Medial and Lateral Posterior Tibial Slope in the Skeletally Immature

A Cadaveric Study

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Background: An increased posterior tibial slope (PTS) results in greater force on the anterior cruciate ligament (ACL) and is a risk factor for ACL injuries. Biomechanical studies have suggested that a reduction in the PTS angle may lower the risk of ACL injuries. However, the majority of these investigations have been in the adult population.

Purpose: To assess the mean medial and lateral PTS on pediatric cadaveric specimens without known knee injuries.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 39 pediatric knee specimens with computed tomography scans were analyzed. Specimens analyzed were between the ages of 2 and 12 years. The PTS of each specimen was measured on sagittal computed tomography slices at 2 locations for the medial and lateral angles. The measurements were plotted graphically by age to account for the variability in development within age groups. The anterior medial and lateral tibial plateau widths were measured. The distance between the top of the tibial plateau and the physis was measured. The independent-samples t test and analysis of variance were used to analyze the measurements.

Results: The mean PTS angle for the medial and lateral tibial plateaus was 5.53 ± 4.17° and 5.95 ± 3.96°, respectively. The difference between the PTS angles of the medial and lateral tibial plateaus was not statistically significant (P > .05). When plotted graphically by age, no trend between age and PTS was identified.

Conclusion: This data set offers values for the PTS in skeletally immature specimens without a history of ACL injury and suggests that age may not be an accurate predictive factor for PTS.

Keywords: pediatric; tibia; tibial slope; ACL

The incidence of anterior cruciate ligament (ACL) tears has increased over the past 20 years. These injuries can be extremely debilitating and are associated with intra-articular damage to the knee. Anatomic risk factors for sustaining an ACL tear include femoral intercondylar notch width, ACL thickness, increased anteroposterior knee joint laxity, female sex, and other anatomic variations. In particular, the posterior tibial slope (PTS) has been implicated as an important risk factor for ACL injuries. Anatomically, the tibia slopes from its high side anteriorly to its low side posteriorly to accommodate the native, elliptical shape of the femoral condyles. Furthermore, the side-to-side geometry of the tibial plateau is known to be asymmetric, with the medial side concave and the lateral side flat to convex. This complex osseous anatomy is designed to accommodate the complex knee joint through an arc of motion that moves through 3 dimensions. Normative computed tomography (CT) values of the PTS in adults have been published and suggest mean values for the medial and lateral compartments of 6.6° ± 1.8° and 9.5° ± 2.6°, respectively.

While anatomic research on the PTS has been conducted on adults, few studies have analyzed the PTS anatomy of pediatric and adolescent patients. Further, limited research has stratified PTS data according to age. Finding population variables that help predict the PTS is important, as patients with greater PTS angles appear more likely to sustain an ACL tear and other intra-articular damage to the knee. Dare et al showed that, in a cohort of patients aged 12 to 17 years, the lateral PTS was...
significantly higher in those with ACL injuries. Access to pediatric knees or specimens is very limited, especially for younger age groups, although access to this tissue may provide insight into the development of the PTS in growing patients.

Dekker et al. found that 32% of adolescents involved in youth sports with a previous ACL injury acquired a secondary ACL injury. For these patient groups at a high risk for primary and secondary ACL injuries, an assessment of the tibial slope may be part of the evaluation process. In some centers, alteration of the tibial slope may be part of the treatment algorithm to reduce the risk of future ACL injuries. Most of the research to date has evaluated the overall tibial slope, without distinction of the medial and lateral tibial plateaus. Joint geometry of the knee and differing tibial slopes affect biomechanics. A high posterior slope in either the medial or lateral compartment can result in anterior translation of the tibia and compressive forces, which place significant strain on the ACL.

The purpose of this study was to evaluate the PTS of the medial and lateral tibial plateaus in a cohort of skeletally immature specimens (without known knee injuries) on high-resolution CT scans. Our hypothesis was that the tibial slope might change during development, similar to other lower extremity alignment parameters in growing children.

METHODS

The pediatric tissue specimens utilized in this study were donated to a graft harvesting facility (AlloSource) before initiation of this study. All specimens were processed to rule out diseases and bacterial infections, as required by the US Food and Drug Administration and the American Association of Tissue Banks guidelines. Specimens were then vetted for deformities by AlloSource and excluded if found. Consent was obtained from all of the donors’ families to use the tissue for research purposes. No genetic information was obtained, and no contact was made with donor families. Thus, institutional review board approval was not needed.

