Correlation of Tibial Tubercle Overgrowth With Increased Posterior Tibial Slope

A Novel Radiographic Assessment

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Background: An elevated posterior tibial slope (PTS) is associated with an increased risk for anterior cruciate ligament and meniscal injury. Recent evidence suggests that the PTS is elevated in patients with Osgood-Schlatter disease.

Purpose: To determine whether there is an association between objective measures of anterior tibial tubercle growth and PTS.

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

Methods: A total of 100 radiographs were randomly selected from a sample of patients who had received a lateral knee radiograph that captured at least 15 cm of the tibia distal to the knee joint line at a single institution between December 2020 and March 2022. The PTS was measured, and tibial tubercle growth was quantified with 2 novel measurements. For these measurements, a line was drawn on the radiograph from the most anterosuperior point on the tibia to the point on the anterior cortex of the tibia 10 cm distal from the starting point. The tibial tubercle height (TTH) was measured as the perpendicular distance from this line to the most prominent portion of the anterior tibia. The anterior tibial tubercle angle (TTA) was measured as the angle between the endpoints of the line made previously and the most prominent portion of the tibial tubercle, with a more acute angle indicating a more prominent tibial tubercle. The relationship between TTA, TTH, and PTS was evaluated using a univariate linear regression model.

Results: The mean patient age was 33.1 ± 14.1 years. The mean TTA was 158.6° ± 4.7°, the mean TTH was 8.8 ± 2.0 mm, and the mean PTS was 9.7° ± 2.6°. A significant correlation was found between PTS and TTA ($r = -0.46$; $\beta = -0.46$; $P < .001$) as well as TTH ($r = 0.43$; $\beta = 0.43$; $P < .001$).

Conclusion: Objective measures of anterior tibial tubercle overgrowth correlated with an elevated PTS. Every 2.2° of anterior TTA deviation from the mean and every 2.3 mm in TTH deviation from the mean correlated with a 1° difference in the PTS. This suggests a link between the development of the tibial tubercle and PTS, and it potentially helps to explain why the PTS is elevated in certain patients.

Keywords: tibial tubercle overgrowth; Osgood-Schlatter disease; posterior tibial slope; knee

The posterior tibial slope (PTS), a radiographic measure of proximal tibial angulation as seen on a lateral radiograph, has a significant effect on knee joint biomechanics. Cadaveric studies have established the important contribution that the PTS has toward knee stability and ligamentous and meniscal loading.[1,2,6,7,16] This is partially related to increased anterior tibial translation, which is known to be a consequence of an elevated PTS.[16] Bernhardson et al[2] showed that the force experienced by the anterior cruciate ligament (ACL) during axial loading was elevated in cadaveric specimens with increased tibial slopes. Shelburne et al[15] used software modeling to calculate the effect of changes in PTS on ligamentous loading and anterior tibial translation, demonstrating that as the PTS increased, so did the shear forces of the femur on the tibia, with increased tensile forces being exerted on the ACL to restrain this movement. Clinically, this contribution has been supported in the literature, with evidence demonstrating a link between increased PTS and a higher

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incidence of ACL injury in young athletes.[5,9,11,16] In patients who have already had an ACL reconstruction surgery, it has been suggested by Bernholt et al[3] that elevated PTS is associated with an increased incidence of posterior meniscal tears. Additionally, a randomized controlled trial by Cruz et al[4] demonstrated that increased PTS was associated with a higher risk of ACL graft failure regardless of graft type used. PTS has also been implicated in the loading of the posterior cruciate ligament (PCL), and it is an important factor to consider when planning reconstructive procedures of the tibia.[1] Although the importance of the PTS has been robustly studied, there is a paucity of literature addressing the causal mechanism and factors that lead to an elevated PTS.

