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Tibial spine fractures: state of the art

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ABSTRACT

Tibial spine fractures (TSF) are avulsion fractures at the site where the anterior cruciate ligament (ACL) inserts onto the tibial eminence. TSFs typically affect children and adolescents aged 8 to 14 years. The incidence of these fractures has been reported to be approximately 3 per 100,000 per year, but the rising involvement of pediatric patients in sporting activities is increasing the number of these injuries. TSFs are historically classified on plain radiographs according to the Meyers and McKeever (MM) classification system, which was introduced in 1959, but the renewed interest in these fractures and the increasing use of MRI led to the recent development of a new classification system. A reliable grading protocol for these lesions is paramount to guide orthopedic surgeons in determining the correct treatment for young patients and athletes. TSFs can be addressed conservatively in the case of nondisplaced or reduced fractures or surgically in the case of displaced fractures. Different surgical approaches and, specifically, arthroscopic techniques have been described in recent years to ensure stable fixation while limiting the risk of complications. The most common complications associated with TSF are arthrofibrosis, residual laxity, fracture nonunion or malunion, and tibial physis growth arrest. We speculate that advances in diagnostic imaging and classifications, combined with greater knowledge of treatment options, outcomes, and surgical techniques, will likely reduce the occurrence of these complications in pediatric and adolescent patients and athletes, allowing them a timely return to sports and everyday activities.

EPIDEMIOLOGY AND MECHANISM OF INJURY
Tibial spine fractures (TSFs), also known as tibial eminence or intercondylar eminence fractures, are defined as bony or chondral avulsions of the tibial plateau at the insertion point of the anterior cruciate ligament (ACL) [1]. Although TSFs are rare in the general population, with an incidence estimated at approximately 3 per 100,000 per year, the occurrence is rising due to a dramatic increase in sports activity in the pediatric and adolescent population [2, 3]. Indeed, these injuries are most common in skeletally immature patients between 8 and 14 years old and represent up to 2-5% of knee lesions in children and adolescents evaluated for a knee joint effusion [4, 5, 6]. In a recent large multicenter study, DeFrancesco et al. concluded that the incidence of pediatric TSFs is higher for males compared to females, although this difference only manifests after age 10; Moreover, the age at which the highest number of these fractures occur is higher for males (13-14 years) than females (11-12 years) [7]. Epidemiologic studies highlighted that the higher occurrence of TSFs is related to organized sports; other common causes are bicycle accidents, motor vehicle collisions, and outdoor sports (including skiing and skateboarding) [8, 9]. The classic mechanisms of injury are a forced knee flexion with simultaneous tibial external rotation, an uncontrolled tibial external rotation combined with a planted foot, or hyperextension of the knee with a valgus or rotational force [10, 11]. The mechanisms are similar to those that cause ACL tears in adults, in which the overload tensile force applied to the ligament results in an intrasubstance lesion [12]. In children, however, avulsion fractures occur more easily because the strength of the incompletely ossified tibial plateau is inferior to that of the ACL [13, 14]. This is in line with the finding that the ACL volume reaches adult values before the growth spurt, which is thought to be a way of protecting the pediatric knee from ACL tears during this period [15]. It also aligns with the epidemiologic findings that TSFs usually occur at ages typically preceding skeletal maturity, with differences between males and females [7].
Tibial spine fractures are most commonly classified according to the Meyers and McKeever (MM) classification system based on conventional radiographic imaging [16]. In the MM system, created in 1959, TSFs are classified as type I, type II, or type III. Zaricznyj later modified this classification system by adding type IV as a category in 1977 [17]. Type I fractures are the simplest, nondisplaced fractures of the tibial medial eminence. Type II fractures are defined as fractures in which the most anterior portion of the tibial spine is avulsed superiorly while the posterior part remains attached to the tibial plateau in a hinged pattern. Type III fractures are completely displaced fragments entirely separated from the fracture bed. Ultimately, type IV fractures are displaced fractures with the comminution of the fragment.

Recently, MRI has become a common tool for assessing TSFs since it immediately identifies associated soft tissue injuries such as meniscal tears or osteochondral injuries. Moreover, MRI can be used to analyze fracture fragment size, pattern, and displacement. Furthermore, MRI is fundamental in evaluating the integrity of the ACL since concomitant ACL injury and TSF avulsion may occur with a rate reported up to 12-19%, progressively increasing in older patients [18].

