Tibial Spine Fractures in the Child and Adolescent Athlete

A Systematic Review and Meta-analysis

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Background: Tibial spine fractures (TSFs) are uncommon injuries that may result in substantial morbidity in children. A variety of open and arthroscopic techniques are used to treat these fractures, but no single standardized operative method has been identified.

Purpose: To systematically review the literature on pediatric TSFs to determine the current treatment approaches, outcomes, and complications.

Study Design: Meta-analysis; Level of evidence, 4.

Methods: A systematic review of the literature was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines using PubMed, Embase, and Cochrane databases. Studies evaluating treatment and outcomes of patients <18 years old were included. Patient demographic characteristics, fracture characteristics, treatments, and outcomes were abstracted. Descriptive statistics were used to summarize categorical and quantitative variables, and a meta-analytic technique was used to compare observational studies with sufficient data.

Results: A total of 47 studies were included, totaling 1922 TSFs in patients (66.4% male) with a mean age of 12 years (range, 3-18 years). The operative approach was open reduction and internal fixation in 291 cases and arthroscopic reduction and internal fixation in 1236 cases; screw fixation was used in 411 cases and suture fixation, in 586 cases. A total of 13 nonunions were reported, occurring most frequently in Meyers and McKeever type III fractures (n = 6) and in fractures that were treated nonoperatively (n = 10). Arthrofibrosis rates were reported in 33 studies (n = 1700), and arthrofibrosis was present in 190 patients (11.2%). Range of motion loss occurred significantly more frequently in patients with type III and IV fractures ($P < .001$), and secondary anterior cruciate ligament (ACL) injury occurred most frequently in patients with type I and II fractures ($P = .008$). No statistically significant differences were found with regard to rates of nonunion, arthrofibrosis, range of motion loss, laxity, or secondary ACL injury between fixation methods (screw vs suture).

Conclusion: Despite variation in TSF treatment, good overall outcomes have been reported with low complication rates in both open and arthroscopic treatment and with both screw and suture fixation. Arthrofibrosis remains a concern after surgical treatment for TSF, but no significant difference in incidence was found between the analysis groups. Larger studies are necessary to compare outcomes and form a consensus on how to treat and manage patients with TSFs.

Keywords: pediatric sports medicine; knee ligaments; ACL; general sports trauma

Tibial spine fractures (TSFs) are rare knee injuries that most commonly affect children and adolescents.[19] Given the ossification patterns of the knee, injuries sustained during rotation, pivoting, or hyperextension lead to avulsion fractures at the insertion site of the anterior cruciate ligament (ACL) on the tibial spine. Considered to be equivalent to ACL tears in older populations, TSFs share similarities in mechanism of injury and subsequent instability. Classification of these injuries has traditionally been based on the system devised by Meyers and McKeever, in which fractures are classified based on the degree of fragment displacement, with types I and II being nondisplaced or displaced fractures with an intact posterior hinge, and types III and IV being completely displaced and comminuted fractures, respectively.[32] Multiple complications arising after injury and/or surgery have been described in the literature, with arthrofibrosis and residual ligamentous laxity being the most common.[25,50]

Traditionally, the Meyers and McKeever classification has been used to guide treatment. Type I and II fractures are more amenable to nonoperative treatment, whereas type III and IV fractures typically undergo either open

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reduction and internal fixation (ORIF) or arthroscopic reduction and internal fixation (ARIF) repair. With recent advances in arthroscopic surgery, more surgeons have opted for a minimally invasive approach for treatment of these fractures with varying methods of fixation.[5,11,17,40] Despite recent advances, controversy and variability remain among treating physicians with regard to fixation methods, surgical timing, and optimal imaging modalities, among other factors. Given the heterogeneity of the literature, this study was performed to systematically review the literature on TSFs to determine the current treatment approaches, outcomes, and complications.

METHODS

Screening Process

This systematic review was performed in accordance with the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines using the PubMed, Embase, and Cochrane databases. A comprehensive search was conducted for randomized controlled trials, case-control studies, cohort studies, and case series ($n > 3$) that documented the clinical outcomes of pediatric patients with TSFs. Search terms from previously published reviews were identified, and the following terms were used during our search: "(tibia OR tibial) AND (eminence OR spine OR intercondyle OR intercondylar OR inter-condyle OR inter-condylar) AND (youth OR high school OR child OR adolescent OR pediatric)."

