What Are the Causes and Consequences of Delayed Surgery for Pediatric Tibial Spine Fractures? A Multicenter Study

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Background: The uncommon nature of tibial spine fractures (TSFs) may result in delayed diagnosis and treatment. The outcomes of delayed surgery are unknown.

Purpose: To evaluate risk factors for, and outcomes of, delayed surgical treatment of pediatric TSFs.

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

Methods: The authors performed a retrospective cohort study of TSFs treated surgically at 10 institutions between 2000 and 2019. Patient characteristics and preoperative data were collected, as were intraoperative information and postoperative complications. Surgery $\geq$21 days after injury was considered delayed based on visualized trends in the data. Univariate analysis was followed by purposeful entry multivariate regression to adjust for confounders.

Results: A total of 368 patients (mean age, 11.7 ± 2.9 years) were included, 21.2% of whom underwent surgery $\geq$21 days after injury. Patients who experienced delayed surgery had 3.8 times higher odds of being diagnosed with a TSF at $\geq$1 weeks after injury (95% CI, 1.1-14.3; $P = .04$), 2.1 times higher odds of having seen multiple clinicians before the treating surgeon (95% CI, 1.1-4.1; $P = .03$), 5.8 times higher odds of having magnetic resonance imaging (MRI) $\geq$1 weeks after injury (95% CI, 1.6-20.8; $P < .007$), and were 2.2 times more likely to have public insurance (95% CI, 1.3-3.9; $P = .005$). Meniscal injuries were encountered intraoperatively in 42.3% of patients with delayed surgery versus 21.0% of patients treated without delay ($P < .001$), resulting in 2.8 times higher odds in multivariate analysis (95% CI, 1.6-5.0; $P < .001$). Delayed surgery was also a risk factor for procedure duration >2.5 hours (odds ratio, 3.3; 95% CI, 1.4-7.9; $P = .006$). Patients who experienced delayed surgery and also had an operation >2.5 hours had 3.7 times higher odds of developing arthrofibrosis (95% CI, 1.1-12.5; $P = .03$).

Conclusion: Patients who underwent delayed surgery for TSFs were found to have a higher rate of concomitant meniscal injury, longer procedure duration, and more postoperative arthrofibrosis when the surgery length was >2.5 hours. Those who experienced delays in diagnosis or MRI, saw multiple clinicians, and had public insurance were more likely to have a delay to surgery.

Keywords: tibial spine; tibial eminence; pediatric knee; pediatric sports medicine

Tibial spine fractures (TSFs) are often considered to be a pediatric analog to anterior cruciate ligament (ACL) tears in adolescents and adults.[12,24] Like ACL injuries, TSFs are becoming more prevalent with increasing athletic participation.[5] However, they remain much rarer than their ligamentous counterpart at an incidence of 3 fractures per 100,000 children annually.[1,5,20,31] Numerous studies have demonstrated that delays in pediatric ACL reconstruction result in an increased incidence and severity of concomitant meniscal and chondral pathology, which may lead to poorer outcomes.[15,23,25,35] However, the literature on delayed treatment of TSFs is scarce.[9]

Given the rare nature of TSFs and the small number of surgeons experienced in treating them,[17] there is potential for delays in the diagnosis and management as well as variations in the approach to evaluation and treatment. As previously reported for other injuries, such issues may also be exacerbated by demographic factors.[6,16,18,28,32] An improved understanding of the variables contributing to delays in the treatment of tibial eminence fractures may

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drive future research and provide opportunities to expedite and optimize the care of these patients.

The purpose of this study was to identify risk factors for delayed surgical management of pediatric TSFs as well as the associated consequences. Our hypothesis was that socioeconomic and demographic factors affect the timing of surgical treatment after a TSF and that delayed surgical treatment may result in an increased prevalence of concomitant intra-articular pathology as well as heightened risk of postoperative complications.

METHODS

This retrospective study was determined to be exempt from institutional review board approval. All patients with a TSF treated operatively between 2000 and 2019 at 1 of 10 tertiary children's hospitals were screened for inclusion in the study. Patients >18 years of age, those with additional lower extremity fractures, or those with an unknown date of injury were excluded from analysis. Patients were required to have at least 3 months of documented postoperative follow-up. Overall, 401 patients were eligible, of whom 33 were excluded because of undocumented date of injury or lack of postoperative follow-up. Subsequently, 368 patients meeting inclusion criteria were included in the study.