PTS has been found to be elevated in patients with a diagnosis of Osgood-Schlatter disease (OSD). In a study by Green et al,[8] the PTS was found to be elevated in patients who had a clinical diagnosis of OSD compared with controls without an OSD diagnosis. Green et al hypothesized that the growth stimulation of the anterior tibial tubercle seen in OSD predisposed one to an elevated PTS in the population with a confirmed diagnosis of OSD. However, this hypothesis did not comment on a general patient population outside of OSD and did not evaluate objective measurements of the anterior tibial tubercle.[15]

The purpose of this study was to use 2 novel measurement techniques for anterior tibial tubercle overgrowth to determine whether a relationship existed between anterior tibial tubercle overgrowth and elevated PTS in a generalizable patient population. We hypothesized that the measurements for anterior tibial tubercle growth would directly correlate with the PTS.

METHODS

Cohort Selection

The study protocol was approved by our institutional review board. A total of 100 patients who met inclusion criteria were selected at random from a query of our institution's Picture Archiving and Communication System (PACS) (IntelliSpace Radiology Enterprise 4.5; Philips North America); patients were randomized with the assistance of a computerized random number generator. All patients considered for inclusion had received a lateral knee radiograph between December 2020 and March 2022. The inclusion criterion was a lateral radiograph that captured at least 15 cm of the tibia distal to the knee joint line to allow for tibial axis measurement. Exclusion criteria were radiographs demonstrating an open physis, a history of proximal tibial surgery, a history of physeal arrest or stimulation, previous fractures, known deformity-causing illnesses, lower extremity neoplasms, or osteoarthritis. Additionally, patients with inadequate lateral radiographic imaging as observed by gross misalignment of the femoral condyles were excluded. Patient information (age, sex, and body mass index [BMI]) was collected from the patient chart using an electronic medical record (Epic; Epic Systems).

Radiographic Measurements

All measurements were performed in the institutional PACS, with examples demonstrated in Figure 1. The PTS was measured on the lateral radiograph using the proximal anatomic axis landmark method, which has been reported in previous literature.[2,8] The anatomic axis of the tibia was found by connecting the midpoint between the anterior and posterior cortices at 5 and 15 cm distally on the tibia. The PTS was measured as the angle between a line perpendicular to this anatomic axis and a line across the medial tibial plateau (Figure 1A). Two novel radiographic indices were then measured on the lateral knee radiograph. These indices were created based on our observations of tibial morphology in the developing knee and designed with the intention of providing a means to quantify the degree of prominence of the tibial tubercle. The anterior tibial tubercle height (TTH) was measured by first drawing a line from the most anterosuperior point on the tibial plateau to a point 10 cm distal on the anterior tibial cortex. The TTH was measured as the perpendicular distance from this line to the most prominent portion of the anterior tibia (Figure 1B). We chose 10 cm as the distal endpoint of the index line because the tibial tubercle roughly measured 5 cm distally on the tibia, and therefore a 10-cm line placed the tubercle at the approximate midpoint for measurement simplification. Further, this distance was sufficiently distal as to avoid the prominence of the tubercle, allowing the height of the tubercle to be measured from the baseline anterior tibial cortex. The anterior tibial tubercle angle (TTA) was measured as the angle between the endpoints of the line made above and the most anteriorly prominent portion of the tibial tubercle (Figure 1C).

Validation of Novel Measurements

Interrater reliability was measured using the intraclass correlation coefficient (ICC) between 2 medical student

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Ethical approval for this study was obtained from the University of Utah (reference No. 00071733).