Inclusion and Exclusion Criteria

Searches were performed in the aforementioned databases, including studies published between 1990 and August 22, 2022. The inclusion criteria for our review were studies that reported on imaging-confirmed TSFs and outcomes in pediatric patients with a mean age <18 years. Studies whose patients' mean age was >18 years were included if outcomes of patients <18 years old were reported separately. Studies with all patients aged >18 years, studies that did not report injury confirmed by radiographs or advanced imaging (computed tomography or magnetic resonance imaging), and/or studies reporting on asymptomatic patients were excluded. Two investigators (N.V.H. and M.V.C.) evaluated the abstracts from all captured studies. Full-text journal articles were accessed for those abstracts that could not be eliminated from the initial review. Full-text articles were reviewed based on the eligibility criteria by the same 2 investigators. Our search strategy following PRISMA guidelines is illustrated in Figure 1.

Data Collection

Included studies were analyzed by 2 authors (K.J.O. and S.B.), and data were collected for general study information including type of study, level of evidence, patient demographic characteristics, number of each fracture type, treatments, and outcomes. We were particularly interested in comparing outcomes and complication rates between different fracture types and surgical treatments. Specifically, comparisons were made between patients who had ORIF versus ARIF treatment, screw versus suture fixation, and Meyers and McKeever type I and II versus type III and IV fractures.[32] The outcomes and complications extracted were rates of nonunion, arthrofibrosis, range of motion (ROM) loss, ACL laxity, rates of secondary ACL injury, and patient-reported outcome measures such as the Lysholm score, Tegner score, and International Knee Documentation Committee (IKDC) subjective score. Additional complications such as symptomatic hardware and infection rates were reported in a descriptive fashion.

Data Analysis

A meta-analysis with a DerSimonian and Laird random-effects model was constructed to compare dichotomous outcomes between studies for patients with type I and II versus type III and IV fractures, ORIF versus ARIF, and screw versus suture fixation. Forest plots were generated and used to assess for study heterogeneity and to provide summary estimates. In accordance with previous reviews with study heterogeneity, a random-effects model was chosen to combine the effects of multiple studies.[12,18] To allow for analysis and to prevent computational error, a 0.5 continuity correction was added to any cell with no events in

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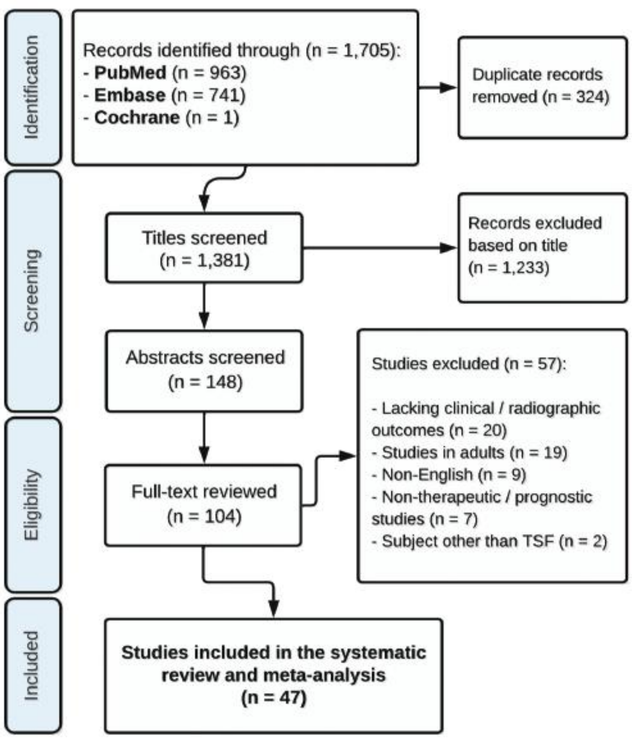

Figure 1. PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) flowchart.

a given study.[20] $P < .05$ was considered statistically significant. Weighted means were used to report functional outcome scores. Descriptive statistics were used to describe injury characteristics and outcomes that did not have sufficient data for meta-analysis. Statistical analysis was performed using Comprehensive Meta-Analysis Version 4.0.[9]

RESULTS

Study Selection

Our initial search yielded 1705 studies. After removal of duplicates, abstract screening, and full-text screening, 47 studies[*] met inclusion/exclusion criteria and were selected for our review, with a total of 1922 TSFs. All studies in our review were observational, and only 11 studies were classified as having level 3 evidence,[†] with the remaining 36 studies being classified as evidence level 4.[55] No level 1 or level 2 evidence studies were included. The majority of patients in our cohort were male (66.4%), and the weighted mean age of our cohort was 12 years (range, 3-18 years).[3,4,14,43]

