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The Relationship Between Posterior Tibial Slope and Anterior Cruciate Ligament Injuries

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Background: Two previous studies have examined the association between an increased posterior tibial slope and anterior cruciate ligament (ACL) injuries as measured on plain radiographs. The study results were contradictory, with 1 reporting a statistical difference and the other showing no association.

Purpose: To determine if there is a difference in posterior tibial slope angle between patients with a history of noncontact ACL injury and a control group with no history of ACL injury. A secondary objective was to examine differences in tibial slope angle between male and female subjects within each group.

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

Methods: We identified all noncontact ACL injuries that were treated operatively at the United States Military Academy, West Point, New York, from 2004 to 2007. We digitally measured the posterior tibial slope from plain film radiographs of 140 noncontact ACL injuries, stratified them by sex, and compared them with a control cohort of 179 patients and radiographs.

Results: Subjects in the noncontact ACL group had significantly greater slope angles (9.39° ± 2.58°) than did control subjects (8.50° ± 2.67°) (P = .003). The trend toward greater tibial slope angles in the noncontact ACL group was also observed when each sex was examined independently; however, the difference was only statistically significant for the female subjects between the injury and control groups (9.8° ± 2.6° vs 8.20° ± 2.4°) (P = .002).

Conclusion: Despite the identification of an increased posterior tibial slope as a possible risk factor for women, more research that combines the multifactorial nature of an ACL injury must be performed.

Keywords: tibial slope; noncontact; ACL, risk factors

Various studies have attempted to identify risk factors associated with ACL injuries. These factors include decreased notch width, subtalar pronation, changing hormonal levels, poor neuromuscular control, ligamentous laxity, high body mass index, sex, and knee recurvatum.[1,4,10-13,15,17,19,21-23]

Tibial slope may also be an identifiable risk factor for ACL injuries. In the consensus statement from a recent research conference on ACL injuries, variations in tibial slope, among other anatomical and structural factors, were noted as important knowledge gaps related to the risk of ACL injury.[18] Tibial slope is defined as the angle formed at the intersection of a line parallel to the posterior tibial inclination and a line that bisects the diaphysis of the tibia.

The relationship between posterior tibial slope (PTS) and increased anterior tibial translation was measured by Dejour and Bonnin,[6] who noted that for every 10-degree increase in PTS there was an associated increase in tibial translation. This was true for both ACL-deficient and ACL-intact knees using monopodal stance.[6]

Giffin et al[8] reported that as the tibial inclination was increased, there was an associated anterior translation of the tibia relative to the femur. Although they did not find any increase in the in situ forces of the cruciate ligaments, they suggested that altering the tibial slope may be beneficial for ACL-deficient or posterior cruciate ligament-deficient knees to improve resting position and joint congruity.[8]

Two articles have reported conflicting results when examining the role of PTS as an independent risk factor for noncontact ACL injuries.[5,14] Meister et al[14] found no association between PTS and ACL injuries. However, Brandon

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et al[5] concluded that there was a relationship between increased PTS and ACL injuries, and that there was no difference between male and female slope measurements.

The purpose of this study was to determine if there is a difference in PTS angle between patients with a history of noncontact ACL injury and a control group with no history of ACL injury at the United States Military Academy at West Point, New York, and the associated military population. A secondary objective was to examine differences in tibial slope angle between male and female subjects within each group.

The null hypothesis is that there is no difference in the PTS angle between patients with a history of noncontact ACL injury and a control group without history of ACL injury. The second null hypothesis is that there is no difference in PTS angles based on sex stratification within each group.

Study exemption for this investigation under the provision for the "Secondary Use of Existing Data for Research" was granted by the local institutional review board at Keller Army Community Hospital, with secondary review by U.S. Army Clinical Investigation Regulatory Office.

MATERIALS AND METHODS

A retrospective review of all ACL reconstructions performed at our institution from 2004 to 2007 was conducted. Subjects were identified using our electronic surgical scheduling system (S3, Microsoft, Seattle, Washington). Additional ACL reconstructions that were performed before the use of S3 were identified through an independent ACL research project. The medical charts and operative reports were then reviewed to determine whether the procedure was a primary ACL reconstruction or revision, and whether the injury resulted from a contact or noncontact mechanism. If the mechanism of injury was not recorded, the patient was interviewed via e-mail or by telephone to determine the mechanism of injury. All subjects were available for follow-up.

If a noncontact mechanism of injury was established, a radiographic review was performed through our IMPAX digital software system (Agfa, Ridgefield, New Jersey). Inclusion criteria were met if a true lateral view of the operative knee was available for subsequent measurement of PTS.

