)	0.001
Female	37 (30.6)	66 (48.5)	
Mechanism of injury			
Fighting	7 (4.1)	4 (2.9)	
Contact sport	30 (17.3)	29 (21.4)	0.48
Non-contact sport	63 (36.4)	43 (31.6)	
Motor vehicle accident	44 (25.4)	34 (25)	
Falling	18 (10.4)	20 (14.7)	
Associate injury			
Yes	76 (43.9)	102 (75)	< 0.001
No	97 (56.1)	34 (25)	
Tear type			
Complete tear	36 (20.8)	-	
High grade partial tear	39 (22.5)		-
Low grade partial tear	98 (55.7)		

ciate injuries. No significant association was found between the patients lateral and medial PTS and gender (**table II**).
In patients with an ACL tear, the mean medial PTS was not significantly different between the male and females and in different age groups. The mean lateral PTS was significantly more in females and the older age group (**table III**).
According to the logistic regression analysis, lateral PTS was a significant risk factor of an ACL tear, so that for every 1° increase in lateral PTS, the risk of ACL tear increased 1.37-fold. Age, sex, and associate injury were other significant risk factors of an ACL tear.

DISCUSSION

In this study, we evaluated the role of PTS as a risk factor of ACL injury, considering the role of other clinicodemographic characteristics of the patients in this association. According to our univariate analysis, both medial and lateral PTS were more in patients with an ACL tear. In patients with an ACL tear, lateral PTS was significantly increased in females and older patients. In multivariate analysis, lateral PTS was a significant risk factor for an ACL tear. Older age, female gender, and associate injury were identified as other risk factors for an ACL tear.

Table II. Comparison of medial and lateral PTS in different subgroups of patients.

Variable	Medial PTS	P-value	Lateral PTS	P-value
ACL tear				
Positive	7.87 ± 1.21	< 0.001	7.47 ± 1.11	< 0.001
Negative	7.31 ± 1.15		6.95 ± 1.17	
Type of tear				
Complete tear	7.66 ± 1		7.4 ± 0.88	
High-grade partial tear	7.48 ± 0.99	< 0.001	7.09 ± 0.94	< 0.001
Low-grade partial tear	8.14 ± 1.31		7.66 ± 1.2	
Age group				
< 20 years	6.54 ± 1.32		6.29 ± 1.44	
20-29 years	7.43 ± 0.83	< 0.001	7.01 ± 0.96	< 0.001
30-39 years	7.73 ± 0.93		7.44 ± 0.89	
> 40 years	8.2 ± 1.4		7.79 ± 1.22	
Sex				
Male	7.55 ± 1.15	0.2	7.18 ± 1.15	0.23
Female	7.74 ± 1.3		7.34 ± 1.08	
Associate injury				
No	7.47 ± 1.08	0.008	7.14 ± 1.08	0.01
Yes	7.84 ± 1.34		7.39 ± 1.27	

PTS: Posterior Tibial Slope.

Table III. Logistic regression analysis showing the association of PTS and other characteristic.

Variable	Odds ratio	95% CI	P-value
Lateral PTS	1.37	1.08-1.74	0.01
Age	1.03	1.002-1.059	0.039
Sex	2.91	1.679-5.057	< 0.001
Associate injury	3.308	1.958-5.588	< 0.001

PTS: Posterior Tibial Slope; Cl: Confidence Interval.

Previous studies have investigated the association of PTS with an ACL tear. Şenişik *et al*., in a longitudinal study, examined the effect of PTC on the risk of ACL in soccer players. PTS in the injured players was more significant than in injured players. In addition, a higher PTS was observed in the dominant legs of injured players compared to the non-dominant legs (22). The case group in the current study was not limited to soccer players. However, similar to the study of Şenişik *et al*., PTS (medial and lateral) was higher in the injured group.

Stijak *et al*. examined the effect of the PTS on the ACL lesion in a matched case-control study. According to the results of this study, the lateral PTS was significantly greater in the case group (ACL tear) than in the control group (ACL intact), while the medial PTS was lower than the control group. In both groups, the difference between the lateral and medial PTS was statistically significant (15). Similar to the study of Stijak *et al*., we observed a significant difference between medial and lateral PTS. Although both medial and lateral PTS were significantly greater in patients with an ACL tear in our univariate analysis, only lateral PTS was identified as a risk factor of an ACL tear in multivariate analysis.

Hohmann *et al*. evaluated the correlation between PTS and noncontact. PTS was significantly more in patients with an ACL injury in Comparison with those without ACL injury. In the ACL injury group, PTS was significantly more in the female group. They concluded that increased PTS contributes to noncontact ACL injuries in females but not in males (23). In this study, we used MRI for the evaluation of PTS. Nevertheless, similar to the study of Hohmann *et al*., we found a greater lateral PTS in female patients who had an ACL tear.