Injury and Treatment Characteristics

The most common type of fractures per the Meyers and McKeever classification system were type III (n = 855; 44.5%), followed by type II (n = 852; 44.3%), type I (n = 138; 7.2%), and type IV (n = 77; 4%). Fracture types were grouped together based on severity and displacement for the purposes of this study (type I and II vs type III and IV). A total of 45 studies specified the number of patients treated by ORIF, ARIF, and nonoperative methods, with most patients undergoing operative treatment (ORIF, n = 291; ARIF, n = 1236; nonoperative, n = 297). Fixation methods were reported in 35 studies, with screw (n = 411) and suture (n = 586) fixation being the most commonly used methods of fracture fixation. Other methods of fixation, such as absorbable pins and K-wires, were described and reported in 11 studies (n = 108).[‡] For the purposes of analysis, outcomes were compared only for studies using screw and suture fixation, because these are the 2 most commonly used methods of fracture fixation. Associated injuries were reported in 20 studies (n = 1338), with 427 patients (31.9%) having concomitant injuries. Soft tissue entrapment, meniscal injuries, and ligamentous injuries were the most commonly reported injuries. When specified, concomitant injuries were more frequently reported in patients with type I and II fractures (n = 68) and those treated arthroscopically (n = 195). Injury and treatment characteristics are summarized in Table 1.

Nonunion

Rates of nonunion were reported in 35 studies (n = 1683), and nonunion was relatively uncommon, occurring in 13 patients total (0.7%). Fracture nonunion was most commonly associated with type III fractures (n = 6) and fractures treated nonoperatively (n = 10). A total of 24 studies had sufficient data for meta-analysis comparing rates of nonunion between type I and II fractures (n = 337) and type III and IV fractures (n = 464).[§] In the 24 studies used for the meta-analysis, no patients in the type I and II fracture group had nonunion and 8 patients (1.7%) in the type III and IV fracture group had nonunion. Six patients who developed nonunion had type III fractures and were treated nonoperatively. Meta-analysis identified no significant difference in rates of nonunion between fracture types ($P = .588$).

Insufficient data were available for meta-analysis comparing nonunion rates for ORIF versus ARIF and screw versus suture fixation groups. Descriptive statistics are therefore provided instead. Seven studies had extractable data comparing nonunion rates between patients treated with ORIF (n = 120) and ARIF (n = 700).[3,14,38,45,46,50,51] No patients in the ORIF group developed nonunion of their fracture, whereas 1 patient (0.1%) in the ARIF group went on to develop nonunion. Five studies had extractable data comparing nonunion rates between screw (n = 96) and suture (n = 84) fixation methods.[5,38,42,50,51] No patient in whom screw fixation was used developed nonunion, whereas 1 patient (1.2%) in the suture group developed nonunion.

*References 1-8, 11, 13, 14, 17, 21-31, 33-54, 56-58.
†References 3, 5, 14, 29, 37, 38, 42, 46, 48, 51, 58.
‡References 11, 17, 26, 27, 31, 34, 37, 38, 42, 43, 50.
§References 3-8, 13, 17, 21, 22, 27, 28, 34, 35, 38, 41, 47, 50-54, 56, 57.

TABLE 1
Counts and Descriptions of Injury and Treatment Characteristics[a]

	No. of Patients With Characteristic Reported/ No. of Patients Where Characteristic Was Evaluated (No. of Studies)	Totals, n (%)
Concomitant injury	427/1338 (20)	Complete or partial ACL tear, 48 (11) Meniscal injury, 320 (71) Soft tissue entrapment, 49 (11) MCL injury, 7 (1) LCL injury, 1 (<1) Other ligamentous injury, 12 (3) Chondral injury, 13 (3) Total, 450[b]
Fracture type	94/731 (10)	Type I + II, 68 (72) Type III + IV, 26 (28)
Operative approach	216/565 (7)	ORIF, 21 (10) ARIF, 195 (90)
Fixation method	28/97 (3)	Screw, 10 (36) Suture, 18 (64)

[a]ACL, anterior cruciate ligament; ARIF, arthroscopic reduction and internal fixation; LCL, lateral collateral ligament; MCL, medial collateral ligament; ORIF, open reduction and internal fixation.
[b]More than 1 injury per patient.

