Lateral Posterior Tibial Slope in Male and Female Athletes Sustaining Contact Versus Noncontact Anterior Cruciate Ligament Tears

A Prospective Study

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Background: Lateral posterior tibial slope (PTS) has been identified as a risk factor for primary anterior cruciate ligament (ACL) tears.

Purpose/Hypothesis: The purpose was to prospectively determine if there was a difference in lateral PTS between male and female athletes sustaining contact ACL tears as compared with a group of sex-, age-, and activity-matched athletes who sustained noncontact ACL tears. It was hypothesized that there would be no difference in degree of lateral PTS between contact and noncontact mechanisms among patients sustaining primary ACL tears in sports.

Study Design: Cohort study; Level of evidence, 3.

Methods: Data from patients who underwent primary ACL reconstruction without posterior cruciate ligament injury between 2016 and 2018 by a single surgeon were prospectively analyzed. Measurements of lateral PTS were performed on magnetic resonance imaging. Mean values of lateral PTS were compared between the ACL tear groups. Additionally, a group of patients with intact knee ligaments were matched to patients with ACL tears to serve as controls.

Results: A total of 245 patients had complete primary ACL tears during the inclusion period. Of these, 56 (23%) reported a contact mechanism of injury at the time of ACL tear, and 56 patients who sustained noncontact ACL tears were matched to the contact ACL tear group. There were no significant differences in sex ($P \geq .999$), age ($P = .990$), or body mass index ($P = .450$) between the patient groups. The mean lateral PTS was 9.1° ± 2.9° for the ACL contact and 9.9° ± 3.0° for the ACL noncontact group ($P = .180$). There was a significant difference in mean lateral PTS between the ACL tear groups (noncontact and contact: 9.5° ± 3.0°) and matched control group (5.6° ± 1.9°, $P = .0001$).

Conclusion: The lateral PTS was significantly increased among patients with contact and noncontact ACL tears as compared with controls. However, there were no differences in lateral PTS between patients who sustained contact and noncontact ACL tears. Lateral PTS measured on magnetic resonance imaging does not appear to be predictive of the mechanism of injury type among patients who sustain a contact or noncontact primary ACL tear.

Keywords: tibial slope; ACL reconstruction; ACL tear risk

Contact and noncontact anterior cruciate ligament (ACL) tears are common among active patients. Numerous reported risk factors have been reported for ACL tears, including decreased ACL volume, narrow femoral intercondylar notch, narrower femoral bicondylar width, hormonal influences, quadriceps-hamstring force imbalance, and poor jump-landing mechanics.[2,8,11,13,16,19] Additionally, recent studies reported that increased lateral posterior tibial slope (PTS) is a risk factor for primary ACL tears.[1,7,15,17] There is also a reported increased risk of ACL graft failure after ACL reconstruction (ACLR) among patients with increased PTS measured on lateral radiographs and lateral PTS measured on magnetic resonance imaging (MRI) scans as compared with controls.[3,21] While medial tibial slope, medial tibial depth, lateral tibial plateau radius of curvature (convexity),

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and lateral tibial slope were assessed in prior reports, lateral PTS measured on MRI is the most consistently reported risk factor among patients with ACL tears.[7,15,20]

Although lateral PTS was previously assessed in noncontact ACL tears and compared with controls, there is a lack of evidence evaluating lateral PTS with MRI for male and female athletes sustaining contact versus noncontact ACL tears. Therefore, the purpose of this study was to prospectively determine if there was a difference in lateral PTS between male and female athletes sustaining contact ACL tears as compared with a group of sex-, age-, and activity-matched athletes who sustained noncontact ACL tears. It was hypothesized that there would be no difference in the degree of lateral PTS between contact and noncontact mechanisms among those sustaining primary ACL tears in sports.

METHODS

Study Design

Following institutional review board approval (Vail Health Hospital), data were prospectively gathered from patients presenting with a primary ACL tear at a single institution between July 2016 and July 2018. Inclusion criteria included patients with complete primary ACL tears that occurred during sport involvement in which a contact mechanism was reported at time of injury (ie, external force). The mechanism of injury was confirmed during the patient interview. Each patient was asked if his or her knee or body came into contact with an external force (eg, another person or object) at the time of injury, which was documented by the principal investigator. Data were also prospectively collected from patients with complete primary ACL tears that occurred during sport involvement in which noncontact mechanisms were reported at the time of injury (ie, twist, jump/land). The contact ACL tear group was matched to the noncontact ACL tear group according to age, sex, and activity level.