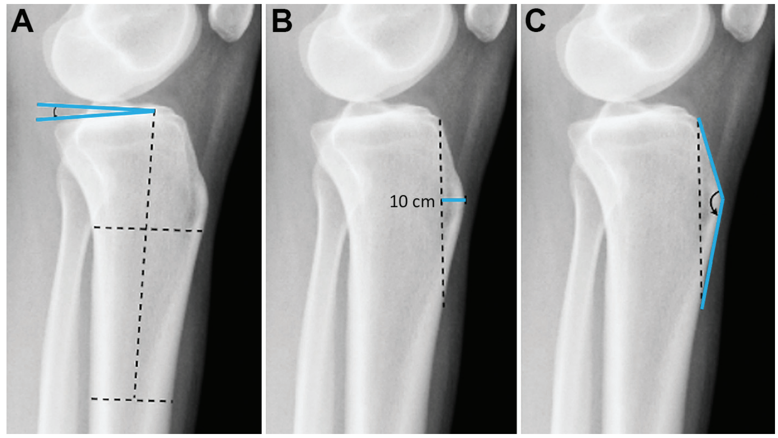

Figure 1. Lateral radiograph of a left knee demonstrating the radiographic parameters. (A) The anatomic axis of the tibia (vertical dashed line) was found by connecting the midpoint of the anterior and posterior cortices at 5 and 15 cm distally on the tibia (horizontal dashed lines). The angle between the line perpendicular to the anatomic axis and a line across the medial tibial plateau (blue lines) was measured as the posterior tibial slope. (B and C) Measurements of the anterior tibial tubercle height (blue line in B) and anterior tibial tubercle angle (angle between blue lines in C) are shown in comparison with the reference line (dashed line in B and C).

reviewers (C.D.R.H., D.L.F.) using a 2-way mixed-effects model with 25 randomly sampled patients. Both reviewers were trained by the senior author (S.K.A.). Intrarater reliability was assessed in the following manner: after a 1-week washout period, the same 2 reviewers were blinded to patient information and PTS and were tasked with repeating all measurements on 25 randomly selected patients. To minimize possible anchoring bias from taking multiple measurements at once, only 1 measurement was taken on each patient at a time. After 48 hours, each reviewer was tasked with collecting at random 1 of the 2 remaining measurements. After a final 48-hour washout period, the reviewers collected the remaining missing angle and/or height on each of the 25 patients.

Based on established guidelines,[10] inter- and intrarater reliability was interpreted as follows: ICC values between 0.90 and 1.00 were considered excellent agreement, while values between 0.75 and 0.90, 0.50 and 0.75, and 0.00 and 0.50 were considered good, moderate, and poor agreement, respectively.

Statistical Analysis

All statistical analyses were conducted using SPSS Version 28 (IBM). Correlation was determined using univariate linear regression with a P value <.05 indicating statistical significance. Simple linear regression analysis was also used to evaluate the correlation between patient and measurement variables. A critical Pearson correlation coefficient (r) of ±0.195 was determined using a significance threshold of .05 and a study population size of 100 individuals.

RESULTS

The characteristics of the 100 patients whose radiographs were included in the analysis are reported in Table 1. The mean anterior TTA was 158.6° ± 4.7° the mean TTH was 8.8 ± 2.0 mm, and the mean PTS was 9.7° ± 2.6°.

On interrater reliability analysis, the ICCs between the 2 reviewers were 0.993, 0.946, and 0.978 for TTH, anterior TTA, and PTS, respectively, indicating excellent agreement. The mean ICCs for intrarater reliability between the reviewers after a 1-week washout period were 0.893, 0.898, and 0.883 for TTH, anterior TTA, and PTS, respectively, indicating good agreement.

Knees with a larger PTS were found to have a more acute anterior TTA and a greater TTH, indicating a more prominent tibial tubercle (Figure 2). On univariate linear regression analysis, a significant correlation was found between PTS angle and anterior TTA (r = −0.46; β = −0.46; P < .001) (Figure 3A) as well as TTH (r = 0.43; β = 0.43; P < .001) (Figure 3B). There was no significant correlation between PTS and age or sex (r = 0.80; P = .99), but a significant inverse correlation was found between PTS and BMI (r = −0.14; β = −0.23 P = .02). There was no significant correlation between age, sex, or BMI and the anterior TTA or tubercle height.