We collected demographic and clinical data, including age, sex, race, insurance status, and information regarding the injury, via chart review. Pre-, intra-, and postoperative data points were collected, with attention to timing of orthopaedic evaluation from time of injury, utilization and timing of magnetic resonance imaging (MRI), and time from injury to surgery. We also recorded visits to other clinicians before evaluation by the treating surgeon. Concomitant injuries identified intraoperatively were also recorded, as was the total operating time from skin incision to closure, and the type of treatment (ie, open or arthroscopic fixation, implant type, and concomitant procedures). Decisions regarding evaluation and treatment were made according to the preferences of the treating surgeon rather than a uniform protocol over the course of this retrospective study. Similar to previous studies,[7,26,29] we defined arthrofibrosis as an extension deficit $\geq 10^\circ$ and/or flexion deficit $\geq 25^\circ$ compared with the contralateral knee at 3 months after surgery.

When analyzing time elapsed between injury and management or treatment, these variables were first evaluated as continuous and then transformed to categorical variables based on observed trends in the data. We considered surgery performed $\geq$21 days after the injury to be delayed in this analysis, based on visualized trends. First, a scatterplot was created to determine the variation in time between injury and surgery for the entire cohort, and a clear inflection point was seen at 21 days. Next, the surgeons involved with the study were queried and a consensus was reached that 21 days was an appropriate cutoff for defining delayed surgery based on clinical experience.

Statistical analyses were performed by members of the research team with advanced biostatistical training with SPSS for Macintosh (Version 27.0; IBM). Calculations included standard descriptive statistics for demographic variables. The Kolmogorov-Smirnov test was used to determine whether continuous variables were normally distributed. Means were reported ±SD for normally distributed variables and medians with interquartile ranges (IQRs) for non-normal variables. Means were compared with independent-samples *t* tests, and the Mann-Whitney *U* test was used for nonparametric variables. Analysis of categorical variables was performed using the Fisher exact test or chi-square test, as appropriate. Univariate analysis was followed by purposeful entry logistic regression to adjust for confounders. A significance threshold of $P < .05$ was applied for all tests.

RESULTS

The mean age for the 368 study patients was 11.7 ± 2.9 years, and 68.5% were male. The mean follow-up period was 10.0 ± 1.1 months. The median time between injury and surgery was 11 days (IQR, 13 days). In total, 78 patients (21.2%) underwent surgery at $\geq$21 days after injury. In univariate analysis, patients who underwent delayed surgery experienced longer time between injury and diagnosis as well as injury and MRI. These patients also had a higher proportion of boys, public insurance, and previous visits to other clinicians before the treating surgeon. A univariate analysis of preoperative variables is shown in Table 1.

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TABLE 1
Preoperative Comparisons Based on Surgical Timing[a]

	≥21 Days (n = 78)	<21 Days (n = 290)	*P*
Age, y	11.8 ± 2.9	11.7 ± 2.9	.8
BMI	20.6 ± 4.9	20.6 ± 4.5	>.99
Days between injury and diagnosis	15.0 (14.0)	3.0 (6.0)	**<.001**
0-6	20 (25.6)	228 (78.6)	**<.001**
≥7	58 (74.4)	62 (21.4)	
MRI obtained	56 (71.8)	116 (40.0)	**<.001**
Days between injury and MRI	13.0 (15.0)	4.0 (5.0)	**<.001**
0-6	13 (23.2)	92 (79.3)	**<.001**
7-20	26 (46.4)	24 (20.7)	
≥21	17 (30.4)	0 (0.0)	
Sex			**.04**
Male	61 (78.2)	191 (65.9)	
Female	17 (21.8)	99 (34.1)	
Race/ethnicity			.9
White	37 (47.4)	140 (48.3)	
Black	16 (20.5)	47 (16.2)	
Latinx	4 (5.1)	17 (5.9)	
Other/unknown	21 (26.9)	86 (29.7)	
Insurance			**.02**
Public	39 (50.0)	102 (35.2)	
Private	39 (50.0)	188 (64.8)	
Previous clinician seen	62 (79.5)	188 (64.8)	**.04**
Previous surgeon seen	20 (25.6)	43 (14.8)	**.02**
Meyers and McKeever classification			.1
I	2 (2.6)	3 (1.0)	
II	33 (42.3)	102 (35.2)	
III	28 (35.9)	138 (47.6)	
IV	12 (15.4)	27 (9.3)	
Unknown	3 (3.8)	20 (6.9)	

[a]All values are reported as mean ± SD or n (%) except for days between injury and diagnosis and days between injury and MRI, which are reported as median [IQR]. Bolded *P* values indicate a statistically significant difference between groups ($P < .05$). BMI, body mass index; MRI, magnetic resonance imaging.