All patients who had ACL tears treated surgically were documented prospectively, and their demographic and clinical information were recorded. After 2 years, the data collection period ended, and all patients with contact ACL tears were identified. After the total sample size of the inclusion group (contact ACL tears) was determined, a control group (noncontact ACL tears) was formed based on the prospective data of all ACL tear cases documented during the data collection period. After all patients with noncontact ACL tears were identified, the exclusion criteria were applied, which allowed 1-to-1 matching of patients in both cohorts according to age, sex, and activity level. Exclusion criteria included concomitant posterior cruciate ligament injury, concomitant collateral ligament injuries, prior knee ligament surgery, revision ACLR, partial ACL tears, previous osteotomy, or altered osseous morphology secondary to fracture or underlying condition/disease process. Clinical examination, radiographs, and MRI were assessed to determine the presence of a complete ACL tear, which was confirmed at the time of surgery. In addition, a group of patients with intact ligaments was retrospectively formed on the basis of an internal imaging records system. Patients were then sorted by age and their imaging reviewed to ensure that there were no ligamentous knee injuries. Upon confirmation, the patients' charts—including history, clinical examination, and operative notes—were reviewed to determine inclusion criteria, and patients were matched according to age, sex, and activity level to patients with ACL injuries.

An a priori power analysis was performed to determine the size of the cohort that would be needed in each group to identify meaningful differences in the lateral PTS measurements. We performed a review of the literature evaluating the means and SDs of lateral PTS on MRI between patients with ACL tears and controls, and an effect size was calculated (d = 0.60). With our fixed sample size, a lower effect size was detected (d = 0.53). Based on an overall alpha level of .05 and comparisons for 2-tailed testing, it was determined that 56 patients per group were sufficient to achieve 80% statistical power.

Imaging Evaluation

MRI scans were reviewed and included 1.5- and 3.0-T magnets. All MRI scans had 3-mm slice thicknesses and were conducted with the patient in a supine position and the knee extended. All patients were de-identified and randomized so that measurements were completed in a blinded fashion. Two independent raters (T.J.D., W.J.G.), who are fellowship-trained orthopaedic surgeons, evaluated the MRI scans of the contact and noncontact groups to measure the amount of PTS in the lateral tibial plateau according to a previously validated technique.[10] All raters were blinded to the group designation of all patients, thereby decreasing potential measurement bias.

Measurements of PTS were first determined by defining the anatomic axis of the tibia and the center of the lateral tibial plateau. First, the central sagittal MRI cut was determined where the posterior cruciate ligament attachment and intercondylar eminence were visualized and the anterior and posterior tibial cortices were in a concave shape. Subsequently, the longitudinal tibial axis in the

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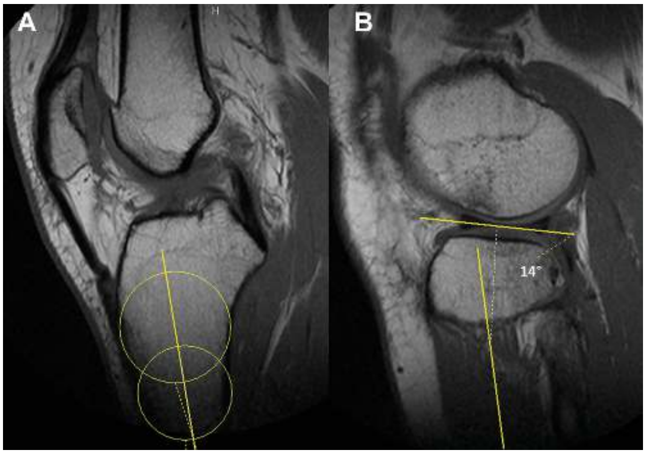

Figure 1. Measurement technique for determining the lateral posterior tibial slope on magnetic resonance imaging. (A) Midsagittal plane identifying the center of the tibial axis. (B) Determination of the lateral posterior tibial slope angle, measuring 14° in a patient with a noncontact anterior cruciate ligament tear.

midsagittal plane was determined by a connecting line through the centers of the 2 best-fit circles positioned on the proximal tibia. The center point of the lateral tibial plateau was then identified on the axial series, which was used to determine the corresponding sagittal slice in the midcondylar plane to measure the lateral PTS. Finally, the slope of the lateral tibial plateau was measured with the angle between the line drawn along the subchondral bone of the lateral tibial plateau line and the longitudinal tibial axis (Figure 1).