A control cohort was established from subjects who reported to the primary care clinic or orthopaedic clinic with a diagnosis of anterior knee pain, patellofemoral syndrome, or knee contusion—superficial bruised knee/abrasion—that had radiographic evaluation that included a lateral knee radiograph. All patients in the control group underwent a detailed physical evaluation of the knee by a sports medicine-trained health care provider. A medical chart review was conducted to rule out any history of ligamentous instability or prior surgery for the affected knee. Subjects with any history of instability or prior surgery were excluded from the control group. Subjects were also excluded if they had any abnormal radiographic findings or physical examination findings consistent with ligamentous instability. Previous arthroscopy for meniscal debridement was not considered to be an exclusion criterion from the control group in the current study.

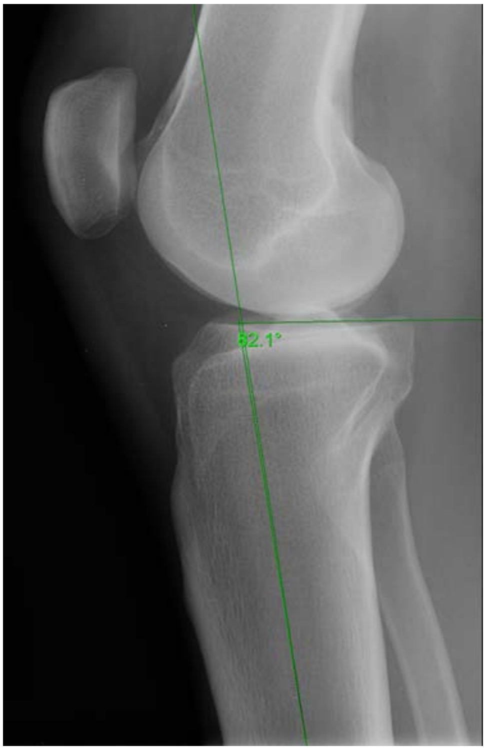

Figure 1. Posterior tibial slope (PTS): the angle formed at the intersection of a line parallel to the posterior tibial inclination and a line that bisects the shaft of the tibia.

All patients had a minimum of 2 radiographic views of the knee, AP and lateral. Two sports medicine-trained orthopaedic fellows (M.S.T. and S.L.) independently evaluated the lateral knee radiographs to establish the PTS for all subjects, using the method described by Dejour and Bonnin[6] to measure the slope of the medial tibial plateau (Figure 1). The PTS angles were measured using the IMPAX system and the digital software measurement package of the computer. One of the 2 raters was blinded to the group (eg, injured vs control) of each subject, and the second rater was not blinded. Interobserver reliability was assessed by randomly selecting the radiographs from 39 subjects for whom both raters measured the PTS angles independently.

Separate 1-way analysis of variance (ANOVA) tests were performed to analyze the data. Differences in PTS between the 2 groups and by gender within each group were examined. The dependent variable in our analysis was PTS angle, and the 2 independent variables were group and gender, each consisting of 2 levels. The 2 levels of the group variable consisted of those subjects with noncontact ACL injuries and an uninjured control group. Within each group, the data were further examined to identify gender differences. Because multiple ANOVA tests were performed, we used the Bonferroni method to adjust the a priori P value required for statistical significance to maintain an overall alpha level of $P < .05$ for the study. Interobserver reliability was assessed by calculating the

TABLE 1
Means, Standard Deviations (SDs), and Analysis of Variance Results for Posterior Tibial Slope by Group and Gender

	Control Group			Injured Group				
	No. of Subjects	Mean	SD	No. of Subjects	Mean	SD	*F* Value	*P* Value
Women	53	8.20	2.4	45	9.80	2.62	9.905	.002
Men	126	8.63	2.65	95	9.20	2.69	2.527	.113
Total	179	8.50	2.58	140	9.39	2.67	9.126	.003

TABLE 2
Means, Standard Deviations (SDs), and Analysis of Variance Results for Posterior Tibial Slope by Gender Within Each Group

	Men			Women				
	No. of Subjects	Mean	SD	No. of Subjects	Mean	SD	*F* Value	*P* Value
Injured Group	95	9.20	2.69	45	9.80	2.62	1.502	.221
Control Group	126	8.63	2.65	53	8.20	2.40	1.022	.313

intraclass correlation coefficient, along with 95% confidence intervals as a measure of precision, between the 2 raters for PTS measures.