Arthrofibrosis

Arthrofibrosis was considered to occur if diagnosis of arthrofibrosis was explicitly mentioned in the text, if manipulation under anesthesia was necessary for residual stiffness, or if there was a 10° extension deficit and/or a 25° flexion deficit 3 months after injury as established by our group's previous studies.[3,18] Arthrofibrosis rates were reported in 33 studies (n = 1700), and arthrofibrosis occurred in 190 patients (11.2%). Arthrofibrosis was reported most in patients with type III fractures (n = 58) and those treated with ARIF (n = 149) and suture fixation (n = 63). In total, 20 studies had sufficient data for meta-analysis comparing arthrofibrosis rates between type I and II fractures (n = 279) and type III and IV fractures (n = 380).[‖] A total of 24 patients (8.6%) in the type I and II fracture group experienced arthrofibrosis after their injury, whereas 72 patients (18.9%) in the type III and IV fracture group developed arthrofibrosis after their injury. Meta-analysis identified no significant differences between arthrofibrosis rates and fracture classifications (P = .237).

Ten studies had sufficient data for meta-analysis comparing rates of arthrofibrosis between ORIF (n = 138) and ARIF (n = 720) groups.[¶] In total, 22 patients (15.9%) in the ORIF group and 151 patients (21.0%) in the ARIF group developed arthrofibrosis after treatment. Meta-analysis revealed no statistically significant difference in rates of arthrofibrosis between ORIF and ARIF groups (P = .672).

Five studies had sufficient data for meta-analysis comparing arthrofibrosis rates between screw (n = 75) and suture (n = 69) fixation.[5,24,38,49,50] A total of 34 patients (45.3%) treated with screw fixation developed arthrofibrosis after treatment, whereas 19 patients (27.5%) in whom suture fixation was used developed arthrofibrosis. Meta-analysis revealed no statistically significant difference in arthrofibrosis rates between the 2 fixation methods (P = .493).

ROM Loss

ROM loss was defined as the presence of >5° of extension contracture or >15° of flexion contracture at final follow-up. ROM was reported in 35 studies (n = 1264), and ROM loss occurred most often in patients with type III fractures (n = 36) and those treated with ARIF (n = 168) and screw fixation (n = 31). A total of 21 studies had sufficient data for meta-analysis comparing ROM loss between type I and II (n = 209) and type III and IV (n = 260) fractures.[#] Eight patients (3.8%) in the type I and II fracture group experienced ROM loss, whereas 32 patients (12.3%) in the type III and IV fracture group experienced ROM loss. Meta-analysis revealed a significant difference in rates of ROM loss, with a 2.45 times greater risk of developing ROM loss with the more displaced type III and IV fractures (P < .001). Of note, none of the patients used to compare ROM loss between fracture types had type I fractures. The forest plot of this association is provided in Figure 2.

Six studies had sufficient data for meta-analysis comparing ROM loss between ORIF (n = 84) and ARIF (n = 494) groups.[24,30,38,46,49,50] A total of 23 patients (27.4%) treated by ORIF developed ROM loss, whereas 168 patients (34%) treated with ARIF developed ROM loss. Meta-analysis did

[‖]References 3, 4, 11, 13, 21-24, 26-28, 34, 35, 38, 47, 49, 50, 52, 54, 56.

[¶]References 3, 14, 24, 29, 38, 45, 46, 49-51.

[#]References 11, 13, 17, 21-24, 26-28, 34, 35, 38, 41, 47, 49, 50, 52, 54, 56, 57.