Statistical Analysis

Inter- and intrarater agreement were assessed for radiographic measurements with a 2-way random effects model to calculate the intraclass correlation coefficient (ICC). The ICC values were interpreted as follows: $\leq$0.40, poor agreement; 0.4 < ICC < 0.75, fair to good agreement; and $\geq$0.75, excellent agreement.[4] Paired *t* tests were used to compare the mean difference in lateral PTS between the contact and noncontact ACL tear groups and between patients with ACL tears (overall) and ligament-intact controls. Additionally, independent sample *t* tests were performed for subgroup analysis comparing sex in the contact and noncontact ACL tear groups. All data were analyzed with SPSS Statistics (v 22; IBM), with an alpha level set at .05 for statistical significance.

RESULTS

A total of 245 patients had complete primary ACL tears during the inclusion period. Of these, 56 (23%) reported a contact mechanism of injury at the time of ACL tear.

TABLE 1
Demographics for All Patients With Complete Primary ACL Tears (n = 112) and Ligament-Intact Controls (n = 56)[a]

	Total	Male	Female
Contact ACL			
n	56	30	26
Age	34.2 ± 15.2	33.1 ± 15.3	35.4 ± 16.0
BMI	24.0 ± 3.0	25.2 ± 2.6	22.5 ± 2.7
Noncontact ACL			
n	56	30	26
Age	34.1 ± 15.5	33.9 ± 15.7	34.5 ± 15.0
BMI	23.5 ± 3.3	24.0 ± 3.8	23.0 ± 2.8
Control			
n	56	30	26
Age	34.1 ± 15.3	33.0 ± 15.1	35.4 ± 15.7
BMI	24.6 ± 2.9	23.9 ± 2.8	24.4 ± 2.8

[a]Values are reported as number or mean ± SD. Patients were matched according to sex, age, and activity level. ACL, anterior cruciate ligament; BMI, body mass index.

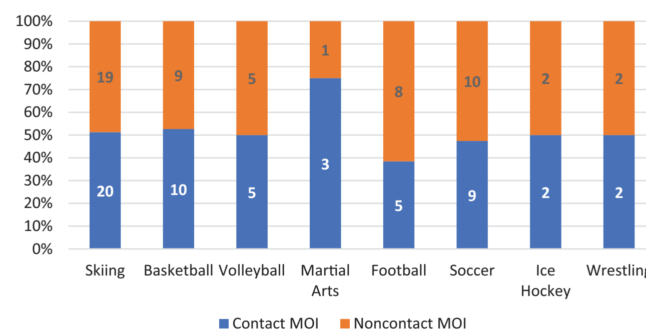

Figure 2. Sport activity reported at the time of anterior cruciate ligament tear among patients who sustained a contact (n = 56) versus noncontact (n = 56) mechanism of injury (MOI).

From the remaining prospective cohort, 56 patients who reported a noncontact mechanism of injury at the time of ACL tear were matched according to sex, age, and activity level. In addition, 56 patients who had no evidence of ligamentous injury at the time of knee surgery were matched to the patients with ACL tears. There were no significant differences in sex ($P \geq .999$), age ($P = .990$), or body mass index ($P = .450$) among the 3 patient cohort groups. Patient demographics are reported in Table 1. Sport activities at the time of ACL tear are reported in Figure 2.

The mean lateral PTS was 9.1° ± 2.9° (95% CI, 8.3°-9.9°) for the ACL contact group and 9.9° ± 3.0° (95% CI, 9.1°-10.8°) for the ACL noncontact group ($P = .180$) (Table 2). There was a significant difference in mean lateral PTS between the ACL tear group (9.5° ± 3.0°; 95% CI, 8.9°-10.1°) and the matched control group (5.6° ± 1.9°; 95% CI, 5.1°-6.1°) ($P = .0001$). Fifteen (26.8%) patients with noncontact ACL tears had a lateral PTS >12°, as compared

TABLE 2
Mean Lateral PTS of Patients with ACL Tears (n = 112) According to Mechanism of Injury[a]

	Contact ACL Tear	Noncontact ACL Tear	*P* Value
Lateral PTS, deg	9.1 ± 2.9	9.9 ± 3.0	.180
SEM	0.40	0.42	—

[a]Values are reported as mean ± SD. Statistical significance, $P < .05$. Patients with contact ACL tears were matched according to sex, age, and activity level to those with noncontact ACL tears. ACL, anterior cruciate ligament; PTS, posterior tibial slope.

