Posterior Tibial Slope and Further Anterior Cruciate Ligament Injuries in the Anterior Cruciate Ligament–Reconstructed Patient

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Background: An injury to the anterior cruciate ligament (ACL) is a multifactorial event influenced by intrinsic and extrinsic risk factors. Recently, the geometry of the proximal tibia has come under focus as a possible risk factor for an ACL injury.

Hypothesis: An increased posterior tibial slope is associated with an increased risk of further ACL injuries in the previously ACL-reconstructed patient.

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

Methods: A total of 200 consecutive patients with isolated ACL ruptures who underwent primary reconstruction with hamstring autografts were enrolled in a prospective longitudinal study over 15 years. The posterior tibial slope was measured from a lateral knee radiograph by 2 blinded observers. The data were analyzed for the association between an increased posterior tibial slope and the incidence of further ACL injuries. Interobserver reliability of the posterior tibial slope measurements was assessed.

Results: Radiographs and follow-up were available for 181 of the 200 enrolled patients. Fifty patients had a further injury to either the ACL graft or the contralateral knee. The mean posterior tibial slope of those with a further ACL injury was 9.9° compared with 8.5° for those with no further injury (P = .001). The mean posterior tibial slope for those with both an ACL graft and contralateral ACL rupture was 12.9°. The odds of further ACL injuries after reconstruction were increased by a factor of 5, to an incidence of 59%, in those with a posterior tibial slope of ≥12°.

Conclusion: An increased posterior tibial slope is associated with increased odds of a further ACL injury after ACL reconstruction. The increased risk is most pronounced in those with a posterior tibial slope of ≥12°.

Keywords: knee; ligaments; ACL injury; posterior tibial slope; risk factors; reinjury; injury prevention

An injury to the anterior cruciate ligament (ACL) is a multifactorial event and is influenced by a number of extrinsic and intrinsic risk factors. Extrinsic risk factors include environmental conditions such as playing surface, shoe type, weather conditions, and type of sport.[1,10,18,22,23] Intrinsic risk factors may be divided into anatomic, hormonal, neuromuscular, and familial.[29] Numerous anatomic variables have been suggested (intercondylar notch width, increased body mass index, landing kinematics, female sex, anatomic alignment); however, there remains no clear evidence in the literature as to the relative contribution of each factor.[2,4,11,15,23,32] Given the frequent injury to the ACL and its subsequent cost,[14,22] the importance of continuing to study and identify risk factors, in particular modifiable or reversible risk factors, is essential.

Recently, the geometry of the proximal tibia, in particular the posterior tibial slope (PTS), has been considered as a risk factor for a primary ACL injury.[12,16,17,26,30,33] It is believed that the PTS directly affects loading of the ACL during a compressive axial force and therefore may contribute to the propensity of the ACL to rupture.[12] As the PTS has been shown to contribute to a primary ACL injury, it stands to reason that this anatomic variation may also contribute to contralateral ACL ruptures and reruptures of the ACL-reconstructed knee. To our knowledge, there are currently no other published data investigating a relationship between the PTS and ACL graft ruptures or contralateral ACL ruptures after ACL reconstruction.

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MATERIALS AND METHODS

A total of 200 consecutive patients with isolated ACL ruptures who underwent primary ACL reconstruction with hamstring tendon autografts between October 1993 and March 1996 were enrolled in the study. An isolated ACL rupture was defined by excluding (1) an associated ligamentous injury requiring surgical management, (2) significant chondral damage (full-thickness cartilage defect) or degeneration, (3) prior meniscectomy, (4) excision of one third or more of 1 meniscus and no significant meniscal root injury or meniscal instability, (5) abnormal radiological findings, (6) an abnormality in the contralateral knee, (7) patients seeking compensation for their injuries, and (8) those who did not wish to participate in a research program. Ethical approval was granted by a local independent ethics committee.

