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Lateral Posterior Tibial Slope in Male and Female Athletes Sustaining Contact Versus Noncontact ACL Tears: A Prospective Study

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Abstract

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

Purpose/Hypothesis: 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 compared to a group of gender, age, and activity-matched athletes who sustain noncontact ACL tears. It was hypothesized that there would be no difference in degree of lateral PTS between contact and noncontact mechanisms sustaining primary ACL tears in sports.

Study Design: Case-control study; Level of evidence, 3.

Methods: Patients who underwent a primary ACL reconstruction without PCL injury between 2016-2018 by a single surgeon were prospectively analyzed. Measurements of lateral PTS were performed on magnetic resonance imaging (MRI). Mean values of lateral PTS were compared between the two ACL tear groups. Additionally, a group of knee ligament-intact patients were matched to the ACL tear patients to serve as controls.

Results: There were 245 total patients who presented with complete primary ACL tears during the inclusion time period. Of these, 56 (23%) reported a contact mechanism of injury at 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 gender (P= 1.000), age (P= 0.990), or BMI (P= 0.450) between the patient groups. The mean lateral PTS was 9.1 $\pm$ 2.9 degrees and 9.9 $\pm$ 3.0 degrees for the ACL contact and ACL noncontact groups, respectively (P= 0.180). There was a significant difference in mean lateral PTS between the ACL tear groups (noncontact and contact) and matched control group (5.6 $\pm$ 1.9 degrees) (P= 0.0001).

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

Keywords: tibial slope, ACL reconstruction, ACL tear risk

FOR REVIEW PURPOSES ONLY:

What is known about the subject: Although the association of sagittal plane tibial slope and ACL tears has been well studied, literature comparing the mechanism of ACL tear (contact versus noncontact) as it relates to lateral PTS is limited.

What this study adds to the existing knowledge: The current study demonstrated no significant differences in lateral PTS between a matched cohort of contact and noncontact ACL tear patients. Therefore, the degree of lateral tibial slope does not appear to be associated with mechanism of injury type (contact versus non-contact) for matched patients who sustained primary ACL tears.

INTRODUCTION

Contact and non-contact 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 have 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 following ACL reconstruction (ACLR) in patients with increased PTS measured on lateral radiographs and lateral PTS measured on magnetic resonance imaging (MRI) scans compared to controls.[3, 21] While medial tibial slope, medial tibial depth, lateral tibial plateau radius of curvature (convexity), and lateral tibial slope have been assessed in prior reports, lateral PTS measured on MRI is the most consistently reported risk factor in patients with ACL tears.[7, 15, 20]

Although lateral PTS has been previously assessed in non-contact ACL tears and compared to controls, there is a lack of evidence evaluating lateral PTS using MRI in 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 compared to a group of gender, age, and activity-matched athletes who sustain noncontact ACL tears. It was hypothesized that there would be no difference in the degree of lateral PTS between contact and noncontact mechanisms sustaining primary ACL tears in sports.

METHODS

Study Design

Following institutional review board approval (*institution blinded for review*), 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 (i.e. external force). The mechanism of injury was confirmed during the patient interview. Patients were asked if their knee or body came in contact with an external force (e.g. another person or object) at the time of injury and was documented by the principal investigator. Data was prospectively collected from patients with complete primary ACL tears that occurred during sport involvement in which a noncontact mechanisms were reported at the time of injury (i.e. twist, jump/land). The contact ACL tear patients were matched to the noncontact ACL tear patients according to age, gender, and activity-level.

All patients who presented with ACL tears for surgery were documented prospectively and their demographic and clinical information were recorded. After a period of 2 years, the data collection period ended and the total patients with contact ACL tears were identified. After gathering the total sample size of the inclusion group (contact ACL tears), a control group (noncontact ACL tears) was built using the prospective data on all ACL tear patients that were gathered during the data collection period. After identifying all noncontact ACL tear patients, the exclusion criteria were applied which allowed for a 1-to-1 matching of patients in both cohorts according to age, gender, and activity-level. Exclusion criteria included concomitant posterior cruciate ligament injury, concomitant collateral ligament injuries, prior knee ligament surgery, revision ACL reconstruction, partial ACL tears, previous osteotomy surgery, 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 and confirmed at time of surgery. In addition, a third group was constructed consisting of knee ligament-intact patients to serve as controls and were matched to the ACL tear patients according to age, gender, and activity-level. Inclusion criteria for control patients included no evidence of ligamentous knee injury (determined by clinical exam, MRI, and arthroscopy) and an available MRI. Exclusion criteria for controls was previous surgery and altered osseous morphology secondary to fracture or underlying condition/disease process.