TABLE 3
Mean Lateral Posterior Tibial Slope of Patients With ACL Tears According to Sex[a]

Mechanism of Injury	Male (n = 60)	Female (n = 52)	*P* Value
Overall	9.3 ± 3.0	9.8 ± 3.0	.320
ACL tear			
Contact	8.9 ± 3.2	9.5 ± 2.8	.461
Noncontact	9.7 ± 2.8	10.2 ± 3.4	.496

[a]Values are reported as mean ± SD (in degrees). Statistical significance, $P < .05$. ACL, anterior cruciate ligament.

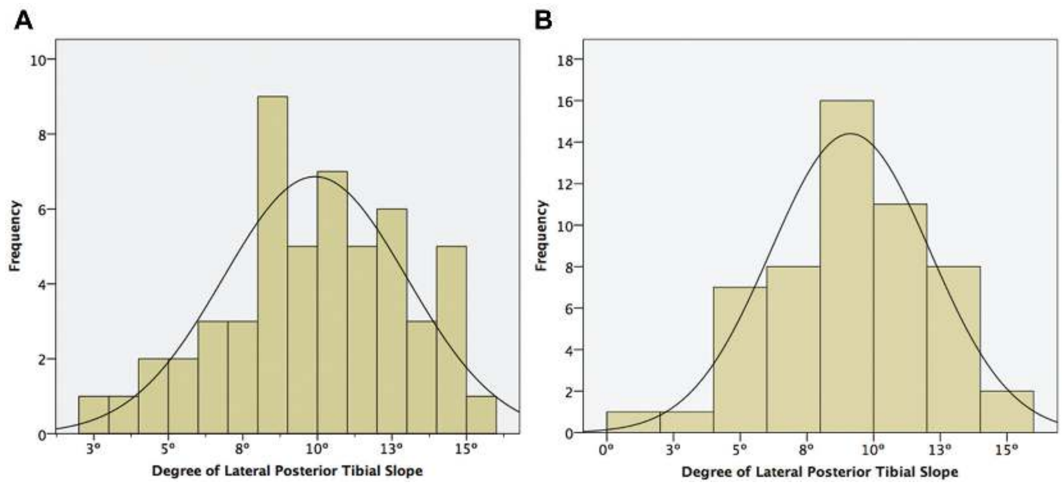

Figure 3. Histogram demonstrating the frequency of lateral posterior tibial slope angle: (A) noncontact ACL tear group (n = 56) and (B) contact ACL tear group (n = 56). ACL tear cases were matched according to sex, age, and activity level. The mean lateral posterior tibial slope was 9.9° ± 3.0° for the noncontact group and 9.1° ± 2.9° for the contact group. ACL, anterior cruciate ligament.

with 10 (17.8%) patients with contact ACL tears (Figure 3). One control patient (1.7%) had a lateral PTS >12° (Figure 4). When the reliability of the tibial slope measurement technique was evaluated, the inter- and intrarater agreement was excellent, with an ICC of 0.804 for interrater reliability and an ICC of 0.805 for intrarater reliability. Additionally, subgroup analysis of ACL tear cases according to sex demonstrated no significant differences in lateral PTS ($P = .320$) (Table 3).

DISCUSSION

The primary finding of this study was that there was no significant difference in the degree of lateral PTS between patients with contact and noncontact ACL tears who were matched according to age, sex, and activity level. Lateral PTS was significantly increased among patients with ACL tears as compared with controls. Furthermore, there were no significant differences in the degree of lateral PTS between males and females in the noncontact and contact patient groups.