All surgery was performed by a single surgeon (L.A.P.) utilizing a surgical technique that has been published in detail previously.[8] Surgery was performed using a single-incision endoscopic technique with a 4-strand ipsilateral hamstring tendon graft. An anatomic femoral tunnel was drilled via the anteromedial portal. Graft fixation was achieved in both tunnels with a 7 × 25–mm titanium round interference screw (RCI, Smith & Nephew, Andover, Massachusetts). Clinical results of this patient cohort have been previously reported.[5] Postoperatively, patients were reviewed at 1, 2, 7, and 15 years after surgery. Clinical review was performed by 1 of 2 highly experienced research physical therapists. Clinical assessments included the Lachman, pivot-shift, and instrumented laxity tests with the KT-1000 arthrometer (MEDmetric Corp, San Diego, California) on both knees. Radiographic assessment was conducted at 2, 7, and 15 years postoperatively with weightbearing anteroposterior, 30° of flexion posteroanterior, lateral, and patellofemoral views.

Patients with a new acute injury were assessed clinically and a diagnosis made on the basis of the clinical findings. A contralateral ACL rupture was confirmed arthroscopically in all patients (n = 19) at the time of contralateral ACL reconstruction. An ACL graft rupture was confirmed in 29 of the 35 patients at the time of revision ACL reconstruction. In those patients who had not undergone revision ACL reconstruction, the diagnosis of an ACL graft rupture was based on clinical findings of a positive pivot-shift examination and/or Lachman test result (grade 2 or more).

The PTS was measured by 2 knee fellowship–trained orthopaedic surgeons using OsiRix software (Pixmeo, Geneva, Switzerland) on the best available digitized lateral radiograph of the knee. The PTS was calculated by measuring the angle between a line drawn tangentially to the medial tibial plateau and the proximal anatomic axis of the tibia. The proximal anatomic axis was determined by a line connecting the midcortical diameters of the tibia at a point 5 and 15 cm distal to the knee joint. The proximal anatomic axis was selected because it has been shown to most accurately reflect the mechanical axis of the tibia and can be drawn on a standard short radiograph of the knee.[34] The mean value was calculated from the 2 observers.

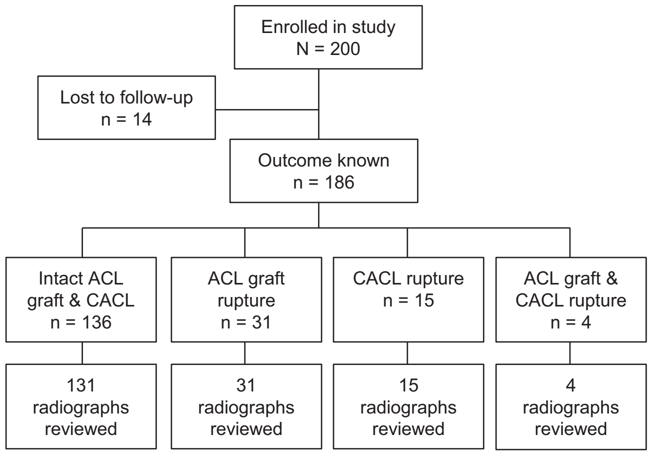

Figure 1. Participant flowchart. ACL, anterior cruciate ligament; CACL, contralateral ACL.

Statistical Analysis

Statistical analysis was performed with SPSS for Windows version 11 (SPSS Inc, Chicago, Illinois). A difference in the mean PTS was assessed with an independent *t* test for a 2-group comparison. χ^2 tests were used to assess the incidence of further injuries in the subgroups of sex and PTS of ≥12°. Binary logistic regression analysis was used to assess the relative contribution of age, sex, and PTS on the incidence of further ACL injuries. Interexaminer reliability of the PTS measurements was assessed with intraclass correlations. For the purposes of statistical analysis, the mean of the 2 examiners was calculated and used. Statistical significance was set at .05.

RESULTS

Of the 200 patients enrolled, 14 patients were lost to follow-up. Of the remaining patients, 181 had suitable radiographs available for measurement of the PTS. Five patients were reviewed at 15 years, but a suitable unrotated lateral radiograph was not available for accurate measurement of the tibial slope. The mean age at surgery was 26 years. There were 90 female and 91 male patients. There were 93 right-sided reconstructions and 88 left-sided reconstructions. The mean time to surgery was 6.7 months (range, 1-84 months) from injury. The mean time to review was 15 years (range, 14.25-16.9 years).