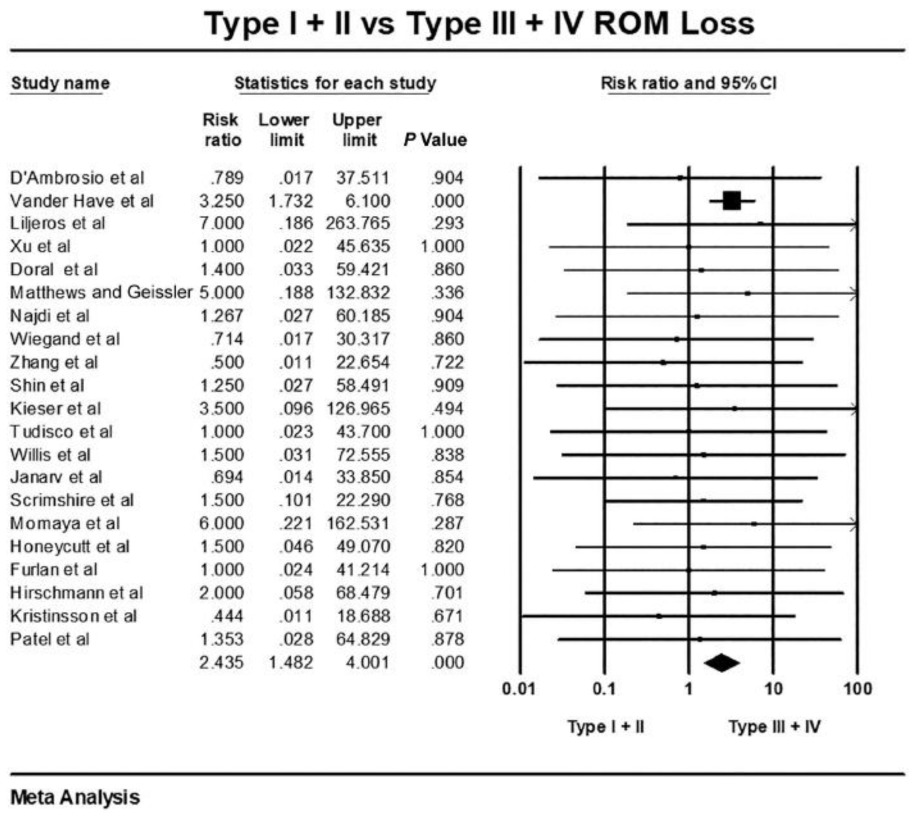

Figure 2. Forest plot for range of motion (ROM) loss between type I and II fractures and type III and IV fractures.

not identify any statistically significant differences in rates of ROM loss between the 2 groups (*P* = .911).

Five studies had sufficient data for meta-analysis comparing ROM loss between screw (n = 75) and suture (n = 69) fixation methods.[5,24,38,49,50] In total, 34 patients (45.3%) in the screw fixation group developed ROM loss, whereas 16 patients (23.2%) in the suture fixation group developed ROM loss. Meta-analysis did not identify a statistically significant difference in ROM loss between screw and suture fixation methods (*P* = .321).

Laxity

Laxity was defined as having positive anterior drawer or Lachman tests at the most recent postoperative follow-up. We found that 36 studies with a total of 1042 patients reported residual laxity rates, with laxity occurring most often in patients with type III fractures (n = 49), in patients treated by ARIF (n = 43), and in patients in whom sutures were used as the method of fixation (n = 13). Fourteen studies had sufficient data for meta-analysis comparing residual laxity rates between type I and II (n = 140) and type III and IV (n = 186) fractures.[**] A total of 24 patients (17.1%) in the type I and II fracture group and 42 patients (22.6%) in the type III and IV fracture group had residual laxity after treatment. Meta-analysis revealed no statistically significant difference in residual laxity between fracture groups (*P* = .292).

Insufficient data were available for meta-analysis comparing residual laxity between patients treated by ORIF and ARIF. Descriptive statistics are provided instead. Three studies had extractable data comparing residual laxity rates between ORIF (n = 17) and ARIF (n = 49) groups.[30,38,45] Eight patients (47.1%) in the ORIF group and 5 patients (10.2%) in the ARIF group had residual laxity after treatment.

Insufficient data were available for meta-analysis comparing residual laxity rates between screw and suture fixation methods. Two studies had extractable data comparing residual laxity between screw (n = 49) and suture (n = 58) fixation groups, with 2 patients (4.1%) in the screw fixation group and no patients in the suture fixation group having residual laxity after treatment.[5,38]

Secondary ACL Injury

Secondary ACL injury rates were determined by studies that reported on patients who had a subsequent soft tissue ACL injury after their original TSF. Fifteen studies with a total of 1476 patients reported on secondary ACL injuries, with 63 patients (4.3%) experiencing secondary

**References 8, 13, 17, 22, 23, 26-28, 33-35, 41, 52, 54.

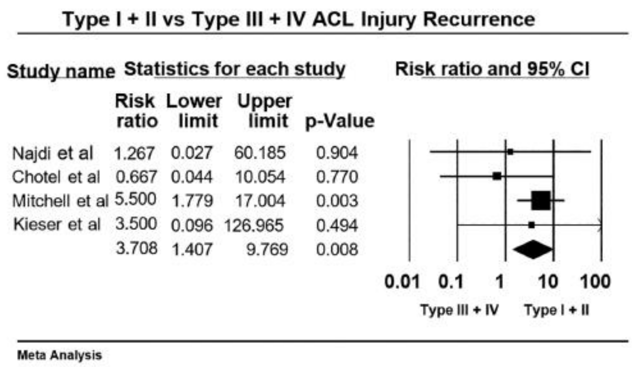

Figure 3. Forest plot for rates of secondary anterior cruciate ligament (ACL) injury between type I and II fractures and type III and IV fractures.

