Original Research

Evaluation of Tibial Slope on Radiographs in Pediatric Patients With Tibial Spine Fractures

An Age- and Sex-Matched Study

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Background: A recent study has reported that the radiographic measurement of posterior tibial slope (PTS) is larger in male pediatric patients with tibial spine fractures (TSF) than in controls. However, they found no difference in PTS between female patients and controls.

Purpose: (1) To identify whether PTS is larger in female pediatric patients with TSF than in female controls and (2) to validate the relationship between PTS and pediatric TSF in male patients.

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

Methods: After an a priori power analysis, 84 pediatric patients with TSF (50 female patients and 34 male patients) and 84 age- and sex-matched controls were enrolled in this study. Demographic information, including sex, age, and race, was recorded. Skeletal maturity was determined based on the stage of epiphyseal union on knee radiographs. PTS was defined as the angle between a line perpendicular to the longitudinal axis of the tibia and the posterior inclination of the medial tibial plateau on standard knee lateral radiographs.

Results: The mean age when the TSF occurred was 11.2 ± 2.7 years for female patients and 12.9 ± 2.5 years for male patients. There was no significant difference in skeletal maturity between female patients and female controls or between male patients and male controls. The mean PTS was not significantly different between female patients (8.8° ± 2.8°) and female controls (8.3° ± 3.1°) (P = .366) or between male patients (9.0° ± 2.8°) and male controls (9.3° ± 2.6°) (P = .675). Those with a PTS >1 SD (2.9°) above the mean (8.8°) had no greater odds (1.0 [95% CI, 0.4-2.5]; $P \geq .999$) of having a TSF than others.

Conclusion: PTS was not found to be a risk factor for pediatric TSF in female or male patients in this study.

Keywords: knee, general; pediatric sports medicine; posterior tibial slope; tibial eminence fracture; tibial spine fracture

Tibial spine fractures (TSF) are avulsion fractures of the anterior cruciate ligament (ACL) from its insertion on the tibial intercondylar eminence. TSF are considered equivalent to midsubstance rupture of the ACL in terms of injury mechanism.[30] A large number of studies have investigated various anatomic risk factors of ACL injuries, including femoral intercondylar notch width, size of ACL, meniscus-bone angle, the angle between the longitudinal femoral axis and Blumensaat line, and posterior tibial slope (PTS), among others.[1,2,11,14,31] However, to the best of our knowledge, only 3 studies have evaluated the anatomic risk factors of TSF in pediatric patients.[14,18,25] PTS is known to be associated with anterior tibial translation and ACL force.[9,17,26] Three prior studies have also investigated this measurement as a potential risk factor for TSF.[18,25,36] A recent pediatric study has revealed that the PTS on radiographs is larger in male pediatric patients with TSF than in male controls.[18] However, this study found no difference in the PTS between female patients and female controls, although the small number of female

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patients in the study limited the statistical power. Another pediatric study[25] and 1 study in adults[36] also reported contradictory results about the relationship between PTS and TSF. These 2 studies did not perform subgroup analysis by sex, probably due to their small sample sizes.

It has been observed that boys are more likely to sustain TSF compared with girls.[8] Previous studies have indicated that there is a significant difference in the PTS between boys and girls who do not have any deformities.[13,24] Given the sex-based differences in the incidence of TSF and the normative value of PTS, it is important to investigate PTS as an anatomic risk factor of TSF separately for boys and girls.

The purpose of the current study was to identify differences in radiographic PTS between pediatric patients with TSF and uninjured controls, with additional stratification by sex. We hypothesized that PTS would be larger in pediatric patients with TSF compared with controls, in both girls and boys.

METHODS

Study Design and Participants

After receiving institutional review board approval, we performed a retrospective cross-sectional study. An a priori power analysis was performed to determine the number of required participants necessary to detect a reported difference of 1.6° in PTS between male pediatric patients with TSF and controls.[18] Assuming that the standard deviation of the PTS is 2.2° in male patients and 2.4° in male controls and 2.8° in female patients and controls[18] and that the ratio of patients to controls is 1:1, 100 female participants (50 patients and 50 controls) and 68 male participants (34 patients and 34 controls) would result in an alpha of .05 and a power of .8. Based on our power analysis, the target cohort was set to be 168 skeletally immature patients (100 girls and 68 boys).