TABLE 2
Peri- and Postoperative Comparisons Based on Surgical Timing[a]

	≥21 Days (n = 78)	<21 Days (n = 290)	*P*
Procedure performed			.6
Arthroscopic fixation	69 (88.5)	243 (83.8)	
Open fixation	8 (10.3)	42 (14.5)	
Closed reduction	1 (1.3)	5 (1.7)	
Fixation technique			.9
Suture-based	50 (64.1)	188 (64.8)	
Screw	28 (35.9)	102 (35.2)	
Concomitant meniscal tear	33 (42.3)	61 (21.0)	**<.001**
Meniscal tear type			.8
Medial	4 (12.1)	10 (16.4)	
Lateral	28 (84.8)	50 (82.0)	
Both	1 (3.0)	1 (1.6)	
Concomitant meniscectomy	8 (10.3)	17 (5.9)	.2
Concomitant chondral injury	2 (2.6)	8 (2.8)	>.99
Surgery length, min	128.4 ± 51.9	116.4 ± 43.0	.05
≤150	54 (69.2)	236 (81.4)	**.04**
>150	24 (29.4)	54 (18.6)	
Arthrofibrosis	7 (9.0)	19 (6.6)	.5

[a]All values reported as mean ± SD or n (%). Bolded *P* values indicate a statistically significant difference between groups ($P < .05$).

TABLE 3
Multivariate Predictors of Surgery ≥21 Days After Injury[a]

	OR (95% CI)	*P*
Public insurance	2.2 (1.3-3.9)	**.005**
Previous surgeon seen	2.1 (1.1-4.1)	**.03**
MRI obtained	3.7 (2.0-6.7)	**<.001**
Days between injury and MRI		
7-20	5.8 (1.6-20.8)	**.007**
≥21	NA	NA
Days between injury and diagnosis		
7-20	3.8 (1.1-14.3)	**.04**
≥21	NA	NA
Female sex	1.3 (0.7-2.5)	.4

[a]Bolded *P* values indicate a statistical significance ($P < .05$). MRI, magnetic resonance imaging; NA, not applicable (unable to calculate since no patients could receive diagnosis or MRI ≥21 days but surgery <21 days after injury); OR, odds ratio.

An analysis of intraoperative findings found that a meniscal tear was encountered in 61 of 290 (21.0%) patients who underwent surgery within 21 days of injury compared with 33 of 78 (42.3%) patients who had delayed surgery ($P < .001$). The median time between injury and surgery for children that had a concomitant meniscal tear was 14 days (IQR, 16 days) versus 10 days (IQR, 12 days) for those who did not have meniscal pathology ($P = .001$). There were no differences between groups regarding the rate of meniscal repair versus meniscectomy or frequency of chondral injury. A significantly greater proportion of patients who underwent delayed surgery had a procedure lasting >2.5 hours. While surgery ≥21 days and surgery length were not independently associated with arthrofibrosis, there was a higher rate of this complication in those who had delayed surgery and also had a surgery length >2.5 hours (19.0% vs 6.3% for all others; $P = .03$). The details of the intra- and postoperative data are shown in Table 2.

After adjusting for covariates in multivariate analysis, patients who underwent surgery ≥21 days after injury had higher odds of having public insurance, seen another surgeon before the treating surgeon, and undergone MRI. These patients were also more likely to have been diagnosed with a TSF later than 1 week after injury and obtained MRI more than 1 week after injury (Table 3). Children who had surgery ≥21 days after injury had significantly higher odds of a concomitant meniscal injury, and Meyers and McKeever type 4 fractures were more likely to

TABLE 4
Multivariate Predictors of Concomitant Meniscal Injury[a]

	OR (95% CI)	*P*
Surgery ≥21 days after injury	2.8 (1.6-5.0)	**<.001**
Meyers and McKeever type 4		
vs type 1	1.5 (0.2-11.5)	.7
vs type 2	3.4 (1.6-7.6)	**.002**
vs type 3	2.4 (1.1-5.1)	**.03**
Sex	1.3 (0.7-2.3)	.4
Race		
Black	1.1 (0.06-20.0)	.9
Latino	0.7 (0.03-13.5)	.8
Other/unknown	0.3 (0.02-5.4)	.4
Age	1.1 (0.9-1.2)	.2

[a]Bolded *P* values indicate a statistical significance ($P < .05$). OR, odds ratio.