The participant flowchart is shown in Figure 1. Of the 181 patients, a total of 50 had a further ACL injury.

The distribution of PTS is shown in Figure 2. The mean PTS for a patient with any further injury was 9.9° compared with 8.5° for a patient with no further injury (P = .001). The mean PTS values for each of the groups with further injuries are shown in Table 1 and Figure 3.

There were 22 patients with a PTS of >12° (12%). Patients with a PTS of >12° had a 59% incidence (13/22 patients) of a further ACL injury compared with a 23% incidence (37/159) for those with a PTS of ≤12° (P = .001) (Figure 4).

TABLE 1
PTS Grouped According to ACL Status[a]

ACL Status	No. of Patients	PTS, Mean ± SD, deg	P Value[b]
Intact ACL and contralateral ACL	131	8.5 ± 2.3	—
Rupture, ACL graft or contralateral ACL	50	9.9 ± 2.3	.001
Rupture, ACL graft	31	9.6 ± 2.3	.12
Rupture, contralateral ACL	15	9.9 ± 2.3	.16
Rupture, both ACL graft and contralateral ACL	4	12.9 ± 1.9	.001

[a]ACL, anterior cruciate ligament; PTS, posterior tibial slope.
[b]Compared with group with intact ACL graft and contralateral ACL.

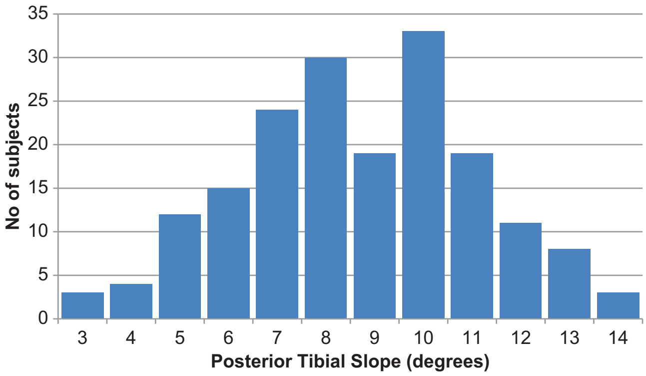

Figure 2. Distribution of posterior tibial slope in 181 patients.

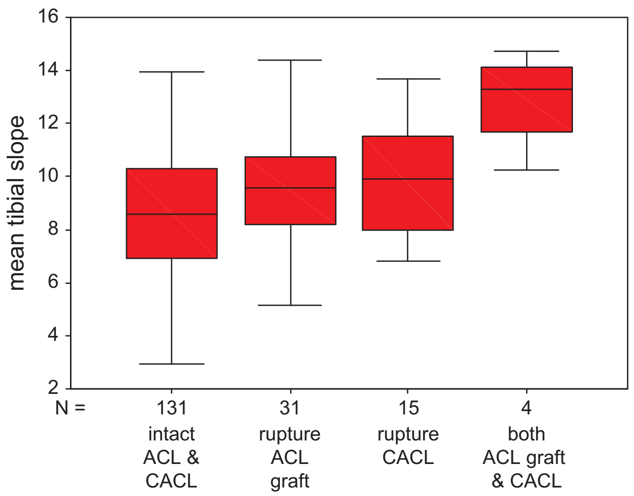

Figure 3. Posterior tibial slope grouped according to anterior cruciate ligament status. ACL, anterior cruciate ligament; CACL, contralateral ACL.

The mean time to further injury was 66 months (range, 2-192 months). The relationship between the tibial slope and time to further injury is shown in Figure 5. There is

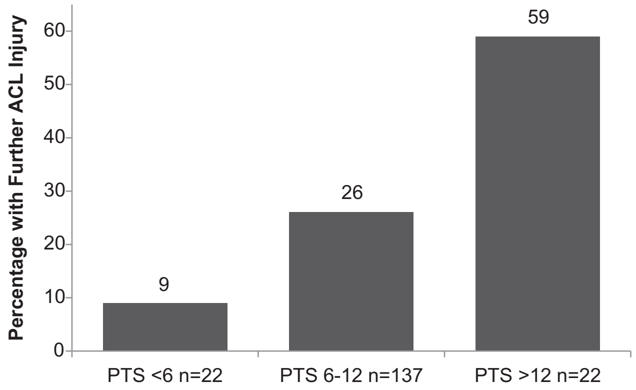

Figure 4. Incidence of further anterior cruciate ligament (ACL) injuries with increasing posterior tibial slope. There was a significant difference between the 3 groups in the incidence of further ACL injuries (*P* = .001). PTS, posterior tibial slope.

