The Relationship Between Posterior Tibial Slope and Pediatric Tibial Eminence Fractures

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Background: Tibial eminence fractures are bony avulsions of the anterior cruciate ligament from its insertion on the intercondylar eminence. Numerous anatomic factors have been associated with anterior cruciate ligament injuries, such as posterior tibial slope, but there are few studies evaluating the association with tibial eminence fracture.

Purpose: To compare posterior tibial slope of pediatric patients with and without tibial eminence fractures. We hypothesized that a steeper posterior tibial slope would be associated with tibial eminence fracture.

Study Design: Cohort study; Level of evidence, 3.

Methods: Patients who underwent surgical treatment of tibial eminence fracture were retrospectively identified between January 2000 and July 2021. Adults aged >20 years and those without adequate imaging were excluded. Controls without gross ligamentous or osseous pathology were identified. Descriptive information and Meyers and McKeever classification were recorded. Posterior tibial slope measurements were obtained by 2 independent orthopaedic surgeons twice, with measurements separated by 3 weeks. Chi-square tests and independent-samples *t* tests were used to compare posterior tibial slope and patient characteristics. Inter- and intrareviewer variability was determined via the intraclass correlation coefficient.

Results: A total of 51 patients with tibial eminence fractures and 57 controls were included. By sex, tibial eminence fractures occurred among 34 male and 17 female patients with a mean age of 10.9 years. The posterior tibial slope among those with tibial eminence fractures (9.7°) was not significantly greater than that of controls (8.8°; $P = .07$). Male patients with a tibial eminence fracture had significantly steeper slopes compared with controls (10.0° vs 8.4°; $P = .006$); this difference was not observed between female patients and female controls. Patients with a slope ≥1 SD above the mean (12.0°) had 3.8 times greater odds (95% CI, 1.3-11.6; $P = .017$) of having a tibial eminence fracture. Male patients with a posterior tibial slope >12° had 5.8 times greater odds (95% CI, 1.1-29.1; $P = .034$) of having a tibial eminence fracture compared with male controls.

Conclusion: Male patients undergoing surgical fixation of a tibial eminence fracture had an increased posterior tibial slope as compared with case-controls. Increased posterior tibial slope may be a risk factor for sustaining a tibial eminence fracture, although the clinical significance of this deserves further investigation.

Keywords: knee; ACL; pediatric sports medicine; anatomic risk factor

Pediatric tibial eminence fractures (TEFs) or tibial spine fractures are bony avulsions of the anterior cruciate ligament (ACL) from its insertion on the incompletely ossified medial intercondylar eminence. The mechanisms of TEF are variable, with reports of low- and high-energy events, from noncontact sporting injuries to motor vehicle collisions.[1,22] The literature suggests that TEFs are observed with forced knee flexion with an internally rotated tibia, as well as instances of knee hyperextension.[1,22,26] Although the mechanism and pathology are akin to those of the adult ACL tear, TEF is much less common, with an incidence of 3 per 100,000 children and adolescents each year.[34]

While the literature has focused on TEF management, studies evaluating injury risk factors are limited. One previous study by Samora et al[31] evaluated risk factors for TEF, including posterior tibial slope (PTS). In their study of 25 patients with matched controls, Samora et al did not find a significant association of PTS with TEF. Although informative, the study had a relatively small sample size, and given the paucity of literature, we look to further evaluate PTS as a potential risk factor for TEF. Numerous morphologic risk factors have been associated with ACL injuries, including PTS, femoral notch

The American Journal of Sports Medicine
1–6
DOI: 10.1177/03635465221137888

width, medial condyle sphericity, and tibial tubercle–trochlear groove distance.[15,19,32,40] Of these, PTS is the most robustly studied factor.[5,14,21,27] Given its analogous comparison with ACL injuries, it is plausible that increased PTS would also be associated with TEF. We hypothesized that pediatric patients with TEF would have increased PTS when compared with uninjured controls.

METHODS

Study Design

After institutional review board approval was obtained (IRB-300008104), a retrospective case-control study was conducted to evaluate the association of PTS and TEF at a large academic tertiary center between 2000 and 2021. Informed consent was not needed. Patients were identified with the use of Current Procedural Terminology code for arthroscopically aided treatment of intercondylar spine and/or tuberosity fracture of the knee, with or without manipulation, with internal or external fixation (29851). Patients aged >20 years and those without adequate imaging were excluded. A total of 51 patients were included in this study for analysis. Controls without TEFs were identified over a similar period but with diagnoses of knee contusions, lacerations, sprains, neoplastic lesions, and patellofemoral pain syndrome. Control patients were excluded if a history of ACL injury, meniscal tear, or Osgood-Schlatter disease was present, as these pathologies have been associated with PTS.[2,11,33,38] This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Extraction