TABLE 5
Multivariate Predictors of Surgery Length >150 Minutes[a]

	OR (95% CI)	*P*
Surgery ≥21 days after injury	3.3 (1.4-7.9)	**.006**
Meyers and McKeever type 4		
vs type 1	0.5 (0.04-6.0)	.6
vs type 2	1.5 (0.5-4.5)	.5
vs type 3	1.2 (0.4-3.5)	.8
BMI	1.1 (0.9-1.2)	.2
Open surgery	2.0 (0.4-11.2)	.4
Surgery for concomitant injuries	1.4 (0.6-3.5)	.4

[a]Bolded *P* value indicates statistical significance ($P < .05$). BMI, body mass index; OR, odds ratio.

TABLE 6
Multivariate Predictors of Arthrofibrosis[a]

	OR (95% CI)	*P*
Surgery ≥21 days after injury and surgery length >150 min	3.7 (1.1-12.5)	**.03**
Surgery ≥21 days after injury	1.7 (0.6-5.0)	.3
Surgery length >150 min	2.3 (0.8-6.5)	.1
Postoperative immobilization (cast)		
Hinged brace	2.0 (0.6-6.3)	.2
Knee immobilizer	2.0 (0.3-12.3)	.4
Male sex	0.6 (0.3-1.6)	.3
Open surgery	1.4 (0.5-4.8)	.5
Age	1.1 (0.9-1.3)	.2

[a]Bolded *P* value indicates statistical significance ($P < .05$). OR, odds ratio.

be accompanied by a meniscal tear than types 2 and 3 (Table 4). Patients who underwent delayed surgery had higher odds of their procedure lasting >2.5 hours (Table 5). Finally, those who were treated ≥21 days after injury in addition to having an operation >2.5 hours had significantly increased odds of postoperative arthrofibrosis, although these variables were not independently predictive of stiffness (Table 6).

DISCUSSION

To date, there is little research on factors that may prolong the time to surgery for children with TSF or on the associated consequences thereof. Most notably, our findings demonstrate that meniscal pathology was discovered more frequently in patients who underwent surgery ≥21 days after injury. Delayed surgery was also associated with a longer surgery duration and postoperative arthrofibrosis. Patients who had a delayed diagnosis, saw multiple clinicians, had public insurance, and underwent MRI before surgical treatment were more likely to experience a prolonged delay between injury and surgery.

The present study found that operative fixation ≥21 days was associated with a higher rate of concomitant meniscal pathology. Studies on ACL reconstruction have demonstrated that children with delays in surgical treatment are more likely to have concomitant meniscal and chondral injuries, ultimately resulting in a worse long-term prognosis.[8,10,25] These studies have reported an increase in the intraoperative incidence of concomitant pathology when compared with MRI findings, suggesting that ongoing instability results in progressive injury.[14] The period of time that is considered delayed for TSFs in this study is significantly shorter than that used to describe ACL injuries. Therefore, progressive injury due to chronic instability likely does not apply to TSF. Our data demonstrated that fracture severity according to the Meyers and McKeever system was also predictive of meniscal injury. This may be because of the mechanism and energy of injury that results in more severe TSFs. However, prolonged time between injury and surgery was still independently predictive of concomitant meniscal pathology, even when adjusting for fracture classification and other factors in multivariate analysis. The exact reason for our findings regarding meniscal pathology is beyond the scope of our data. Regardless of the precise origin, the presence of a meniscal injury may portend a poorer outcome for patients with a TSF. Further research is needed on the cause and long-term prognosis of concomitant meniscal injuries with TSF.

The present study found that patients with delayed surgical treatment were more likely to have an operative time >2.5 hours. This may be related to increased complexity of the surgery or additional procedures required to address concomitant injuries. Furthermore, patients who underwent surgery ≥21 days after injury and also had an operation >2.5 hours had 3.7 times higher odds of developing arthrofibrosis postoperatively. This remains the most common postoperative complication after fixation of TSFs, with a reported incidence ranging from 10% to 29% and frequently requiring reoperation.[4,13,27,33] Watts et al[33] previously found that operative time ≥120 minutes and delay of surgery >7 days from injury led to increased rates of arthrofibrosis. These findings, as well as ours, suggest that there may be an additive effect of delayed surgery, prolonged surgery time, and injury severity on the risk of postoperative stiffness.