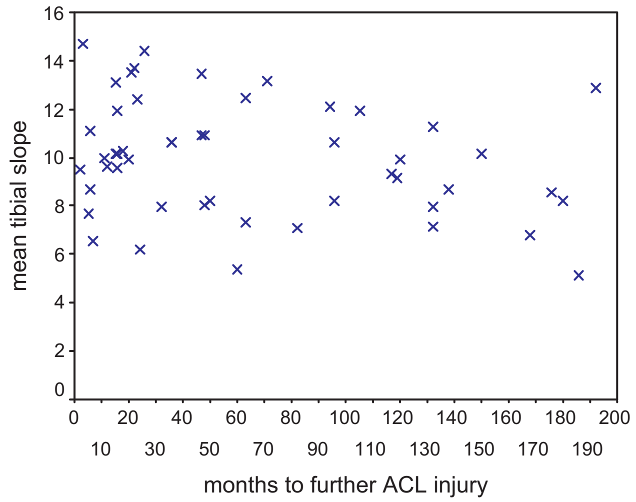

Figure 5. Relationship between time to further anterior cruciate ligament (ACL) injury and mean posterior tibial slope.

a negative correlation (Pearson $r = -0.3$) between a higher tibial slope and months to further injury ($P = .01$).

The incidence of further ACL injuries was not significantly different between male and female patients ($P = .96$). Male patients had a higher mean PTS of 9.3° ± 2.4° compared with the female mean of 8.5° ± 2.3° ($P = .04$). Those who sustained a further ACL injury were significantly younger (mean, 23 ± 9 years) than those with no further injuries (mean, 27 ± 8 years) ($P = .008$). Logistic regression analysis was performed to assess the relative contribution of the variables of sex, age of <18 years, and PTS of ≥12° on the incidence of further ACL injuries. The results are shown in Table 2.

The details of the patients who sustained an ACL graft rupture are shown in the Appendix (available online at http://ajsm.sagepub.com/supplemental).

TABLE 2
Regression Analysis of PTS, Patient Age, and Patient Sex on the Odds of Further ACL Injuries[a]

Factor	Odds Ratio	95% Confidence Interval	*P* Value
PTS of ≥12°	5.2	2.0-13.8	.001
Age of <18 years at surgery	2.9	1.2-6.7	.016
Male sex	0.9	0.4-1.8	.683

[a]ACL, anterior cruciate ligament; PTS, posterior tibial slope.

Reliability

The PTS was measured by 2 orthopaedic surgeons. The mean PTS measured was 9.0° ± 2.5° and 8.8° ± 2.7°, respectively. The intraclass correlation coefficient was 0.88 (95% confidence interval, 0.85-0.91), indicating very high interrater reliability.

DISCUSSION

The results of this study demonstrate an association between an increasing PTS and the incidence of further ACL injuries after ACL reconstruction. This relationship was most evident in those 22 patients with a PTS of >12°, who were found to have a 59% incidence of further ACL injuries or 5 times the greater odds of further ACL injuries when controlled for young age and sex.

The mean PTS was higher in those with either a graft or contralateral ACL rupture compared with those with no further injury (9.9° vs 8.5°, respectively; *P* = .001). Patients with both a graft rupture and contralateral ACL rupture also had a significantly greater PTS when compared with those with no further injury (12.9° vs 8.5°, respectively; *P* = .001). There was a trend toward an increased mean PTS in patients who ruptured their ACL graft or contralateral ACL compared with those with intact ACLs, but this did not reach statistical significance. We can conclude from this that it is those patients with a markedly increased PTS compared with the population mean who are at greatest risk of further ACL injuries.