The patient database of a single, large, pediatric tertiary-care center was searched to identify all patients who visited for TSF or anterior knee pain between March 2009 and April 2023. We found 47 girls and 113 boys aged <18 years who sustained TSF and 6145 girls and 4202 boys aged 5 to 18 years who had anterior knee pain but did not have clinically significant findings on examination or imaging studies. Of the 47 female patients with TSF, 11 were excluded due to inadequate quality of knee radiographs (n = 6), medical conditions/histories possibly affecting bony morphology (n = 4), or unavailability of radiographs at the occurrence of TSF (n = 1). In addition, we included 14 female patients who were randomly selected from a prospectively collected multicenter database for pediatric TSF that was used in a previous study.[27] This multicenter database contained information on patient demographics, orthopaedic history, physical examination, treatment details, and Digital Imaging and Communications in Medicine (DICOM) files. None of the patients included in the present study overlapped with those in the previous study. Thus, the female patient group comprised of 36 female patients from a single-institution database and 14 female patients from a multicenter database. In total, 34 male patients with TSF who were randomly selected from the single-institution database became the male patient group after confirming that they had knee radiographs with adequate quality and were without medical conditions/histories possibly affecting bony morphology. Age- (matched to ±0.2 years) and sex-matched female and male patients with anterior knee pain who were randomly selected from the single-institution database became the female control group (n = 50) and the male control group (n = 34), respectively (Figure 1). Randomization was performed using a random-number generator (Microsoft Excel; Microsoft).

Data Collection

Demographic characteristics, including sex, age, and race, were recorded. Skeletal maturity was determined based on the stage of epiphyseal union on knee radiographs.[18,22] Fracture types were classified according to the modification by Zaricznyj[35] of the Meyers and McKeever classification.[19] PTS, measured on standard lateral knee radiographs, was defined as (1) superimposition of medial and lateral condyles of the distal femur and (2) an open patellofemoral joint space. Knee radiographs at the

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Ethical approval for this study was obtained from the Children's Hospital of Philadelphia (ref No. 15-012614).

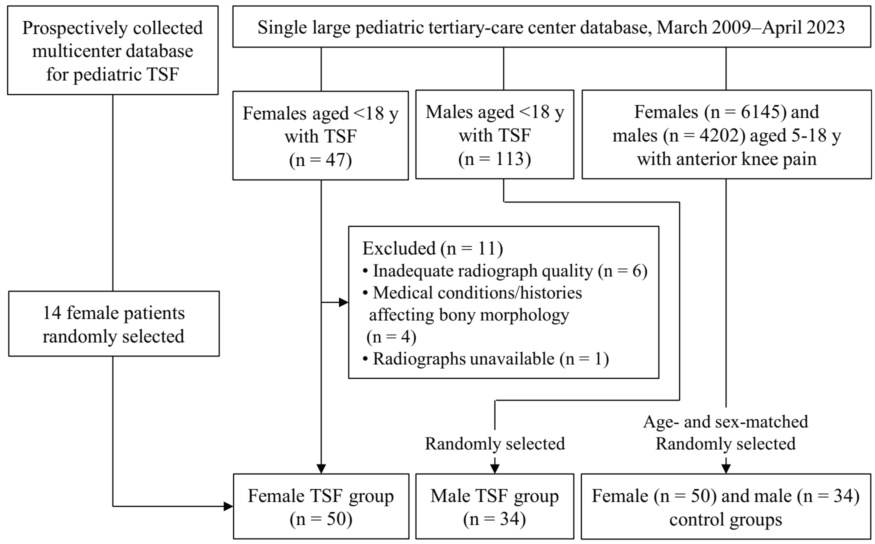

Figure 1. Flowchart of the patient selection process.