The findings of this study indicate no differences in the degree of lateral PTS measured on MRI between the contact and noncontact ACL tear groups. Previous studies reported an increased degree of lateral PTS among patients with ACL tears as compared with uninjured controls.[1,9] Our current results support these previous findings and indicate that lateral PTS is a risk factor for patients with primary ACL tears as compared with ligament-intact controls. This correlation was confirmed in biomechanical models that reported increased anterior tibial translation and ACLR graft force with increased PTS.[5,14,22] Clinically, it was reported that patients with an increased PTS (>12°) are at a significantly higher risk for ACLR graft failure.[12,21] In the current study, the mean lateral PTS of patients with ACL tears was 9.5°, with 25 (22%) patients having a slope >12°. Thus, theoretically, these patients may be at higher risk for ACLR graft rupture; however, further longitudinal research is needed to determine risk stratification for ACLR graft failure and nonmodifiable risk factors such as tibial slope.

Currently, there is limited evidence evaluating tibial slope as a risk factor for primary ACL tear depending on

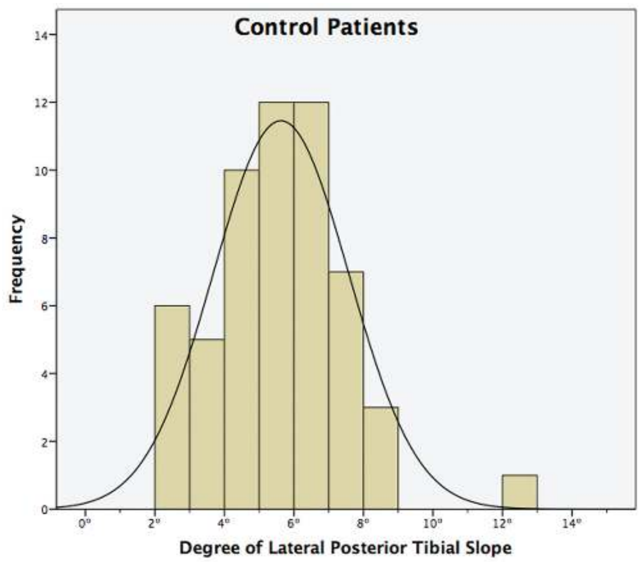

Figure 4. Histogram demonstrating the frequency of lateral posterior tibial slope angle in ligament-intact controls (n = 56). Controls were matched according to sex, age, and activity level to patients with anterior cruciate ligament tears. The mean lateral posterior tibial slope was 5.6° ± 1.9° for the control group.

the mechanism of injury (contact vs noncontact). The results of the current study indicate no differences in the degree of lateral PTS between patients with noncontact ACL tears and matched patients who sustained contact injuries. Therefore, it appears that patients of similar age, sex, and activity level have similar risks of ACL tear regardless of noncontact or contact mechanism of injury, although further clinical studies with larger sample sizes are needed to confirm this finding.

In the current study, there were no significant differences in the degree of lateral PTS between males and females. Sonnery-Cottet et al[17] reported a significant increased degree of tibial slope in 50 patients with isolated ACL tears as compared with an age- and sex-matched uninjured control group. However, sex was not examined independently. Previous studies found increased tibial slope among females but not males who sustained noncontact ACL tears.[9,18] Authors theorized that this correlation may contribute to the higher incidence of noncontact ACL injuries seen among females.[6] The current study suggests no difference in ACL tear risk when lateral PTS was evaluated between males and females for contact and noncontact mechanisms of injury.

The results of the current study may suggest that patients in the noncontact group with a higher-than-mean PTS may be experiencing greater native ACL forces, similar to those seen during contact injuries, whereas patients in the contact cohort may have experienced ACL tears at lesser forces at the time of injury. While the current study cannot measure the in situ forces experienced by the ACL tear group at the time of injury, it may be possible that patients with a higher-than-mean PTS are at a higher risk for ACL tears during jump landing and pivoting movements that are similar to the forces experienced during contact injuries.

This study is not without limitations. Tibial slope measurements were performed on MRI with various magnet strengths (1.5 and 3.0 T), which could affect the interpretation of the tibial slope degree. However, the previously described technique demonstrated excellent intrarater reliability and interrater agreement. Additionally, patient outcomes were not analyzed in the current study, which may have provided insight regarding lateral PTS measurements, specifically for patients with ACL tears who had a tibial slope >12° and were at risk for ACLR graft failure.

CONCLUSION

Lateral PTS was significantly increased among patients with contact and noncontact ACL tears as compared with controls. However, there were no differences in lateral PTS between patients who sustained contact and noncontact ACL tears. Lateral PTS measured on MRI does not appear to be predictive of the type of mechanism of injury for patients who sustain a contact or noncontact primary ACL tear.

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