DISCUSSION

The study results established an association between increased PTS and tibial tubercle overgrowth, as demonstrated by 2 novel measures of anterior tibial growth: the anterior TTA and the TTH. Furthermore, we found that the relationship between increased PTS and tibial tubercle overgrowth was characterized by linear regression modeling with a significant degree of correlation. In this case, the anterior TTA was inversely correlated with PTS (r = −0.46; β = −0.46; P < .001) and the TTH was directly correlated with PTS (r = 0.43; β = 0.43; P < .001). Using the ratio generated by the β value from the linear regression model, we found that, on average, every 2.2° of anterior

TABLE 1
Baseline Patient and Radiographic Data of the Study Population (N = 100)[a]

Variable	Value
Age, y	
Mean	33.1 ± 14.1
Range	14.3-65.9
Body mass index, kg/m^2	
Mean	26.5 ± 6.8
Range	18.0-58.0
Sex	
Female	55 (55)
Male	45 (45)
Operative side	
Left	49 (49)
Right	51 (51)
Anterior tibial tubercle angle, deg	158.6 ± 4.7
Tibial tubercle height, mm	8.8 ± 2.0
Posterior tibial slope, deg	9.7 ± 2.6

[a]Data are reported as mean ± SD or n (%) unless otherwise specified.

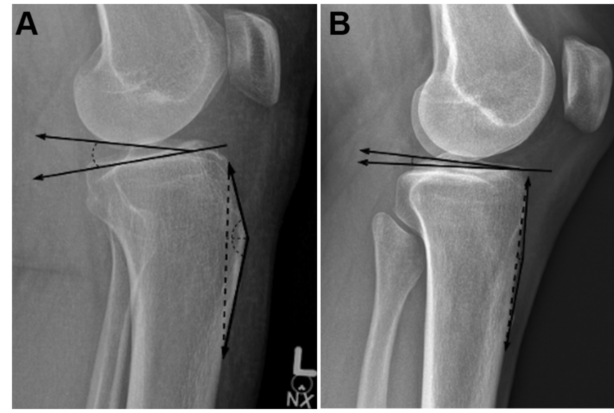

Figure 2. Representative radiographs. (A) The left knee of a 38-year-old patient with a large posterior tibial slope (20.6°) and corresponding acute anterior tibial tubercle angle (149.6°) and increased tibial tubercle height (12.4 mm). (B) The left knee of a 30-year-old patient with a small posterior tibial slope (4.1° and corresponding obtuse anterior tibial tubercle angle [172.4°] and decreased tibial tubercle height (3.5 mm).

TTA deviation from the mean and every 2.3 mm in TTH deviation from the mean correlated with an approximately 1° difference in the PTS. The novel metrics demonstrated good to excellent intra- and interrater agreement (ICC, ≥0.883 for all). Within the scope of this study, we were able to identify a negative relationship between PTS and BMI (r = −0.14; β = −0.23; P = .02). However, we did not find a relationship between either measure of anterior tibial tubercle growth or BMI, reducing the likelihood that this variable confounded the results of the study.

In a study by Green et al,[8] patients with symptomatic OSD were found to have increased PTS compared with a disease-free control group. Green et al hypothesized that the PTS elevation seen in OSD is related to the growth of the anterior tibial tubercle; however, no direct measurements of the anterior tibia were taken, and therefore the authors were unable to evaluate the validity of their hypothesis using objective metrics. The present study confirms the relationship between anterior tibial tubercle growth and elevations of PTS, by providing evidence demonstrating a correlation between tibial tubercle overgrowth and PTS. Additionally, in the present study, we evaluated this relationship in a more generalizable patient population, rather than the specific OSD population used in Green et al.

The degree of proximal tibial growth is likely multifactorial and dependent on genetics, activity, and other factors. In a longitudinal study by Pritchett,[14] the proximal tibia was shown to contribute to approximately 57% of