occurrence of TSF were used to determine PTS. When radiographs were of inadequate quality, immediate postoperative radiographs or radiographs at the first or second postoperative visit (within 8 weeks postoperatively) were used to measure PTS. The PTS was measured using the modification by Messner et al[18] of the method by Bernhardson et al,[3] which also was applied in a recent study on the relationship between PTS and pediatric TSF[18] (Figure 2). Briefly, the longitudinal axis of the tibia was defined by a line connecting the center of 2 digitally generated circles. The circles were positioned at 5 and 15 cm distal to the tibial joint line and sized to best fit within the tibia, making their circumference tangent to anterior and posterior outer cortices of the tibia. When radiographs did not cover the 15-cm length distally from the tibial plateau, circles were positioned at the distance from the tibial joint line with a 1:3 ratio (ie, 4 and 12 cm). The angle between a line perpendicular to the longitudinal axis of the tibia and the posterior inclination of the medial tibial plateau was defined as the PTS.

All radiographic measurements were performed by 2 authors (C.H.S. and A.N.S.) using NilRead PACS viewer version 5.1.10 (Hyland Software). To determine intra- and interobserver reliability, measurements of the PTS were performed by reviewer 1 (C.H.S.) and reviewer 2 (A.N.S.) on 2 different days, 3 weeks apart, after a consensus-building session to define the PTS.

Figure 2. Measurement of the PTS on a knee lateral radiograph. The PTS is the angle between a line perpendicular to the longitudinal axis of the tibia and the posterior inclination of the medial tibial plateau. The longitudinal axis of the tibia was defined by a line connecting the center of 2 circles positioned at 5 cm and 15 cm distal to the tibial joint line, respectively. Distances between 2 near black dots are set equal to each other, making distances from the tibial joint line to the center of each circle at a ratio of 1:3. PTS, posterior tibial slope.

Statistical Analysis

Statistical analyses were performed using STATA 15.1 (Stata Corp). Intra- and interobserver reliabilities were evaluated using intraclass correlation coefficients (ICCs) calculated assuming absolute agreement and a single measurement with a 2-way random-effects model. The ICC provides a general measure of agreement or consensus for

TABLE 1
Characteristics of the Study Groups[a]

	Tibial Spine Fracture (n = 84)	Control (n = 84)	*P* Value
Age, y			
Overall	11.9 ± 2.7 (6.1-17.8)	11.8 ± 2.7 (6.3-17.6)	.800
Female	11.2 ± 2.7 (6.1-17.2)	11.1 ± 2.6 (6.3-17.1)	.888
Male	12.9 ± 2.5 (7.7-17.8)	12.7 ± 2.3 (7.6-17.7)	.800
P value[b]	.004	.004	
Sex			
Female	50 (59.5)	50 (59.5)	≥.999
Male	34 (40.5)	34 (40.5)	
Race			.916
White	53 (63.1)	50 (59.5)	
African American	17 (20.2)	19 (22.6)	
Hispanic	3 (3.6)	6 (7.1)	
Asian	3 (3.6)	2 (2.4)	
Other	4 (4.8)	3 (3.6)	
Not available	4 (4.8)	4 (4.8)	
Stage of epiphyseal union			.227
Stage 0	45 (53.6)	34 (40.5)	
Stage 1	18 (21.4)	23 (27.4)	
Stage 2	11 (13.1)	17 (20.2)	
Stage 3	6 (7.1)	9 (10.7)	
Stage 4	4 (4.8)	1 (1.2)	
Fracture type[c]			NA
Type I	1 (1.2)	NA	
Type II	20 (23.8)	NA	
Type III	55 (65.5)	NA	
Type IV	8 (9.5)	NA	

[a]Data are presented as n (%) or mean ± SD (range). NA, not applicable.
[b]*P* value for within-group comparison between female and male patients showed a statistically significant difference in age; $P < .05$.
[c]Modified Meyers and McKeever classification.[35]

continuous data (PTS).[16] An ICC of >0.75 was considered excellent.[5]

The Fisher exact test was used to compare distributions of sex and race and to compare skeletal maturity between the patient and control groups. The Student *t* test was used to compare the mean age and PTS values between the patient and control groups and between girls and boys after the Kolmogorov-Smirnov normality test. The distribution of race and mean age values were compared between female patients from the single institutional database versus the multicenter database using the Fisher exact test and Wilcoxon rank-sum test, respectively.