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. The authors performed a review of the literature evaluating the means and standard deviations of lateral PTS on MRI between ACL tear patients and controls and an effect size of $d = 0.60$ was calculated. With our fixed sample size, a lower effect size of $d = 0.53$ was detected. Based on an overall alpha level of 0.05 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 both 1.5-T 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 (*initials blinded for review*), who are fellowship-trained orthopaedic surgeons, evaluated the MRI scans of both 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 PCL 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 midsagittal plane was determined by a connecting line through the centers of the two 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 then measured using the angle between the line drawn along the subchondral bone of the lateral tibial plateau line and the longitudinal tibial axis (Figure 1).

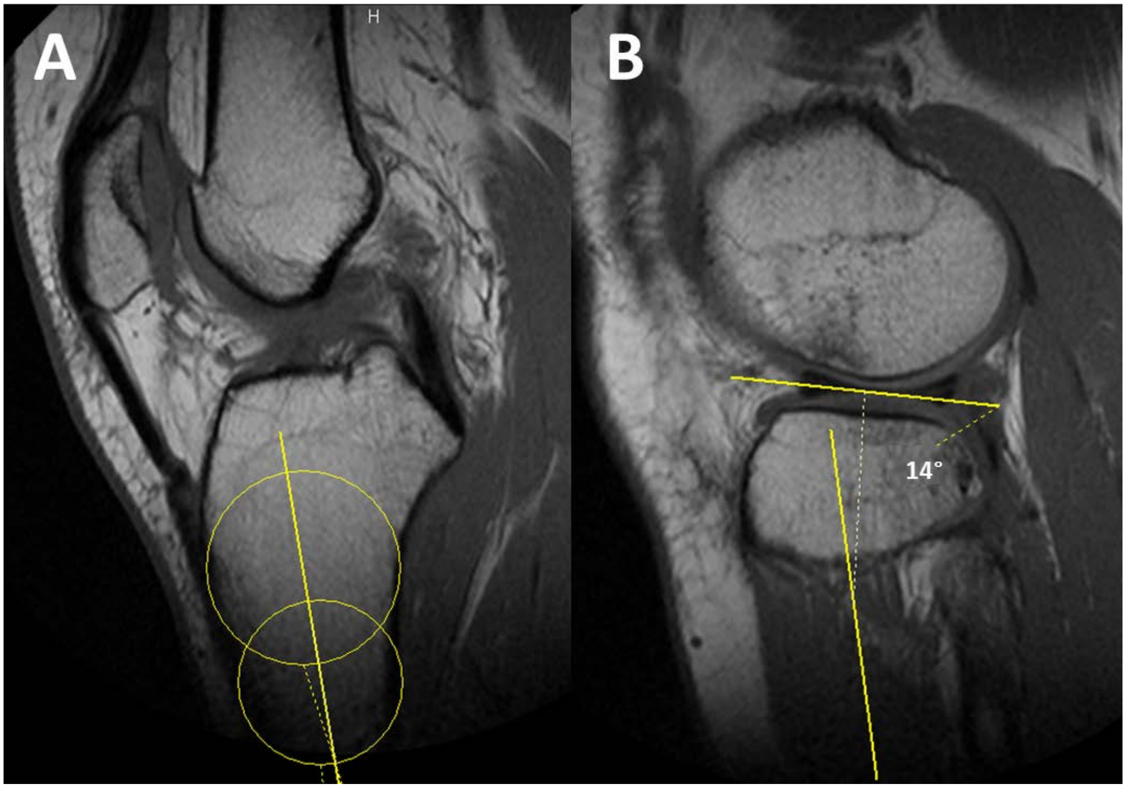

Figure 1. Measurement technique for determining lateral posterior tibial slope on magnetic resonance imaging. A) Midsagittal plane identifying the center of the tibial axis. B) Determination of lateral posterior tibial slope angle (degrees), measuring 14 degrees in a patient with a noncontact ACL tear.