RESULTS

A total of 192 patients were identified as having undergone primary ACL reconstruction during the 3-year study period. Noncontact injury mechanism was responsible for 140 ACL injuries and subsequent operations (95 men, 45 women). The average age of the patients was 24.9 years (±7.9 years). The remaining injuries were contact-related and were therefore excluded from further analysis. The control group consisted of 179 patients (126 men, 53 women). The average age of the control group was 25.4 years (±8.7 years).

An ANOVA revealed significant differences in tibial slope angle between the 2 groups (Table 1). Subjects in the noncontact ACL group had significantly greater tibial slope angles (9.39° ± 2.58°) when compared with control subjects (8.50° ± 2.67°). The trend toward greater tibial slope angles in the noncontact ACL group was also observed when each gender was examined independently; however, the difference was only statistically significant for women between the injury and control groups (9.8° ± 2.6° vs 8.20° ± 2.4°).

The differences in tibial slope angles between men and women within each group was also examined (Table 2). The ANOVA results revealed no significant within-group differences between men and women. Analysis of interrater reliability yielded an interrater reliability coefficient of 0.93 (95% confidence interval = 0.86-0.96).

DISCUSSION

In 2003, Uhorchak et al[22] reported the risk factors associated with noncontact ACL injuries in West Point cadets. Identifiable risk factors for both male and female cadets included a small femoral notch width (along with associated parameters of its measurement; ie, notch width index, eminence width, and so forth) and generalized ligamentous laxity. Female cadets had additional risk factors that included increased body weight and body mass index, and KT-2000 arthrometer (MEDmetric Corp, San Diego, California) laxity values that were 1 standard deviation above the mean at 134 N. The reported relative risk was 2.7 times greater for a noncontact ACL injury in these female cadets than for cadets with less knee laxity. They concluded, however, that despite their findings, there are other risk factors that contribute to noncontact ACL injuries that were not investigated.[22] Unfortunately, the parameter of our study was one of those that was not measured.

As independent, nonmodifiable risk factors, the debate of the significance of notch width and PTS and their influence on ACL injuries appears to be unresolved.[18] Souryal and Freeman[19] have reported that a small intercondylar notch width index results in an increased risk for ACL injury. LaPrade and Burnett[13] found similar results when evaluating collegiate athletes. However, Teitz et al[21] and Anderson et al[3] found no association between ACL injuries and notch width. It has also been reported that caution should be undertaken when measuring the intercondylar notch because of inaccuracy with identifying the anterior outlet on plain film radiographs.[2]

The 2 previously published articles evaluating the association between PTS and noncontact ACL injuries have resulted in conflicting outcomes.[5,14] Meister et al[14] compared 50 knees from 49 ACL-deficient patients (25 men) with 39 age-matched patients (17 men) with patellofemoral pain. Physical examination and arthroscopy were used to confirm the ACL injury in study group, and physical examination alone was used for the control group. A single examiner measured both groups. The average slope was 9.7° for the injured group versus 9.9° for the uninjured group. They concluded that PTS was not an identifiable risk factor for a noncontact ACL injury.[14]

Brandon et al[5] performed a similar analysis using a larger cohort of patients (100 patients, 66 men) for evaluating the tibial slope and included a group and gender stratification. The injury cohort was determined by history, physical examination, and MRI. Eighty-seven of the 100 patients within the injury cohort had isolated ACL injuries without compromise of the secondary stabilizers. These 87 patients were further evaluated to determine the association between an increasing PTS and what they call "low-grade" or "high-grade" pivot shift. It is not reported if all pivot shift examinations were performed by a single examiner. The control group (100 patients, 49 men) was established from patients within the private practices of the authors who had a diagnosis of patellofemoral pain. No mention of further radiologic workup or if a pivot shift examination was performed on the control group is reported. The authors concluded that, within their study cohort, there was statistical difference between the injury group and the control group. The study also reported a male and female difference between the injury and control groups; however, no gender difference existed within each group. They also reported that a high-grade pivot shift is associated with increasing PTS.[5] However, they did not stratify this outcome by gender. The ultimate conclusion was that an increased PTS is an independent risk factor for ACL injury in both male and female patients.