Waiwaiole *et al*. aimed further to characterize the relationship of PTS with an ACL injury to enable the identification of individuals at greater risk for ACL injury. In addition to investigating the relationship between PTS and ACL injury, they aimed to determine whether there are any patient factors, such as age, race, or sex, that correlate with the association of PTS and ACL injury. They included 107 patients who had undergone surgery for ACL injury and 114 control subjects diagnosed with patellofemoral syndrome. According to their results, medial and lateral PTS were both significantly more significant in the case group. In multivariate analysis, lateral PTS and age were identified as the significant risk factors of ACL injury. However, medial PTS, race, and sex were not significant predictors of ACL injury in the multivariate model (19). Grassi *et al*., in their MRI Case-Control Study, evaluated the relationship between Steep Posterior Tibial Slope, Anterior Tibial Subluxation, Deep Posterior Lateral Femoral Condyle, Meniscal Deficiency, and Multiple Anterior Cruciate Ligament Failures. A steep posterior tibial slope and an increased depth of the lateral femoral condyle represent a common finding among patients who experience multiple ACL failures.

Moreover, higher values of anterior subluxation were found among patients with repeated failure and those with a medial or lateral meniscal defect (24). In another study, Suprasanna *et al*. evaluated the Comparison of anatomical risk factors for noncontact anterior cruciate ligament injury using magnetic resonance imaging. They found that Narrow Notch width index and increased Patellar tendon tibial shaft angle are predictors of ACL injury. PTTS angle, which has been studied as a function of knee flexion angle, can be an independent predictor of ACL injury (25). In contrast to our study, Hudek *et al*. evaluated Noncontact ACL Injury Association with the Posterior Tibial and Meniscal Slope and found no apparent link between the medial or lateral PTSs and ACL injury. There is no apparent link between the relative difference in the medial and lateral PTSs and noncontact ACL injury (26). In a comparative MRI study by Elmansori *et al*., they found that increased tibial slopes, both bony and meniscal, are risk factors for ACL injury. As the meniscus tends to correct the observed slope towards the horizontal, loss of the posterior meniscus may potentiate this effect by increasing the functional slope (27). Similar to the study of Waiwaiole *et al*., lateral PTS and age were significant predictors of ACL injury in multivariate analysis of the present study. By contrast to the study of Waiwaiole *et al*., the female gender was also a significant predictor of ACL injury in multivariate analysis of the current series.

Altogether, the results of the current study reveal that characteristic features of subjects could be used for identifying patients who are at greater risk of ACL injury and could potentially benefit from the modification of PTS also need to follow up many patients to show a difference, therefore, a retrospective study may be the optimal way to study this association.

The strength point of our study was the measurement of PTS using MRI and OsiriX software, which provides a more accurate assessment in Comparison with radiographs. The main weakness of this study was its retrospective identity. Another is Ignoring other influential factors such as meniscal slope and evaluation of them in this study. Therefore, future prospective studies are warranted to support the results obtained in this study. Purely radiological definition of injury, the definition of associated injury were the other limitations of our study.

CONCLUSIONS

Both medial and lateral PTS are significantly greater in patients with an intact ACL tear in comparison with patients with intact ACL. However, only lateral PTS is a significant risk factor for an ACL tear in multivariate analysis. Therefore, Lateral PTS should be regarded as a risk factor for an ACL tear. In patients with an ACL tear, PTS was significantly more in females and

older patients. Therefore, Female gender and older age are also identified as independent risk factors for an ACL tear.

Study limitation

One of the major limitations of our study is lack of sample however our data values could led us to the previous conclusion. But further studies with a greater sample size is recommended. Another limitation of our study is not including the values of the meniscal lateral tibial slope and meniscal medial tibial slope in our data analyzing. In one study conducted by Ferretti *et al* a prospective evaluation was undertaken of 200 consecutive patients undergoing acute ACL reconstruction and The comprehensive evaluation of soft tissue and osseous factors such as the meniscal lateral tibial slope and meniscal medial tibial slope has identified that injury to the ALS is the most important risk factor for grade 3 pivot shift in acute ACL-injured knees (28) , which indicates the essential of evaluating those factors in further studies.

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None.

DATA AVAILABILITY

All of the relevant data of this study is available in the office of Orthopedics Surgery division at Alzahra Hospital, Sofeh Blvd, Isfahan, Iran.

CONTRIBUTIONS

HAA, AF: main idea and supervision of the whole work. HM, MA: data collection. GJS: revision of the manuscript. SMM: writing of the first draft of the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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