injuries. Four studies had sufficient data for meta-analysis comparing secondary ACL injury rates between type I and II (n = 38) and type III and IV (n = 65) fractures.[8,24,33,35] Eleven patients (28.9%) in the type I and II fracture group and 6 patients (9.2%) in the type III and IV fracture group experienced a secondary ACL injury. Meta-analysis identified a statistically significant difference in secondary injury rates between the 2 groups, with a 3.7-times higher relative risk of secondary injury in the type I and II fracture group (*P* = .008). A forest plot for this association in provided in Figure 3.

Four studies had data sufficient for meta-analysis comparing secondary ACL injury rates between ORIF (n = 73) and ARIF (n = 445) groups.[24,29,45,46] Two patients (2.7%) treated with ORIF had secondary injuries, whereas 13 patients (2.9%) in the ARIF group had secondary injuries. Meta-analysis did not identify any statistically significant differences in rates of secondary ACL injuries between the 2 groups (*P* = .633).

Insufficient data were available for meta-analysis comparing rates of secondary ACL injury between screw and suture fixation. Descriptive statistics are presented instead. Two studies had extractable data comparing the rates of secondary ACL injury between screw (n = 37) and suture (n = 40) fixation methods, with 3 patients in both groups (8.1% and 7.5%, respectively) going on to sustain a secondary ACL injury.[5,24]

Other Complications

Five studies reported on treatment complications other than those previously mentioned. Given the heterogeneity of these reported complications, meta-analysis could not be conducted. Instead, a descriptive summary of each complication is provided. Repeat TSFs were reported in 1 study, where 2 of 41 (4.9%) nonoperatively treated patients with type II fractures needed operative treatment for a second ipsilateral fracture.[48] Leg-length discrepancy, a common concern when treating skeletally immature patients, was reported in a single study, where 6 of 420 patients (1.4%) treated with ARIF had a leg-length discrepancy at final follow-up.[46] Three of 32 patients with postoperative arthrofibrosis experienced distal femoral fracture after manipulation under anesthesia.[50] A study described 1 patient with postoperative hemarthrosis requiring aspiration and another patient with a superficial wound infection that was managed nonoperatively.[29] Only 1 study directly compared the difference in hardware removal rates between screw (n = 35) and suture (n = 33) fixation, where 22 patients (62.9%) with screw fixation and 3 patients (9%) with suture fixation required a return to the operating room for symptomatic hardware removal.[5]

Patient-Reported Outcome Measures

Frequency weighted means for Lysholm, Tegner, and IKDC patient-reported outcome scores were calculated for each of our study subgroups. In total, 23 studies reported Lysholm scores, 9 studies reported Tegner scores, and 5 studies reported IKDC scores. The weighted means for each of our study groups are outlined in Table 2. Five studies (n = 168) reported on return to sport rates, with only 2 patients failing to return to their original playing level.[4,5,14,38,49] Of these 5 studies, only 2 studies (n = 136) reported on time to return to sport, with a weighted mean of 6.53 months. Of the 2 studies comparing differences in return to sport between fracture type, operative approach, and fixation method, no statistically significant differences were found between subgroups.[5,38] Only 1 study (n = 477) reported on physeal arrest rates, with 6 patients having leg-length discrepancy 5 years after arthroscopic treatment.[46]

DISCUSSION

Although uncommon, TSFs are important injuries for the physician to understand and know how to treat. Primarily affecting children and adolescent athletes at an incidence of 3 per 100,000, TSFs can result in time away from sport and lead to unwanted consequences for the young athlete.[4] Complications such as arthrofibrosis and residual ligamentous laxity have been well-documented after injury, and there is evidence to suggest that TSFs increase the risk of ACL tears later in life.[37,50] This study serves as a systematic review of the current literature on TSFs, comparing treatment approaches, outcomes, and complications associated with each injury type and surgical technique.