Statistical Analysis

Interrater and intrarater agreement was assessed for radiographic measurements using a two-way random-effects model to calculate the intraclass correlation coefficient (ICC). The ICC values were interpreted as follows: ICC ≤ 0.40 = poor agreement; 0.4 < ICC < 0.75 = fair to good agreement; ICC ≥ 0.75 = excellent agreement.[4] Paired *t*-tests were used to compare the mean difference in lateral PTS between the contact ACL tear group and the noncontact ACL tear group and between ACL tear patients (overall) and ligament-intact controls. Additionally, independent sample *t*-tests were performed for subgroup analysis comparing gender in both contact and noncontact ACL tear patients. All data were analyzed using SPSS Statistics Version 22 (IBM, Armonk, New York, USA), with an alpha level set at .05 for statistical significance.

RESULTS

There were 245 total patients who presented with complete primary ACL tears during the inclusion time period. Of these, 56 (23%) reported a contact mechanism of injury at the time of ACL tear. From the remaining prospective cohort, 56 patients who reported a noncontact mechanism of injury at time of ACL tear were matched according to gender, 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 ACL tear patients. There were no significant differences in gender (*P*= 1.000), age (*P*= 0.990), or BMI (*P*= 0.450) between the three patient cohort groups. Patient demographics are reported in Table 1. Sport activity at the time of ACL tear are reported in Figure 2.

Table 1. Patient demographics for all patients with complete, primary ACL tears (n=112) and ligament-intact control patients (n=56).[a] Patients were matched according to gender, age, and activity-level.

	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. BMI, body mass index; ACL, anterior cruciate ligament.

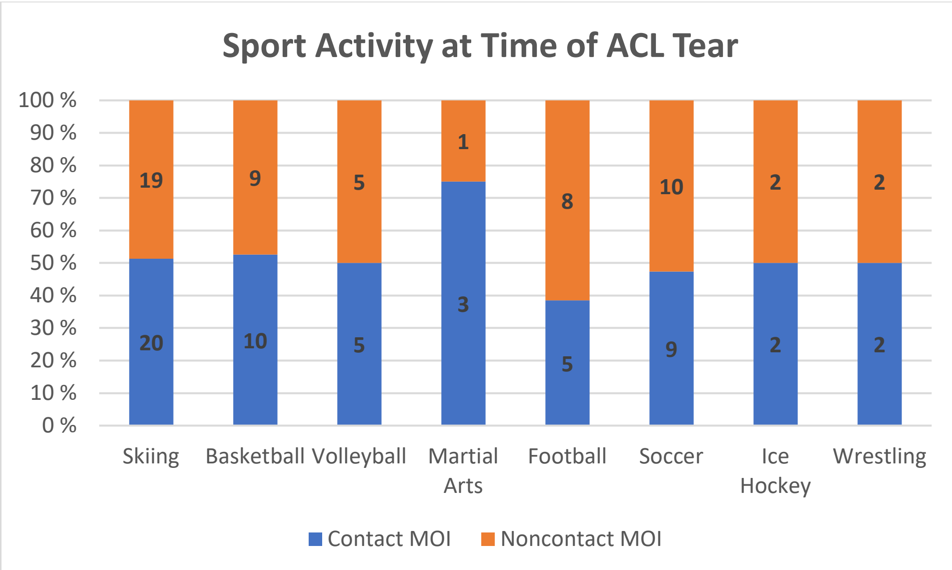

Figure 2. Sport activity reported at time of ACL tear in patients who sustained a contact (n=56) versus noncontact (n=56) mechanism of injury (MOI).

The mean lateral PTS was 9.1 ± 2.9 degrees (95% confidence interval [CI]: 8.3˚, 9.9˚) and 9.9 ± 3.0 degrees (95% CI: 9.1˚, 10.8˚) for the ACL contact and ACL noncontact groups, respectively (*P*= 0.180) (Table 2). There was a significant difference in the mean lateral PTS between the ACL tear group (9.5 ± 3.0 degrees; 95% CI: 8.9˚, 10.1˚) and matched control group (5.6 ± 1.9 degrees; (95% CI: 5.1˚, 6.1˚) (*P*= 0.0001). Fifteen (26.8%) noncontact ACL tear patients had a lateral PTS > 12 degrees, compared to 10 (17.8%) contact ACL tear patients (Figure 3). One control patient (1.7%) had a lateral PTS > 12 degrees (Figure 4). When evaluating the reliability of the tibial slope measurement technique, it was found that the interrater 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 patients according to gender demonstrated no significant differences in lateral PTS (*P*= 0.320) (Table 3).

Table 2. Mean lateral PTS for ACL tear patients (n=112) grouped according to mechanism of injury. Contact ACL tear patients were matched according to gender, age, and activity-level to noncontact ACL tear patients.