Delays in diagnosis and subsequent treatment may be related to the rarity of TSFs, as they account for only 3 per

100,000 children's fractures.[3,13,19] At initial presentation, patients may have nonspecific physical examination findings such as an effusion, decreased range of motion, and difficulties with weightbearing.[3] While most fractures can be identified on radiographs, a small or incompletely ossified fragment may be difficult to visualize. A Danish study of pediatric knee injuries in a national malpractice claims system found that TSF was the most commonly missed diagnosis.[22] The present study found that nearly a third of children were diagnosed more than 1 week after injury. Our retrospective data are unable to determine whether this finding is the result of delays in seeking care versus missed diagnoses by clinicians. Nonetheless, the relative rarity of the fracture, nonspecific symptoms, and difficulties diagnosing TSFs on radiographs may lead to prolonged time between injury and diagnosis and subsequent treatment.

In this study, patients who had surgical treatment more than 21 days after injury were 3.8 times more likely to have undergone MRI. This modality is valuable in identifying concurrent soft tissue pathology requiring surgical management, such as meniscal tears, meniscal entrapment, and ligamentous injuries, and may affect treatment decisions in terms of operative versus nonoperative management.[2,21,30] However, barriers often exist in timely completion of advanced imaging. These include the frequent lack of availability in the emergency department or at urgent care centers, the need for prior insurance authorization, and proper patient screening.[34] Although our study found that obtaining an MRI was a risk factor for a delay in surgery, this does not imply that it should not be part of the pretreatment evaluation for TSFs. Rather, to limit surgical delays, MRI should be ordered judiciously and obtained promptly after initial evaluation.

Additionally, seeing multiple clinicians was a risk factor for an increased time between injury and surgery. Of patients who underwent surgery $\geq$21 days after injury, 79.5% previously saw a provider of any specialty and 25.6% saw another orthopaedist before the treating surgeon. Many patients may require a primary care referral to a specialty provider. The intent of such arrangements is to reduce health care costs and limit inappropriate specialty care, but it may prolong the time to treatment of uncommon conditions like TSFs.[11] Additionally, a limited number of surgeons are experienced in treating these fractures. In a survey of the Pediatric Orthopaedic Society of North America, the majority of surgeons (62.4%) treated 3 or fewer TSFs per year.[17] Such trends may have been a factor in the sizable proportion of patients in this study who saw another orthopaedist before the treating surgeon. An improved physician-to-physician referral system and a better understanding of patient factors and preferences may be needed to reduce this delay in the treatment of an acute fracture. Ultimately, as early treatment is not the only factor in achieving an excellent outcome, the current health care infrastructure requires a balance between timely surgery and access to an experienced surgeon.

Insurance status may compound the issues that stem from the uncommon nature of TSFs and scarcity of providers experienced in providing treatment. The present study found that patients with public insurance were more likely to undergo surgical treatment $\geq$21 days after injury. Numerous studies have highlighted that pediatric patients with public insurance face barriers to timely orthopaedic specialty care, including limited patient resources, a small number of providers willing to see publicly insured patients, a lack of appointment times, and delays in referrals.[6,19,25,32] Primary care physicians and treating clinicians in the acute setting may need to consider a more thorough initial workup as well as more hands-on follow-up of referrals if a patient's insurance status adversely affects access to prompt advanced imaging and surgical evaluation.

Despite its multicenter design and inclusion of a relatively large number of TSFs, this investigation is not without biases inherent to retrospective studies. Many patients lacked documentation of long-term outcomes, so reliable data analysis could not be conducted beyond the short-term postoperative period. Patient-reported outcome measures were not routinely recorded. Additionally, the study was conducted at tertiary pediatric institutions and may not be generalizable to all nonacademic or community-based centers. Our data are limited to medical record documentation, and therefore, we were unable to adjust for possible confounding factors such as mechanism of injury and patient activity level. Finally, the retrospective nature of this study limits our ability to make concrete conclusions regarding cause and effect, and we are only able to report on associations.

CONCLUSION

In the present study, patients who underwent delayed surgical treatment of TSFs were found to have higher rates of concomitant meniscal injury, longer procedure duration, and postoperative arthrofibrosis when surgery length was >2.5 hours. Public insurance and referrals to multiple clinicians before the treating surgeon led to a prolonged time between injury and surgery. These results provide an opportunity to optimize care and postoperative outcomes for children that are at highest risk for delayed treatment.

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