Multiple treatment methods using both open and arthroscopic approaches were encountered in our review.[7,11,13,21,22,34,40,57] Overall, generally good outcomes were seen among all patients, with similar patient-reported outcomes (Lysholm, Tegner, IKDC scores) across all groups. Nonunion was uncommon in our study, with only 13 patients of a possible 1638 having difficulty with fracture healing.[8,47,53] The majority of these injuries were type III and IV fractures treated nonoperatively, supporting the idea that displaced fractures should be treated operatively to ensure adequate reduction.[32] The only

TABLE 2
Weighted Means of Patient-Reported Outcome Measures[a]

	Type I and II Fractures		Type III and IV Fractures		ORIF		ARIF		Screw Fixation		Suture Fixation	
	Total Patients	Mean Score	Total Patients	Mean Score	Total Patients	Mean Score	Total Patients	Mean Score	Total Patients	Mean Score	Total Patients	Mean Score
Lysholm	128	94.8	179	94.6	37	97.4	226	93.6	50	97	85	92.2
Tegner	37	7	59	7.4	13	7.9	104	7.3	23	8.9	33	7.5
IKDC	103	89.9	112	92.1	26	87.6	198	92	0		124	90.5

[a]ARIF, arthroscopic reduction and internal fixation; IKDC, International Knee Documentation Committee; ORIF, open reduction and internal fixation.

statistically significant differences we found when comparing subgroups on meta-analysis were rates of ROM loss and secondary ACL injury between fracture groups. As discussed by previous studies, a key risk factor for ROM loss after TSF repair is time to remobilization after injury or surgery.[38,50] With increased fracture displacement, there may be more hesitancy to begin rehabilitation protocols after injury, leading to residual stiffness and ROM loss. Rehabilitation protocols have varied in regard to the method (casting vs bracing) and duration of postoperative immobilization (ranging from immediate passive ROM to 6 weeks of immobilization). Recent work has demonstrated that shorter immobilization periods result in improved ROM and earlier return to sport when compared with prolonged immobilization, provided that adequate and stable fixation is obtained.[3,38] We found no significant differences when comparing ROM loss between open and arthroscopic approaches or when comparing screw and suture fixation. Although these findings may be obscured by the small number of studies comparing this outcome, the more likely explanation is that other factors such as immobilization time and presence of concomitant injuries play a larger role in postoperative ROM.

We found significant differences when comparing rates of secondary ACL injuries between fracture types, with fracture types I and II entailing an increased risk for development of secondary ACL injury. Although statistically significant, these findings may be misleading, as Mitchell et al[33] explained that although a larger proportion of patients with type II fractures went on to have ACL injury and require reconstruction, there were no statistically significant differences in secondary ACL injuries within each fracture group. Instead, the thought is that untreated partial ACL injuries have a greater influence on the incidence of secondary injury. Partial ACL injuries that may occur at the same time as TSFs have been shown to increase the likelihood of needing ACL reconstruction, with as many as 38% of pediatric and 51% of adult partial ACL tears requiring subsequent reconstruction.[15,16,36] A proposed mechanism for this progression is damage to the intrinsic proprioceptive receptors of the ACL, as it is stretched during a TSF.[10] As these proprioceptive fibers are damaged, neuromuscular control is decreased, which negatively influences the reflexive firing of the quadriceps and hamstring muscles predisposing the knee to more ligamentous injury. This process lends itself to determining how residual laxity plays a role in the rate of secondary injury and overall outcomes. Interestingly, however, although knees with type III and IV fractures had more reported objective laxity, no statistically significant differences in residual laxity were found compared with those with type I and II fractures. The importance of residual laxity remains controversial, as several studies have reported excellent functional outcomes despite positive Lachman or anterior drawer signs.[23,25] Rather, some authors argue that positive pivot-shift tests, used as a proxy for functional laxity, are more indicative of poor outcome scores and subjective instability. Unfortunately, because of the lack of extractable data, we were not able to compare rates of functional laxity between groups via meta-analysis.