Participants were classified into 3 risk groups according to the mean and SD of the overall PTS as calculated: (1) low risk (>1 SD below the mean); (2) average risk (≤1 SD of the mean); and (3) high risk (>1 SD above the mean). The Fisher exact test was used to calculate the odds ratios (ORs) of having a TSF for a particular risk group, with the other two risk groups pooled together. For all statistical tests, *P* values <.05 were considered statistically significant.

RESULTS

A comparison of the characteristics of the study groups is shown in Table 1, and Table 2 shows a comparison of the female patients from the 2 different databases. The mean age was similar between the study groups: 11.9 ± 2.7 years (range, 6.1-17.8 years) for the TSF group and 11.8 ± 2.7 years (range, 6.3-17.6 years) for the control group ($P = .800$). The mean age was older in male patients with a TSF (12.9 ± 2.5 years; range, 7.7-17.8 years) than in female patients with a TSF (11.2 ± 2.7 years; range, 6.1-17.2 years) ($P = .004$) and in male controls (12.7 ± 2.3 years; range, 7.6-17.7 years) than in female controls (11.1 ± 2.6 years; range, 6.3-17.1 years) ($P = .004$). There was no significant difference in skeletal maturity between patient and control groups ($P = .227$), female patients and female controls ($P \geq .099$), or male patients and male controls ($P = .416$).

The intraobserver reliability for PTS indicated excellent agreement, with an ICC of 0.855 (95% CI, 0.807-0.892) in reviewer 1 and 0.85 (95% CI, 0.8-0.889) in reviewer 2. Interobserver reliability also indicated excellent agreement, with an ICC of 0.79 (95% CI, 0.721-0.843). The mean of the 2 measurements by the first reviewer was used for the statistical analysis of the results.

The mean PTS was not significantly different between patients with a TSF and controls ($P = .639$), female patients with a TSF and female controls ($P = .366$), or male patients with a TSF and male controls ($P = .675$) (Table 3).

Based on the overall mean PTS (8.8°) and standard deviation (2.9°), the 3 risk groups were defined as follows:

TABLE 2
Characteristics of Female Patients With Tibial Spine Fractures From a Single-Institution Database Versus a Multicenter Database[a]

	Single-Institution Database (n = 36)	Multicenter Database (n = 14)	*P* Value
Age, y	11.5 ± 2.8 (6.1-17.2)	10.3 ± 2.4 (6.5-14.3)	.210
Race			.197
White	22 (61.1)	9 (64.3)	
African American	7 (19.4)	1 (7.1)	
Hispanic	1 (2.8)	1 (7.1)	
Asian	3 (8.3)	0 (0)	
Other	2 (5.6)	0 (0)	
Not available	1 (2.8)	3 (21.4)	

[a]Data are presented as n (%) or mean ± SD (range).

TABLE 3
Comparison of Posterior Tibial Slope According to Study Group and Sex[a]

	Tibial Spine Fracture	Control	*P* Value
Posterior tibial slope, deg	8.9 ± 2.8 (2.5-17.0)	8.7 ± 2.9 (0.8-15.0)	.639
Female	8.8 ± 2.8 (2.5-17.0)	8.3 ± 3.1 (0.8-14.5)	.366
Male	9.0 ± 2.8 (4.0-15.0)	9.3 ± 2.6 (3.0-15.0)	.675
P value	.791	.133	

[a]Data are presented as mean ± SD (range).

low (PTS <5.9°); average (PTS 5.9°-11.7°); and high (PTS >11.7°). Patients in the high-risk group had no greater odds (OR = 1.0; 95% CI, 0.4-2.5; $P \geq .999$) of having a TSF than those in the other risk groups (Table 4). Subgroup analysis by sex revealed no greater odds of having a TSF in the female high-risk group (OR = 1.2; 95% CI, 0.3-4.2; $P \geq .999$) or male high-risk group (OR = 0.8; 95% CI, 0.2-3.6; $P = .742$) compared with the other female or male risk groups, respectively.