Patient characteristics, including age, sex, and race, were obtained from the medical record. TEFs were classified using the Meyers and McKeever classification on radiographs and any available magnetic resonance imaging or computed tomography scans.[26] Skeletal maturity was documented per the classification system described by O'Connor et al.[28] PTS was measured using the method described by Bernhardson et al[3] on either the lateral knee or a lateral tibial radiograph. Measurements were made using perfect lateral radiographs before any surgical intervention if possible, although in instances where this imaging was unavailable or inadequate, the postoperative image was instead used from either the first or second postoperative visit (within 6 weeks of surgery). The radiology technicians at our institution are instructed to obtain perfect lateral radiographs with complete overlap of the femoral condyles, and if this is not achieved, the patient is sent back for a repeat radiograph. The PTS was measured by first marking points 5 and 15 cm distal to the tibial joint line. Circles were placed at these distances to mark the midpoint of the tibial diaphysis, with the outline of the circles in tangent with the anterior and posterior cortices. A line was drawn to intersect the 2 midpoints to create the anatomic axis, and a second line was drawn perpendicular to this axis at the level of the joint line. The posterior slope was then measured by the angle between the posterior inclination of the medial tibial plateau and this perpendicular line (Figure 1). If the radiograph did not have 15 cm of tibial length, a similar 3:1 ratio of measurement points (ie, 12 and 4 cm; 10 and 3.33 cm) distal to the tibial plateau was utilized to determine the anatomic axis. Radiographs without $\geq$10 cm of tibial length were excluded (n = 2 patients). PTS measurements were recorded by 2 independent orthopaedic surgeons (A.S.M., M.K.M.) twice, with a 3-week interval between measurements. The mean of the 4 measurements was used for the corresponding PTS for each patient. Measurement reliability was assessed using the intraclass correlation coefficient (ICC) via a 2-way mixed model based on absolute agreement.[20] This was performed for intra- and interreviewer consistency overall and between participant groups.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics for Macintosh Version 27. Chi-square tests were used to compare sex and race distribution between cases and controls. Independent-samples t tests were performed to compare age and PTS between cases and controls for each sex. Bivariate correlation analyses was performed to assess the relationship of PTS to age and Meyers and McKeever classification. Odds ratios (ORs) were calculated for 3 patient groups with PTS angles measuring $\geq$1 SD below the mean (low risk), within 1 SD of the mean (normal risk), and at least 1 SD above the mean (high risk).

RESULTS

A total of 51 patients with TEFs were evaluated: 34 (66.7%) male and 17 (33.3%) female. The mean age for all patients with TEFs was 10.9 years. The mean age by sex was 11.4 years for boys and 10.0 years for girls. The

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Submitted June 15, 2022; accepted September 25, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: M.B.F. has received hospitality payments from Medtronic USA. E.W.B. has received consulting fees from Link Orthopaedics, Orthopaedic Design, and LinBio Corp and support for education from Prime Surgical. A.M.M. has received consulting fees from Fidia Pharma USA and Miach Orthopaedics; a grant from DJO; and support for education Prime Surgical, Smith & Nephew, Arthrex, and Peerless Surgical. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Figure 1. Lateral knee radiograph illustrating the technique used for obtaining PTS measurements through the tibial anatomic axis. PTS, posterior tibial slope.

mean age of the controls (n = 57) was 11.6 years for all patients (P = .164), 11.7 years for boys (P = .624), and 11.5 years for girls (P = .108). The racial distribution between groups was also similar (P = .704). Patient characteristics are further characterized in Table 1. With respect to Meyers and McKeever classification, of all patients with TEFs, 47.1% had type II; 41.2%, type III; and 11.8%, type IV (Table 2).

Before PTSs were compared, a Shapiro-Wilk normality test indicated no evidence of nonnormality for the data between groups (TEF, P = .355; control, P = .413); therefore, an independent-samples t test was carried out. The PTS for those with TEFs was no different than that for controls (TEF, 9.7° ± 2.4°; control, 8.8° ± 2.7°; P = .072). However, by sex, male patients with a TEF had a significantly steeper PTS compared with male controls (TEF, 10.0° ± 2.2°; control, 8.4° ± 2.4°; P = .006). For female patients, there was no significant difference in PTS between cases and controls (TEF, 9.1° ± 2.8°; control, 9.4° ± 2.8°; P = .730). Independent-samples t tests demonstrated no significant differences in PTS between boys and girls within either controls (male, 8.4° ± 2.4°; female, 9.4° ± 2.8°; P = .154) or cases (male, 10.0° ± 2.2°; female, 9.1° ± 2.8°; P = .218) (Table 2). Fisher exact test showed no significant difference in skeletal maturity between controls and cases (P = .302), male controls and male cases (P = .068), or female controls and female cases (P = .122).