Arthrofibrosis, a feared complication after TSF, was shown to occur regardless of fracture type, operative approach, or fixation method used. Because manipulation under anesthesia entails the risk of distal femoral fracture and physeal growth arrest, it is important to identify patients who are likely to develop arthrofibrosis in order to prevent this complication.[50] Bram et al,[3] who set out to identify the injury and treatment characteristics that increase the risk for arthrofibrosis, found 4 risk factors: traumatic injury, concomitant ACL injury, younger age, and postoperative cast immobilization. These risk factors are related to one another in that a traumatic injury is likely to result in a displaced or comminuted fracture pattern (type III and type IV, respectively) that is more likely to entail concomitant ACL injuries and require longer operation and immobilization periods. Concomitant ACL injuries have been previously linked to higher-grade fractures, with a 7-times higher risk of arthrofibrosis with a confirmed ACL injury. Shimberg et al[46] reported that earlier initiation of ROM was associated with a decreased risk of arthrofibrosis. Those authors went on to retrospectively analyze a cohort of 40 knees undergoing surgical treatment for TSFs and found a 12-times higher likelihood of developing arthrofibrosis when ROM exercises were initiated 4 weeks after surgery ($P = .029$).[46] Although we did not analyze time to ROM rehabilitation in the current study, it is understandable that a prolonged immobilization period increases the risk of arthrofibrosis, with several studies providing significant evidence to support early mobilization (<4 weeks from injury) in TSF patients regardless of injury characteristics. Neither operative approach nor fixation method showed any significant difference in arthrofibrosis rates, as is evident from previous studies comparing these groups directly.[5,14,51] Edmonds et al[14] showed that arthrofibrosis was more likely to occur in patients who underwent surgical management, implying that surgery itself rather than the injury severity or mechanism is to blame for arthrofibrosis and suggesting that patients with <5 mm of displacement be treated nonoperatively to avoid that risk. Biomechanical studies have shown that sutures have higher peak failure and more consistent fixation with repetitive cycling compared with cannulated screws. Further, screw fixation inevitably leads to reoperation for hardware removal, something that patients and their families should be aware of when discussing treatment options.[1,2,5]

Concomitant soft tissue injuries were relatively common in the studies that we reviewed, given that 31.9% of patients within the 20 reporting studies had an additional soft tissue injury affecting the menisci, ACL, or collateral ligaments. With up to 69% of TSFs having associated soft tissue injury, it is important to properly assess and treat these additional injuries to avoid negative consequences and delayed return to activity.[39] Our study found that concomitant injuries were more commonly associated with type I and II fractures and those treated arthroscopically. However, Shimberg et al[46] demonstrated that this association is likely because of increased identification with advanced imaging and arthroscopy itself rather than a true disparity in incidence between groups. The incidence of these associated injuries is not trivial, as soft tissue entrapment may impede adequate reduction of the fracture and lead to malunion or nonunion.[14,35,46,47] It is therefore imperative to identify these injuries and treat them accordingly to prevent complications that would result in deformity or increased time away from activity. To evaluate injuries associated with TSFs, advanced imaging such as magnetic resonance imaging may be used to plan treatment and set expectations regarding recovery time.[44]

Our study is limited by the fact that the studies we evaluated had a relatively low level of evidence. Evidence level 4 studies outnumbered level 3 studies by $>$3-fold, highlighting the need for larger comparative studies. Additionally, in our search we found multiple methods of fixation other than traditional screws or sutures. Most of these studies were case series, which could not be included in the meta-analysis, and it was difficult to draw any conclusions regarding their utility in the treatment of these injuries. Another limitation is the inability to directly review the radiographic and advanced imaging findings in the included studies. As such, we are unable to comment on the specific details of complications found on imaging beyond what was described in the included studies. Finally, there was no standardized method of reporting patient-reported outcomes, and the studies used different scoring systems to assess patient function and satisfaction after treatment. Although the outcome scores that were reported were good or excellent, larger studies using a uniform system of collecting patient-reported outcomes as well as return to sport should be conducted to obtain a better understanding of how each treatment option affects patients in the long term.

This is the most recent study focusing on the current methods used to treat TSFs in children and adolescent patients. This has been a topic of increased research, as there is a vested clinical interest in treating these injuries and optimizing outcomes for these patients. Despite the variety of treatment methods, overall good outcomes can be expected for all patients regardless of fracture severity or treatment used. Significantly increased rates of ROM loss and secondary ACL injury were seen with type III and IV and type I and II fracture classifications, respectively, although there may be confounding factors that influence these outcomes more than the injuries themselves. Current evidence points to the importance of early mobilization after treatment to avoid complications such as ROM loss and arthrofibrosis. Additionally, advanced imaging provides a more complete picture regarding associated injuries and aids in surgical planning, as the incidence of concomitant injuries associated with TSF is very high. No current evidence is available to recommend one treatment method over another, but diagnosing and treating concomitant injuries, obtaining stable fixation, and starting early ROM seem to improve outcomes.

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