A database of 39 pediatric knee CT scans (0.625-mm slices) was analyzed using OsiriX imaging software (Version 10.0.3; Pixmeo). The database consisted of specimens between the ages of 2 and 12 years. The PTS was measured on sagittal CT slices at 2 locations by an undergraduate research assistant: (1) the medial tibial plateau at the midregion of the medial femoral condyle, as determined on a coronal slice through the femoral condyle, and (2) the lateral tibial plateau at the midregion of the lateral femoral condyle, as determined on a coronal slice through the femoral condyle (Figure 1). Measurements selected at random were checked by a fellowship-trained orthopaedic surgeon to confirm accuracy.

Sagittal images of the midregion of the medial femoral condyle and the midregion of the lateral femoral condyle were overlaid on top of a sagittal image of the most central aspect of the tibial spine using the “image fusion” tool in OsiriX. This tool allows the user to blend 2 separate images together for analysis. Utilizing the software, we then applied a Positron...
Emission Tomography “(PET) filter” to the blended sagittal image of the knee at the most central aspect of the tibial spine (Figure 2).30

The measurement of the PTS was then performed by placing 2 lines parallel to the diaphysis of the tibia, using 1 located in the middle of the diaphysis and 1 located at the most posterior aspect of the diaphysis. The middle of the diaphysis was approximated at half the greatest width of the medial plateau. The posterior margin of the diaphysis was identified as by the most superior posterior edge of the medial plateau. The most proximal aspect of both the medial and lateral tibial plateaus was then identified, and angle measurements were taken in reference to the parallel lines (Figure 2).

The 39-specimen database was then analyzed using the independent-samples $t$ test and analysis of variance. Analysis was performed using SAS Enterprise Guide (Version 4.2; SAS Institute). The PTS measurements were recorded and plotted graphically by age to account for the variability in development within age groups.

RESULTS

A total of 39 specimens (age range, 2-12 years) were analyzed. The mean PTS angle for the medial and lateral tibial plateaus was $5.53^\circ \pm 4.17^\circ$ and $5.95^\circ \pm 3.96^\circ$, respectively (Table 1).

The difference between the PTS of the medial and lateral tibial plateaus between all specimens was not statistically significant ($P > .05$; independent-samples $t$ test and analysis of variance). When plotted graphically, no trend between age and PTS was identified (Figure 3).

DISCUSSION

The collected data show that the medial and lateral PTS were highly variable in pediatric patients and that the PTS decreased with age, consistent with our hypothesis. When plotted graphically, no trend between age and PTS was identified. The mean PTS angle for the medial and lateral tibial plateaus was $5.53^\circ \pm 4.17^\circ$ and $5.95^\circ \pm 3.96^\circ$, respectively. In the setting of primary and revision ACL surgery in the skeletally immature patients, tibial slope measurements may be important variables to consider for treatment.

These results are important in the setting of a pediatric ACL injury, as studies have shown that a greater PTS results in more frequent ACL tears in both adult18,42 and pediatric athletes.3 These injury rates may be caused by the increased strain placed on the ACL.15,26 These forces are accentuated in skeletally immature athletes, who experience frequent axial loading during sports.32 A high PTS angle, as well as increased sports participation, sport specialization, and year-round play, is associated with ACL injuries.34 Although surgical reconstruction of the ACL can restore knee stability, patients with a greater PTS may be more likely to experience less favorable outcomes and reinjuries.27,45 Understanding which skeletally immature athletes may be at a greater risk for sustaining an ACL tear or future ACL retear may help target this population for preventive training18 or, perhaps, postoperative alterations to their rehabilitation program to mitigate the effects of the increased slope.

To understand what a pathological PTS is, we must first know what a “normal” PTS is. Salmon et al.31 in 2018, reported on 20-year outcomes from ACL reconstruction using a hamstring tendon autograft in patients with an increased PTS that they defined as $>12^\circ$ and showed that

### Table 1

| Age, y | No. of Specimens | Medial Tibial Slope, deg | Lateral Tibial Slope, deg |
|--------|------------------|--------------------------|--------------------------|
| 2      | 3                | 7.56 ± 6.56              | 12.15 ± 2.23             |
| 4      | 5                | 8.34 ± 3.13              | 4.96 ± 2.00              |
| 5      | 5                | 4.00 ± 3.00              | 3.08 ± 2.10              |
| 7      | 7                | 4.80 ± 5.32              | 3.87 ± 3.15              |
| 9      | 10               | 6.78 ± 5.28              | 6.73 ± 4.63              |
| 10     | 2                | 3.85 ± 0.72              | 6.17 ± 1.64              |
| 11     | 6                | 4.07 ± 1.99              | 5.10 ± 2.94              |
| 12     | 1                | 6.36 ± 0.00              | 11.84 ± 0.00             |
| All specimens | 39             | 5.53 ± 4.17              | 5.95 ± 3.96              |

*Data are shown as mean ± SD. $P > .05$, unless otherwise indicated.