In agreement with Brandon et al,[5] we found that there was a statistical difference between our control group and the injured group. However, when the groups were stratified on the basis of gender, we found that only the women showed a statistical difference (Table 1). No difference in PTS was noted between the injured and control groups for men when our analysis was stratified by gender, which suggests that the variability between women in the injured and control groups influenced the overall statistical model when male and female subjects were combined. We also found, as did Brandon et al, that there was no difference between genders within the control group or the injured group (Table 2); however, this may have been because of inadequate statistical power in the current study. Regardless, the differences between men and women within the injured (0.60°) and control (0.43°) groups were likely of limited clinical importance. The degree of slope that would be clinically relevant is still open for debate, as we are discussing a few degrees of difference between groups.

When the PTS measurements of the 2 studies (Brandon et al[5] and ours) are compared, our results show less PTS for the injured group in all stratifications (Table 3). This may be the result of differences in the measurement methods and techniques used for assessing PTS angle between the 2 studies. The current study used 2 independent raters, with a high degree of interrater consistency (intraclass correlation coefficient = 0.93) for tibial slope measurements between raters. Brandon et al[5] used a single rater, and no information was presented on the intrarater or interrater reliability for this sole rater. Furthermore, all PTS measurements in the current study were made with a digital computer software measurement system, whereas the study described by Brandon et al used standard radiographs and a handheld goniometer to determine PTS angles. It is possible that the increased precision afforded by the computerized measurement system used in the current study was superior for assessing PTS angles while reducing the likelihood for measurement error when compared with the analog techniques used by Meister et al[14] and Brandon et al.[5] Future studies are needed to evaluate the psychometric properties associated with different measurement techniques for assessing the PTS angle.

TABLE 3
Comparison of Posterior Tibial Slope Measurements[a]

	Control Group		Injured Group	
	I	II	I	II
Total	8.5	8.5	9.4	11.2
Men	8.6	8.4	9.2	10.8
Women	8.2	8.6	9.8	12.0

[a] I, current study posterior tibial slope; II, Brandon et al[5] posterior tibial slope.

Finally, the measurement technique described by Dejour and Bonnin[6] relies on the use of the medial plateau for measurement because it is the most easily recognizable on plain radiography; however, evaluation of the lateral plateau may be more appropriate and warrants further investigation. Stijak et al[20] used MRI and plain radiography to evaluate the relationship between PTS and ACL injury. They found an increased PTS of the lateral plateau for their injury cohort versus the ACL-intact cohort. An increased lateral tibial plateau slope may influence the rotation of the knee and ultimately the pivot shift phenomenon. However, Stijak et al also reported an increased medial tibial plateau slope in their control group versus the injury cohort, which is contrary to our findings. Nevertheless, their research further delineates the need for increased research in this area.

A primary limitation of the current study is its retrospective nature. Despite the large cohorts used to determine the comparative slopes, prospective data collection and follow-up examining several anatomical and structural factors related to ACL injury would be preferential. Furthermore, because MRI studies were not available for all subjects in the control group we had to rely on the information in the medical record to rule out ACL injury in that group. As a result, it is possible that patients with partial ACL injuries may have been missed, although we believe this possibility to be small because patients in our population with incomplete ACL injuries are unable to return to function at a level required by their vocation, and they ultimately undergo ACL reconstruction. The size of the injured female cohort, although larger than in the previous studies, is limited by the collection population at our institution, which may result in some selection bias. However, our patient population receives its care through a closed health care system, and all ACL injuries and reconstructions within our population during the study period were identified and included in the current study.

Another limitation of the study was the lack of both raters being blinded to the cohorts before PTS measurements. However, in view of the high interrater reliability coefficient between the two examiners (0.93), we do not believe that examiner bias is a concern.

The strengths of the study include the large number of measured patients for both the control and injured groups, thus eliminating the possibility of type II error. Two fellowship-trained orthopaedic surgeons measured the radiographs independently and achieved high interrater reliability. Although we are not aware of any study that has specifically evaluated manual versus digital measurement of tibial slope, the use of digital radiographs and computer-assisted angle measurement software is supported in the literature for improved reliability, precision of measurement, and elimination of intrinsic error associated with manual techniques.[7,9,16,18] However, it would be beneficial to perform a study that compares multiple radiographic modalities to determine the most accurate measurement of tibial slope and other anatomical variations.

CONCLUSION

Despite the findings of this study, the clinical significance of an increased tibial slope as an isolated risk factor for ACL injury remains unanswered. The question also remains as to what degree of increased tibial slope should raise concerns about the increased risk for subsequent injury. We will be unable to accurately counsel patients until we have a prospective study, similar to that performed by Uhorchak et al,[22] that evaluates multiple measurable potential risk factors with standardized collection points, long-term follow-up, and outcomes of revision ACL reconstructions.

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