The increased use of MRI in recent years led to the development of a new classification system by Green et al. [19]. This new algorithm defines grade I fractures as non- or minimally-displaced fractures with ≤2 millimeters (mm) of displacement. Grade II fractures are posterior hinged fractures with >2 mm of displacement of the anterior aspect and ≤2 mm of displacement of the posterior aspect of the fragment. Grade III fractures are fractures with either >2 mm of
displacement of the posterior part of the fragment, meniscal or intra-meniscal ligament entrapment, or extension of the fracture to the weight-bearing surface of the medial or lateral tibial plateau.

This MRI-based classification system provides specific, quantitative criteria for classifying fractures according to fragment displacement and tissue entrapment, assisting clinicians with subsequent treatment decisions. Green et al. described how the MRI-based system changed the classification grade in 32.5% of cases compared to the MM system, consequently modifying the treatment algorithm. A reliable classification system and the evaluation of associated injuries are fundamental tools for the appropriate management of TSFs.

ASSOCIATED INJURIES

Associated injuries of TSFs include meniscal entrapment, meniscal tears, concomitant ACL midsubstance lesions, chondral lesions, bone bruises, and tibial plateau fractures [18, 20, 21]. Meniscal injuries in TSF patients are estimated from 32 to 59%, which is directly proportional to the complexity of the fracture type, from type I to type III [22]. Identifying soft tissue injuries is paramount, especially when the damaged tissue is interposed between the avulsed bony fragment and its bed, preventing appropriate closed reduction and constituting itself as an indication for surgical treatment [23]. Kocher et al. identified entrapment of the anterior horn of the medial meniscus, intermeniscal ligament, or anterior horn of the lateral meniscus in 26% of type II fractures and up to 65% of type III fractures [9]. Feucht et al.’s case series of 54 patients found that 37% of all TSFs were accompanied by meniscal injuries, 90% involving the lateral meniscus and 10% the medial meniscus [24]. A longitudinal tear of the posterior horn of the lateral meniscus was the most frequently observed lesion, followed by anterior root detachment of the lateral meniscus. The authors pointed out how this latter specific injury pattern is essential to recognize.
as it represents a functional meniscectomy, and operative reattachment of the meniscal root is recommended. Mayo et al. conducted an observational cohort study in 2019, concluding that nearly 20% of patients with TSF sustained a concomitant ACL injury, ranging from ligament edema/hyperemia to ACL laxity or tears [25]. Of the 129 patients evaluated, 25 ACL injuries were identified: 1 ACL lesion in 27 subjects with type I TSFs, 16 of 59 with type II fractures, and 8 in 43 type III tibial spine fractures. Of the 25 patients with an ACL injury at the time of surgery, 5 (20%) patients later required ACL reconstruction. Residual laxity up to 5 mm has been frequently reported in the affected knee, with a prevalence of a positive Lachman test ranging from 64% to 87% after treatment; however, only a minority of patients reported subjective instability, supposedly because of the integrity of the nerve fibers along the ACL and neuromuscular feedback [22]. In a cohort of 58 patients with TSFs aged 5-18, Mitchell et al. reported an overall proportion of 7% for cartilage injuries and 4% of subjects diagnosed with an intra-articular loose body [21]. Due to the prevalence of associated injuries that need to be repaired, it appears clear that an MRI-based assessment is helpful in many cases for surgical decision-making of TSFs.

TREATMENT

Early diagnosis and treatment of TSFs are fundamental to achieving full recovery and satisfactory outcomes [26]. Most authors recommend nonoperative treatment with immobilization for non-displaced TSFs and minimally displaced TSFs that achieve successful closed reduction [3, 27]. The ideal position of immobilization in a cast is not uniquely defined, specifically whether the patient’s knee should be held in full extension or 20° of flexion. Authors who prefer full extension believe that the fragment is reduced through direct compression by the lateral femoral condyle [3, 19, 28]. However, other researchers argue that 20° of knee flexion avoids tensile forces
of the ACL [28, 29]. Regardless of the immobilization position, authors agree upon the necessity of radiographic controls to monitor the correct position of the fragment.

The treatment for type II fractures is not standardized. If the fragment is minimally hinged without soft tissue meniscal entrapment, an attempt at closed reduction can be performed. If the closed reduction is successful, the knee is immobilized in a cast or splint for 4 to 6 weeks; interval follow-up imaging is mandatory to monitor re-displacement in the initial weeks after diagnosis [30, 31]. If inadequate reduction or re-displacement occurs, as well as in case of initial fracture displacement > 5mm or associated injuries to repair are present, surgical reduction and fixation should be considered. [33, 34].