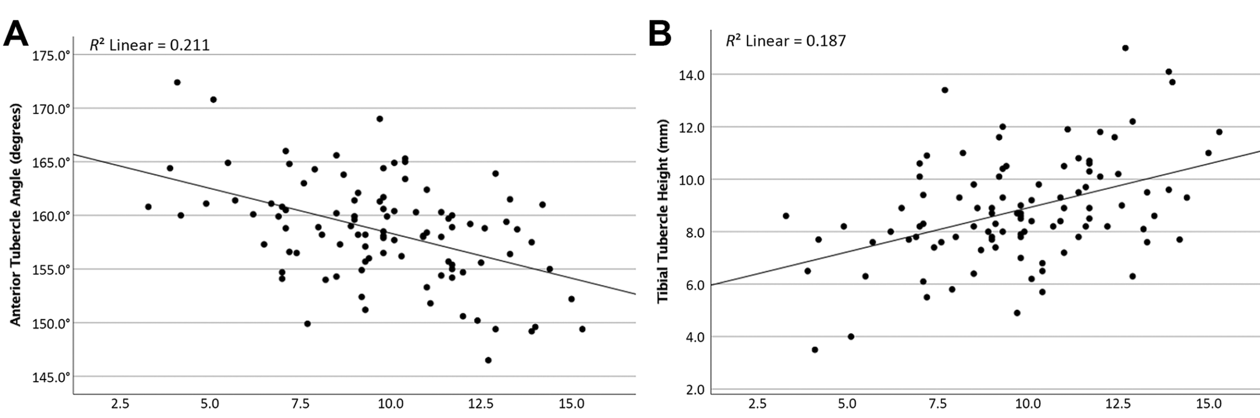

Figure 3. Regression plots of the relationship of posterior tibial slope to (A) anterior tibial tubercle angle and (B) tibial tubercle height.

tibial growth overall, with the contribution varying by age and sex. The secondary ossification center of the tibial tuberosity appears in adolescence and is unique among growth centers in that the loading experienced by the growth plate is primarily tensile because of forces exerted on the growth plate by the patellar tendon, rather than compressive because of the forces of gravity.[13] This tensile, rather than compressive, loading differentiates the tibial tuberosity from the other major growth centers in the human body. As a consequence of the unique biomechanical forces on the tibial tuberosity, the tibial tubercle growth plate differs histologically from the adjacent proximal tibial growth plate, and bone formation occurs on the anterior and superior surface of the tuberosity,[12] which may help explain the ultimate change in PTS observed in the current study.

In the current study, we established a link between PTS and anterior tibial tubercle growth in a nonspecific orthopaedic population, suggesting that the degree of PTS observed in adulthood is influenced in part by the growth of the anterior tibial tubercle during maturation. In addition to informing the surgeon's general knowledge of the anatomic and biomechanical factors that may contribute to elevated PTS, this paper prompts further investigation into whether procedures aimed at halting growth of the tubercle may be beneficial in certain patient populations that may be predisposed toward injury associated with elevated PTS (ie, ACL and PCL rupture). It further calls into question whether evaluation of the degree of anterior tibial tubercle growth may be warranted in patients with OSD in order to identify and stratify patients that may be at particular risk for developing elevated PTS and associated pathology at maturation.

Limitations

There are several limitations of this study. First, while this study can establish a relationship between PTS and anterior tibial tubercle growth, the causality or directionality of that relationship cannot be determined. Second, while the current evidence suggests an association between anterior tibial tubercle and PTS, other factors may also influence the PTS. Third, although the r values observed in this study meet the critical Pearson threshold, there is still variability in the model, suggesting that the PTS is likely also affected by factors beyond what was studied in the present paper. Other confounding variables may exist that affect both anterior tibial tubercle growth and PTS. Fourth, while grossly misaligned lateral radiographs were excluded, there are likely slight variations in rotation or obliquity of each radiograph, which may potentially influence the appearance and measurement of the anterior tibial tubercle and/or tibial slope. Fifth, generalizability of these data may be affected by the inclusion criteria such that radiographs were obtained in patients seen in an orthopaedic rather than a randomized asymptomatic population or a focused specific patient group. Repetition of this work in differing patient populations may be useful in evaluating proximal tibial bony morphology as it relates to specific orthopaedic injuries or the overall population.

CONCLUSION

Objective measures of anterior tibial tubercle overgrowth correlate with an elevated PTS. Every 2.2° of anterior TTA deviation from the mean and every 2.3 mm in TTH deviation from the mean correlate with a 1° difference in the PTS. This suggests a link between the development of the tibial tubercle and PTS, and it potentially helps explain why the PTS is elevated in certain patients.

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