PTS angles were subsequently converted into 3 risk groups based on the angle mean (9.3°) and SD (2.6°): low (<7°), normal (7°-12°), and high (>12°) risk. ORs were performed to compare the frequency of TEFs within these angle ranges. Overall, patients with a PTS >12° had 3.8 times the odds of having a TEF compared with controls (95% CI, 1.3-11.6; P = .017). This increased with male patients, as those with a PTS >12° had nearly 6 times the odds of presenting with a TEF (OR, 5.8; 95% CI, 1.1-29.1; P = .034). This pattern was not observed for female patients (OR, 2.6; 95% CI, 0.5-12.6; P = .247) (Table 3).

Before bivariate correlation was performed between PTS and age/fracture classification, a Shapiro-Wilk normality test was run. The analysis indicated evidence of nonnormality for age and Meyers and McKeever fracture classification (P < .001); therefore, a Spearman correlation was carried out. There was no association between age and PTS (R = 0.023; P = .81). There was a nonsignificant positive correlation between the degree of PTS and Meyers and McKeever classification (R = 0.229; P = .11).

Inter- and Intrareviewer Consistency

Measurement reliability was assessed using the ICC via a 2-way mixed model based on absolute agreement. Based on the 95% CI of the ICC estimate, values <0.5 are considered poor reliability; 0.5 to 0.75, moderate; 0.76 to 0.9, good; and >0.9, excellent. Our PTS measurements were found to have excellent intra- and interreviewer reliability, with an overall inter-reviewer ICC of 0.958. When accounting for case-control groups, the ICC of the TEF group was less reliable (0.938) than that of the control group (0.973); however, both fell within excellent reliability.

DISCUSSION

The current study found that male patients who undergo surgical fixation of a TEF tend to have increased PTS as compared with controls. In addition, patients with TEFs who underwent surgical fixation had 3.8 times greater odds of having a PTS >12° when compared with controls.

Only 1 previous study has evaluated associations of degree of PTS and TEF. Samora et al[31] evaluated 25 patients with TEFs as compared with matched controls. They did not find a statistically significant association of PTS with TEF when comparing cases (8.9° ± 2.4°) with controls (8.5° ± 2.3°) (P = .07), which is similar to the finding of our study. Yet, Samora et al did not perform a subgroup analysis to evaluate characteristics such as sex, likely because of the small population of patients. After stratifying sexes, the current study found that male patients with a TEF had a significantly steeper PTS (10.0° ± 2.2°) compared with male controls (8.4° ± 2.4°) (P = .006). However, for girls, there was no significant difference, which was likely the result of the small number of female patients (n = 17), limiting our statistical power.

We suspect the difference in PTS between sex and association with TEF may be multifactorial. These factors may

TABLE 1
Patient Characteristics[a]

	Tibial Eminence Fracture	Control	*P* Value
Total sample, n	51	57	
Gender			.451
Male	34 (66.7)	34 (59.6)	
Female	17 (33.3)	23 (40.4)	
Age, y	10.9 ± 3.4 (5.0-20.0)	11.6 ± 1.0 (10-13.0)	.164
Male	11.4 ± 3.1 (5.5-18.0)	11.7 ± 1.0 (10.0-13.0)	.624
Female	10.0 ± 3.7 (5.0-20.0)	11.5 ± 0.9 (10.0-13.0)	.108
Race			.704
White	33 (64.7)	39 (68.4)	
Black	13 (25.5)	13 (22.8)	
Hispanic	4 (7.8)	2 (3.5)	
Asian	0	1 (1.7)	
Not available	1 (2.0)	2 (3.5)	

[a]Values are presented as No. (%) or mean ± SD (range).

TABLE 2
Posterior Tibial Slope Measurements[a]

	Tibial Eminence Fracture	Control	*P* Value
Posterior tibial slope, deg	9.7 ± 2.4	8.8 ± 2.7	.072
Male	10.0 ± 2.2 (4.7-13.2)	8.4 ± 2.4 (3.8-15.2)	**.006**
Female	9.1 ± 2.8 (5.3-14.4)	9.4 ± 2.8 (3.2-15.4)	.730
P value	.218	.154	
Meyers and McKeever classification			
Type I	0 (0.0)	—	—
Type II	24 (47.1)	—	—
Type III	21 (41.2)	—	—
Type IV	6 (11.8)	—	—

[a]Values are presented as No. (%) or mean ± SD (range). Bold indicates $P < .05$. Dashes indicate no value.