Previous studies have identified that the incidence of further ACL injuries after ACL reconstruction is increased in those aged <18 years[19,24] and male patients.[6] Male patients in our cohort had a statistically higher PTS compared with female patients (9.3° vs 8.5°, respectively; *P* = .04). This is in contrast to previous studies that have found female patients to have a higher PTS.[7,30] In this series, sex was not a significant independent contributor to the odds of further ACL injuries when controlled for young age and a PTS of ≥12°. While an age of <18 years did increase the odds of further ACL injuries by a factor of 3, a PTS of ≥12° increased the odds of further ACL injuries by a factor of 5. It should be noted that a PTS of ≥12° is relatively uncommon (12% of this series). A PTS of ≥12° was seen infrequently but was a more significant contributor to further ACL injuries than younger age.

This study is the first to examine the relationship between PTS and ACL reinjury after ACL reconstruction. The role of an increased PTS as a risk factor for a primary ACL injury has been previously investigated. A recent meta-analysis by Wordeman et al[33] concluded that the available literature demonstrates a trend toward a link between PTS and the risk of ACL injuries but that inconsistencies in measurement techniques preclude the ability to definitely link the two. They highlighted that a large number of techniques are used to determine the PTS on both plain radiographs and magnetic resonance imaging (MRI), resulting in a wide variability of the "normal" PTS. A normal physiological PTS of between 7° and 13° has been reported.[12] Brandon et al[7] retrospectively measured the PTS of 100 ACL-injured patients and 100 normal control patients. They found a statistically significant increased PTS (11.2° vs 8.5°, respectively) in ACL-injured patients. These findings have been supported by a number of other studies.[27,30,31] We can conclude that PTS influences both primary ACL injuries and those that occur after ACL reconstruction.

An increased PTS is believed to adversely affect the ACL by increasing the amount of anterior tibial translation under axial load. This theory is supported in the literature. Dejour and Bonnin[9] found that for every 10° increase in PTS, there was a 6-mm increase in anterior tibial translation during a single-legged stance. Similar results have been found in cadaveric and computer modeling studies.[13,25] This sustained increased load on the ACL may make it more susceptible to failure.

Our study does have some limitations. The use of a plain lateral radiograph of the knee to calculate the PTS was chosen because it is a readily available method that is routinely used in postoperative assessments after ACL reconstruction. The geometry of the proximal tibia may be too complex to reliably measure from a single radiograph. The slopes of the lateral and medial tibial plateaus are not the same, and it has been suggested that the slope of the lateral tibial plateau may be a more sensitive risk factor for ACL injuries than the medial tibial plateau.[28] These factors can only be measured on MRI, which was not included in our study. Our measurement technique has, however, been shown to have excellent reproducibility with near perfect interobserver reliability. A lateral radiograph is readily available and has a much lower cost than MRI, making it a more commonly used assessment in the clinical setting.

The questions remain as to what value of PTS can be considered a significant risk for an ACL injury and reinjury and whether a corrective osteotomy should be considered to reduce the risk of reinjuries. Our measurement technique has shown excellent interobserver reliability, and for our data, a PTS of ≥12° significantly increased the odds of further ACL injuries. The question of how to manage this increased risk with a high PTS remains unanswered. Modification of the PTS by osteotomy has been undertaken in cadaveric models with mixed results. A number of authors have described valgizing high tibial osteotomy (HTO) in the setting of chronic ACL deficiency, varus malalignment, and arthritic joint disease.[3,20,21] To our knowledge, no authors have investigated decreasing the PTS to reduce the risk of ACL injuries. Given the potential morbidity of an HTO, we do not recommend HTO for those patients with a high PTS at this time. We do recommend quantifying the PTS in patients undergoing ACL reconstruction. For those patients with a high PTS, which was $\geq 12°$ in our study, patient counseling should be undertaken to convey the potentially increased risk of further ACL injuries. Emphasizing a structured rehabilitation program with hamstring strengthening to counter any increased PTS may be one way of minimizing this increased risk.

CONCLUSION

An increased PTS is associated with an increased incidence of further ACL injuries after ACL reconstruction. A PTS of $\geq 12°$ occurs infrequently but increases the odds of further ACL injuries by a factor of 5. Suitable counseling regarding this risk is warranted in those with a very high PTS.

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