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References 2, 7, 13, 18, 21, 24, 33, 35, 36, 43.
adolescents with a PTS >12° were 11 times more likely to rupture their graft and 7 times more likely to rupture their contralateral ACL than were adults with a PTS <12°. The 2020 study of Yoon et al47 of 232 participants followed for a minimum of 10 years suggested that a medial PTS >5.6° or a lateral PTS >3.8° results in significantly more failure of ACL reconstruction. Larger studies will need to be conducted to determine the range of pathological or detrimental PTS angles; however, our data set offers some preliminary values for the PTS in patients without a history of ACL injuries, allowing for comparisons with patients with ACL injuries, which may be applied to future studies.

Conversely, studies have indicated that a shallow PTS angle is associated with posterior cruciate ligament (PCL) injuries.5 High medial and lateral PTS result in a posterior shift of the tibia under axial loading.14 Although PCL injuries in skeletally immature individuals are rare,37 observing the PTS in adolescents in relation to PCL function may lead to better clinical assessments of PCL injuries and deficiencies in children. Subsequently, a causal relationship between ACL and PCL function and the PTS exists.6,11,12,22,26Biomechanical studies of the PTS substantiate this research, as it was found that tibial shear force, anterior tibial translation, and ACL force increase as the PTS increases.14 Nevertheless, little research has been conducted on the optimal tibial slope for ACL and PCL function. Again, before our study, the optimal or “normal” PTS in the adolescent population has not been well reported. A literature review regarding the optimal alignment of the tibiofemoral joint in knee arthroplasty suggested that a tibial slope between 0° and 7° is optimal16; however, this may not be relevant to an active youth population.

Biomechanical studies have suggested that altering a patient’s PTS may lower the risk of ACL injuries. In adults, tibial osteotomy to reduce the PTS has been successfully performed, resulting in decreased tibial translation and reduced forces on the ACL under axial loading.20,46 Several researchers have used tibial osteotomy in higher risk revision ACL cases to lower the risk of secondary ACL injuries.5,10 However, tibial osteotomy to reduce the PTS is a significant surgical intervention. Although pediatric and adolescent patients are at a high risk of primary and recurrent ACL injuries, this procedure poses a significant risk to skeletally immature patients because of the presence of open physes. A direct physeal injury in skeletally immature patients can lead to growth disturbances. In cases in which an increased tibial slope is identified as a risk factor for primary or secondary ACL injuries, the principles of guided growth may warrant further research. In cases of recurrent ACL tears in skeletally immature patients with a significantly increased tibial slope, the principles of guided growth may be applied to future studies.

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Limitations

This study has several limitations, including the small sample numbers in each age group. Furthermore, access to magnetic resonance imaging and CT scans in the very young knees is limited. Limitation is due in part to the need for general anesthesia in young patients. Moreover there is limited indications in this age group for magnetic resonance imaging and CT and therefore access to these images is rare, even retrospectively. Although CT allows for very narrow image slice thicknesses and excellent data acquisition and manipulation, the database of CT scans used for this study was based on access to exceptionally rare pediatric knee tissue available for research. Future studies including a larger number of participants or specimens would enhance this study, although access to adequate numbers may not occur for a prolonged time period.

CONCLUSION

This study offers clinicians information about the developmental anatomy of the PTS in skeletally immature individuals and suggests that age is not a reliable predictive factor for pediatric PTS. This study revealed that the PTS in skeletally immature individuals was highly variable and that the PTS decreased with age. An improved understanding of the developmental anatomy of the pediatric knee expounds on the causal relationships among anatomic parameters, risks of an injury, and possibly developments in the surgical technique. Future clinical studies may benefit from considerations of the development of tibial slope, and potential interventions to alter this development may require further study to lower the risk of recurrent ACL or PCL injuries.

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