	Contact ACL Tear	Noncontact ACL Tear	*P* Value
Lateral PTS[a]	$9.1 \pm 2.9^{\circ}$	$9.9 \pm 3.0^{\circ}$	.180
Standard error of the mean (SEM)	0.40	0.42	N/A

[a]Values are reported as mean ± SD. Statistical significance = $P < .05$. PTS, posterior tibial slope; ACL, anterior cruciate ligament; N/A: not applicable.

Table 3. Mean lateral PTS for ACL tear patients grouped according to gender (male, n= 60; female, n=52).

Mechanism of Injury	Male	Female	*P* Value
Overall	$9.3 \pm 3.0^{\circ}$	$9.8 \pm 3.0^{\circ}$	.320
Contact ACL tear	$8.9 \pm 3.2^{\circ}$	$9.5 \pm 2.8^{\circ}$	.461
Noncontact ACL tear	$9.7 \pm 2.8^{\circ}$	$10.2 \pm 3.4^{\circ}$	.496

[a]Values are reported as mean ± SD. Statistical significance = $P < .05$. PTS, posterior tibial slope; ACL, anterior cruciate ligament.

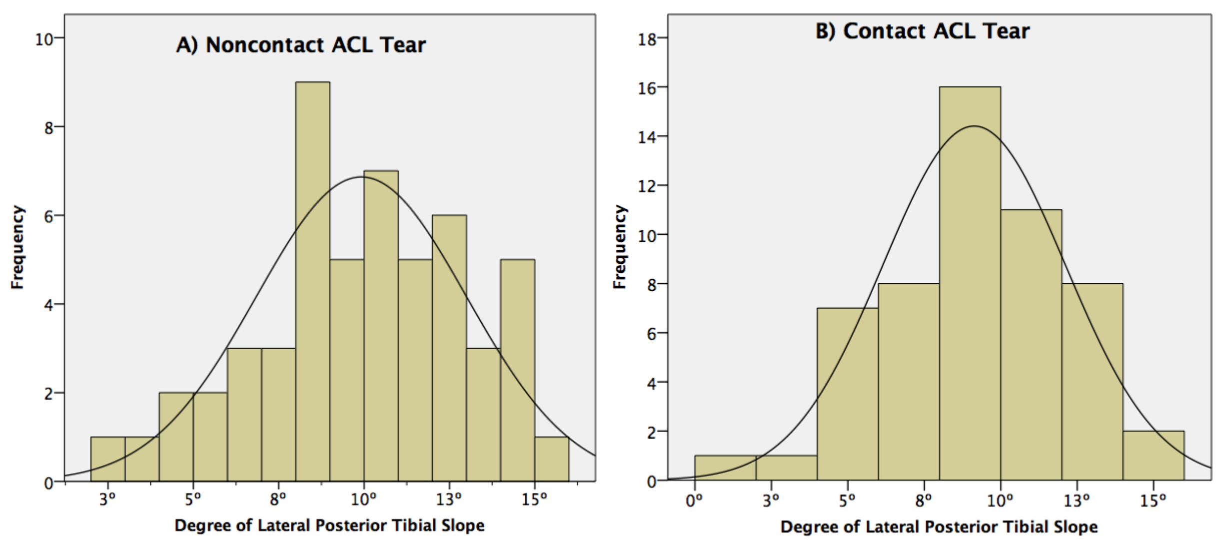

Figure 3. Histogram demonstrating frequency of lateral posterior tibial slope angle (degrees) in A) noncontact ACL tear patients (n=56) and B) contact ACL tear patients (n=56). ACL tear patients were matched according to gender, age, and activity-level. The mean lateral posterior tibial slope was 9.9 ± 3.0 degrees for the noncontact and 9.1 ± 2.9 degrees for the contact ACL tear group.