DISCUSSION

Despite the growing interest in anatomic risk factors for pediatric ACL injuries,[7,10,12,15,23,33] those for pediatric TSF have yet to be sufficiently studied. Our study demonstrated that PTS is not related to the occurrence of TSF in male or female pediatric patients. One of the strengths of our study was that its sample size is the largest among all studies about anatomic risk factors of TSF,[14,18,25,36] a relatively uncommon injury accounting for 2% to 5% of traumatic knee hemarthroses in adolescents.[6,28] This allowed us to perform subgroup analysis by sex with enough statistical power.

In a study by Messner et al,[18] the PTS on radiographs was not significantly different between 17 female pediatric patients with TSF (9.1° ± 2.8°) and 23 female controls (9.4° ± 2.8°). Although the authors presumed that this was likely the result of a type 2 error, we also did not find a difference in PTS between girls with TSF (8.8° ± 2.8°) and female controls (8.3° ± 3.1) even with a larger number of participants and an appropriate power analysis. Our PTS results were similar to those of Samora et al,[25] although they did not perform a subgroup analysis by sex or describe the method of defining the longitudinal axis of the tibia on radiographs. In their study, the PTS was 8.9° ± 2.4° in children with TSF and 8.5° ± 2.3° in controls, showing no significant difference between groups.

Messner et al[18] reported that the PTS in male pediatric patients with TSF (10.0° ± 2.2°) was higher than that in male controls (8.4° ± 2.4°). Compared with our results, their mean PTS was 1° larger in patients and 0.7° smaller in controls, which made the mean difference between the 2 groups (1.6°) significant. Conflicting results between their study and ours might be partially attributed to the difference in the age of the male patients (12.9 vs 11.4 years) and the difference in distribution of fracture type. However, we considered that a 1.6° difference in the PTS might be less than a minimally clinically important difference. According to linear regression analysis in a study by Dejour and Bonnin,[9] every 10° increase in the PTS makes a 6-mm increase in anterior tibial translation on monopodal stance test and a 3.5-mm increase in anterior tibial translation on radiological Lachman test. That means that a 1.6° difference in the PTS is estimated to increase only <1 mm and <0.6 mm on anterior tibial translation on monopodal stance test and radiological Lachman test, respectively. In addition, a 1.6° difference in radiological parameters might be small enough to be caused by a measurement error.

TABLE 4
Odds Ratios of Tibial Spine Fracture for PTS According to Risk Group[a]

	Low-Risk Group (PTS <5.9°)	Average-Risk Group (PTS 5.9°-11.7°)	High-Risk Group (PTS >11.7°)
All patients			
OR (95% CI)	0.9 (0.3-2.4)	1.1 (0.5-2.2)	1.0 (0.4-2.5)
P value	.822	.865	≥.999
TSF[b]	11	60	13
Control[b]	12	59	13
Female patients			
OR (95% CI)	0.7 (0.2-2.1)	1.2 (0.5-3.0)	1.2 (0.3-4.2)
P value	≥.999	≥.999	≥.999
TSF[b]	7	35	8
Control[b]	10	33	7
Male patients			
OR (95% CI)	2.1 (0.3-24.9)	0.9 (0.2-3.0)	0.8 (0.2-3.6)
P value	.393	.779	.742
TSF[b]	4	25	5
Control[b]	2	26	6

[a]CI, confidence interval; OR, odds ratio; TSF, tibial spine fracture.
[b]Data are shown as number of patients.