TABLE 3
Odds Ratios of Pediatric Tibial Eminence Fracture for Posterior Tibial Slope Angle[a]

	Low Risk, <7°	Normal Risk, 7°-12°	High Risk, >12°
Total			
OR (95% CI)	0.5 (0.2-1.3)	0.7 (0.3-1.6)	3.8 (1.3-11.6)
P value	.142	.446	**.017**
Control, n	14	38	5
TEF, n	7	31	13
Male			
OR (95% CI)	0.2 (0.1-0.9)	1.0 (0.4-2.7)	5.8 (1.1-29.1)
P value	**.031**	≥.999	**.034**
Control, n	10	22	2
TEF, n	3	22	9
Female			
OR (95% CI)	1.4 (0.3-6.4)	0.4 (0.1-1.6)	2.6 (0.5-.12.6)
P value	.698	.202	.247
Control, n	4	16	3
TEF, n	4	9	4

[a]OR, odds ratio; TEF, tibial eminence fracture. Bold indicates $P < .05$.

include the various anatomic risks found in similar ACL injuries, hormonal differences between sexes, and differences in timing of skeletal maturity between sexes. Despite finding no difference in skeletal maturity based on knee radiographs between cases and controls in either the male or the female group, it is plausible that differences in skeletal maturity would alter the age of ossification of the tibial eminence, thereby changing the mode of failure between avulsion of the ACL in TEF versus rupture of the ligament itself. In a recent study, DeFrancesco et al[9] reported that the largest number of cases of TEF were seen before skeletal maturity (age 13-14 years in boys and 11-12 years in girls), also supporting this theory. It is suspected that the relatively small sample size and inability to match by age and sex in this study limited further evaluation of the role of skeletal maturity and TEF. Interestingly, in a study using computed tomography to measure PTS, Clinger et al[7] found no difference in PTS among sex or age groups. However, the study excluded individuals <18 years old and utilized a different imaging modality and measurement method than that used in our study and the majority of studies concerning PTS, perhaps attributing to these unique findings.

In regard to anatomic risks for comparable ACL injuries, a few biomechanical and clinical studies have found

PTS to be implicated in ACL tears, as well as other pediatric knee pathologies, such as Osgood-Schlatter disease and tibial tubercle fractures.[11,33] Dean et al[8] demonstrated that as the PTS steepness rises, the strain on the ACL increases, theoretically predisposing it to higher risk of injury. Several others have identified PTS as a risk factor for ACL injuries in pediatric and adolescent populations.[10,29,37] In a recent meta-analysis, Zeng et al[41] also noted that having a steeper PTS led to increased susceptibility to ACL injury. The previous findings in the literature for ACL injuries correlate with our findings of PTS and TEF but do not address the differences that we observed between male and female patients.

When addressing differences in sex for risk of comparable ACL injuries, the literature is variable in its findings. Several anatomic differences have been noted between males and females, which may account for the increased risk of ACL injury in female patients, such as smaller femoral notch widths and ACL cross-sectional area.[6] Multiple studies have reported no difference in ACL injury risk in either male or female patients with steeper PTS.[17,19,25,38] However, several others have found that female patients with an increased PTS are at higher risk of ACL injury,[4,13,16,18,35,36] while fewer have indicated that male patients with increased PTS are at higher risk of ACL injury compared with their female counterparts.[42] The differing findings for sex associations with PTS and ACL injuries limit our ability to draw analogous comparisons for sex associations with PTS and TEF.

In a recent review, Lin et al[24] discussed the role of PTS in graft failure after ACL reconstruction. In particular, the authors suggested that patients with a PTS $\geq 12^\circ$ are at a significantly increased risk of failure, as found by multiple investigators.[23,30,39] Our study evaluated the frequency of this 12° cutoff value in patients with surgically managed TEF. Interestingly, those who underwent surgical fixation of TEF had 3.8 times greater odds of having a PTS $>12^\circ$ as compared with controls. For male patients, the odds were 5.8 times greater.

Limitations

This study is not without limitations. The current study included a relatively small sample size. However, the sample size is twice that of a previously published study on TEF.[31] Ideally, age- and sex-matched controls could have been included, given the large age range seen in our sample; unfortunately, this was not possible. Additionally, our study population contained twice as many male patients as female, potentially limiting our ability to draw conclusions for differences in sex and the effect of skeletal maturity. There is controversy in the literature regarding consistency of radiographic evaluation and measurements of PTS.[12] Despite this, the inter- and intrareviewer reliability was excellent for our study based on the ICC 95% CI. Last, a Current Procedural Terminology code was utilized to identify patients with TEF, creating a potential sampling bias that would have excluded patients with TEF who did not undergo surgical fixation, in particular those with Meyers and McKeever classification type I fractures.

CONCLUSION

Male patients undergoing surgical fixation of a TEF had an increased PTS as compared with controls. In addition, patients who underwent surgical fixation of TEF had 3.8 times greater odds of having a PTS $>12^\circ$ as compared with controls. The clinical significance of these findings remains to be fully understood; however, increased PTS may be a risk factor for sustaining a TEF in male patients. To further understand the implication of PTS on TEF and associated risk factors, studying a larger population may be necessary.

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