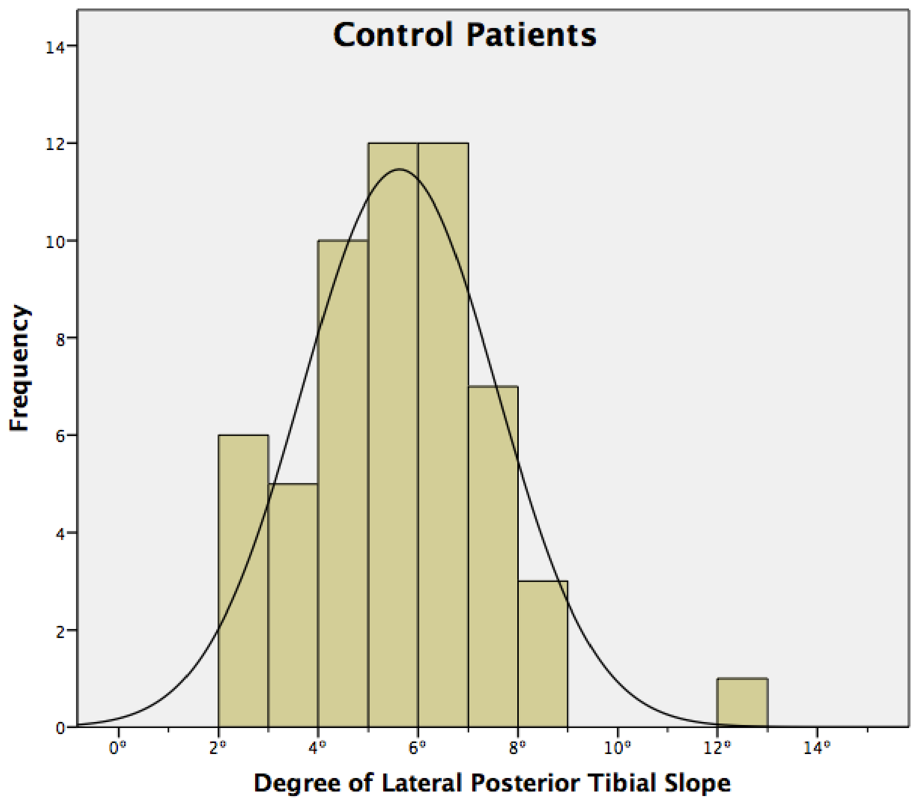

Figure 4. Histogram demonstrating frequency of lateral posterior tibial slope angle (degrees) in ligament-intact control patients (n=56). Control patients were matched according to gender, age, and activity-level to ACL tear patients. The mean lateral posterior tibial slope was 5.6 ± 1.9 degrees for the control group.

DISCUSSION

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

The findings of this study indicate that there were no differences in the degree of lateral PTS measured on MRI between contact and noncontact ACL tear patients. Previous studies have reported an increased degree of lateral PTS in ACL tear patients compared to uninjured controls.[1, 9] Our current results support these previous findings and indicate that lateral PTS is a risk factor for primary ACL tear compared to ligament-intact controls. This correlation has been confirmed in biomechanical models, which report increased anterior tibial translation and ACLR graft force with increased PTS.[5, 14, 22] Clinically, it has been reported that patients with an increased PTS of > 12 degrees are at a significantly higher risk for ACLR graft failure.[12, 21] In the current study, the average lateral PTS of ACL tear patients was 9.5 degrees with 25 (22%) patients having increased slope > 12 degrees. 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 the mechanism of injury (contact vs. noncontact). The results of the current study indicate that there were no differences in the degree of lateral PTS in noncontact ACL tear patients compared to matched patients who sustained contact injuries. Therefore, it appears that patients of similar age, gender, 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 an isolated ACL tear compared to an age and gender matched uninjured control group. However, gender was not examined independently.[17] Previous studies have found increased tibial slope in females and not male ACL tear patients who sustain noncontact ACL tears.[9, 18] Authors have theorized that this correlation may contribute to the higher incidence of noncontact ACL injuries seen in females.[6] The current study suggests no difference in ACL tear risk when evaluating for lateral PTS between males and females for both contact and noncontact mechanisms of injury.

The results of the current study may suggest that noncontact patients with higher than average posterior tibial slope may be experiencing greater native ACL forces that are similar to those seen during contact injury; whereas the contact patient 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 ACL tear patients at the time of injury, it may be possible that patients with higher than average posterior tibial slope are at a higher risk for ACL tears during jump-landing and pivoting movements that are similar to the forces experienced by contact injuries.

This study is not without limitations. Tibial slope measurements were performed on MRI with various magnet strengths (i.e. 1.5 T and 3.0 T), which could potentially affect the interpretation of the tibial slope degree. However, the previously described technique demonstrated excellent intra-rater reliability and inter-rater agreement. Additionally, patient outcomes were not analyzed in the current study which may have provided insight regarding lateral PTS measurements, specifically with ACL tear patients whom tibial slope was > 12 degree and risk of ACLR graft failure.

CONCLUSION

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

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