Although PTS has been described as a risk factor for ACL injuries, we did not find such an association in young patients in TSF. Further anatomic research is necessary to elucidate whether certain anatomic parameters predispose a patient to a TSF versus an ACL tear. This might be achieved through studies comparing various anatomic risk factors on magnetic resonance imaging (MRI) among patients with TSF, patients with ACL injuries, and controls.

There is only a single study in the literature regarding anatomic risk factors for adult TSF.[36] In that study, lateral PTS (7.4° ± 2.3° vs 5.0° ± 3.1°) and medial PTS (5.8° ± 1.9° vs 4.3° ± 2.4°) on MRI were larger in patients than in controls.[36] According to their logistic regression analysis, lateral PTS, but not medial PTS, was independently associated with TSF. Studies on pediatric ACL injuries had mixed results about lateral or medial PTS as a risk factor for ACL injuries.[7,10,12,15,20,23,33] Among 5 studies that measured both lateral and medial PTS,[7,10,12,15,33] 3 studies showed that lateral PTS, but not medial PTS, was greater in children with ACL injuries than in controls.[7,10,15] Another study reported that only the medial PTS is higher in patients than in controls.[33] In the remaining study, lateral and medial PTS were not significantly different between patients and controls.[12] There were 2 studies that compared either lateral or medial PTS between children with ACL injuries and controls.[20,23] One of them reported higher medial PTS in patients than in controls.[23] The other study reported no difference in lateral PTS between the 2 groups.[20] In the current study, we measured medial PTS to validate the results of the previous study on pediatric TSF by Messner et al[18] and found no difference between patients and controls.

The goal of most investigations on risk factors is prevention. Because anatomy, including the PTS, is generally a nonmodifiable risk factor, ACL injury prevention has focused on modifiable risk factors such as proprioceptive balance, neuromuscular control, strength, and flexibility.[21,32] If PTS was a risk factor for the occurrence or recurrence of TSF, patients with high PTS might benefit from osteotomy that decreases the PTS when they undergo an operation for TSF. Compared with adults, lowering the PTS using a guided-growth technique could achieve fewer morbidities in children with open physes.[34] Nevertheless, the current study did not find a significant difference in PTS between children with TSF and controls. This study has a clinical significance for avoiding unnecessary osteotomy or guided growth to lower the PTS until solid evidence about the relationship between PTS and TSF exists.

Limitations

This study has several limitations. First, we used radiographs instead of cross-sectional imaging studies like MRI or computed tomography to measure the PTS. This was because one of the purposes of our study was to validate the results of a previous study that compared medial PTS on radiographs between children with TSF and controls.[18] For consistency, we used the same modality and the same measurement method, which evaluated only the medial (not the lateral) PTS. In skeletally immature young children, there is the possibility of unossified bone not being visible on radiographs. Although MRI is much better for discriminating lateral and medial tibial plateau than radiographs, some studies have also measured lateral and medial PTS separately on radiographs.[18,20,23,33] Because radiographs usually cover more length of the tibia than MRI, radiographs have an advantage in identifying the longitudinal axis of the tibia.[29] A second limitation was that our female patients were from 2 different databases. Although their demographic characteristics were not significantly different (Table 2), including patients from a single database could minimize potential selection bias. However, because the number of female patients enrolled in the multicenter database and the number of female patients in our institutional database were less than our target sample size at commencement of study, we had no choice but to include patients from both databases, and this actually may have led to a greater heterogeneity among patients than those at a single institution alone. Third, the current study analyzed PTS measurements from immediate postinjury radiographs, which may not represent the pre-TSF state. TSF may have affected PTS, and the causal relationship between TSF and PTS remains to be established. Beynnon et al[4] suggested that ACL injury might have changed the subchondral tibial morphology. Therefore, considering the similarity in injury mechanism between ACL injuries and TSF,[30] pre-TSF PTS might differ from post-TSF PTS.

CONCLUSION

PTS on radiographs is not related to the occurrence of pediatric TSF in female or male pediatric patients. Further studies that compare anatomic risk factors on MRI among children with TSF, children with ACL injuries, and controls separately for girls and boys are warranted.

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