Type III TSFs typically necessitate surgical treatment [22, 35, 36]. Nonoperative treatment of these cases results in more nonunions, greater residual laxity, and greater loss of ROM [31]. Surgical treatment can be either open or arthroscopic. A recent large multicenter study demonstrated successful treatment outcomes following both arthroscopic reduction internal fixation (ARIF) and open reduction internal fixation (ORIF) for pediatric TSFs with no significant differences in treatment outcomes or nonunion between the groups while also highlighting that a higher number of concomitant injuries is identified in patients treated with ARIF [37]. We prefer arthroscopic treatment due to smaller incisions, less soft tissue damage, better pain control, a shorter period of hospitalization, and early range of motion [22, 33, 38]. Moreover, arthroscopic treatment can efficiently address associated soft tissue injuries such as meniscal tears and entrapment [22].

The success of surgically treating tibial eminence fractures depends on stable fixation, prompt treatment, and earlier mobilization. However, surgery aims to simultaneously treat
associated soft tissue injuries, such as meniscal tears, meniscal and inter-meniscal ligament entrapment, ACL intrasubstance tears, and removal of loose fragments in the joint [33, 35].

Many fixation methods have been described for treating these injuries, such as sutures, suture anchors, suture bridge and cortical button constructs, adjustable buttons, screws (cannulated or solid, metal or absorbable, traditional or headless), Kirschner wires, metal wires, meniscus arrows device, absorbable nails, and staples [22, 33, 39, 40]. Evidence shows reliable fixation methods need to sustain a cyclic load of at least 300–450 newtons (N) [41]. By far, screws and sutures are the most commonly used implants.

*Screw*

Arthroscopically assisted cannulated screw fixation for tibial eminence fractures is a reliable and well-described treatment that shows satisfactory clinical and radiological outcomes [22, 42]. Najdi et al. reported successful outcomes with screw fixation [43]. The screw technique is relatively simple, stable, low cost, and allows early mobilization and ambulation. It is generally the preferred technique in the case of larger bony fragments. Depending on the bony avulsion characteristics, single or multiple screws can be used and, if necessary, in association with washers. The limitations of screws are related to their association with possible anterior impingement and consequent damage to the articular surface, leading to a high rate of implant removal [22, 33]. Callanan et al. reported that up to 66% of patients treated with screws had a second surgery, mainly for hardware removal [44]. Gigante et al. reported excellent functional recovery with absorbable magnesium screws in intercondylar TSFs, avoiding the necessity of late metal removal [45].
Sutures

Suture fixation is the technique of choice in small bony or cartilage avulsions or significant comminution of the fragments. High-strength sutures are secured at the base of the ACL and then passed through small tunnels to be tied over the anterior cortex of the tibia; another option is to secure the sutures in the tibial plateau with anchors. Different suture techniques have been described, using both absorbable and nonabsorbable sutures. Verdano et al. reported good results in 21 patients with complete union of the avulsed fragment at 2 years of follow-up without complications using absorbable sutures [46]. However, sutures can be technically challenging, and may lead to an increased risk of malreduction of the anterior portion of the fragment [43]. Arthroscopic reinsertion using adjustable button fixation has been recently described with promising results [47].

Screw vs. Sutures

Coyle et al. reviewed 36 published papers constituting 788 pediatric knees, concluding that there is insufficient evidence to support screws or sutures over the other as the definitive fixation of choice [1]. Another recent comparative study in 2019 demonstrated the largely equivalent outcomes between the suture and the screw fixation group in a retrospective cohort of patients [44]. Previous biomechanical studies proved that the strength of suture fixation is higher than that obtained with screws [48, 49], and the same conclusion was reported in a more recent cadaveric comparison [50]. However, significant in vivo outcome differences have not been reported. Therefore, when approaching a TSF, surgeons should acknowledge the advantages and
disadvantages of both techniques and decide on a case-by-case basis, with the final aim of achieving the best secure fixation and early mobilization.

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181 **COMPPLICATIONS**

182 Complications associated with nonoperative and operative treatment of TSFs have been described, including arthrofibrosis, residual knee laxity, nonunion, malunion, and growth arrest [22]. Regarding nonoperative treatment, a recent systematic review demonstrated that persistent objective or subjective laxity (11.1%) and joint stiffness (19.4%) are the most common complications, with a higher prevalence in more severe injuries [51].

187 Postoperative arthrofibrosis remains the most common complication for surgically treated TSFs, with reported rates ranging from 10% to 29% [30, 52, 53, 54, 55]. In investigating risk factors of this abnormal intra-articular collagen deposition, new evidence reported higher risk in patients with concomitant ACL tears, not a sport-related mechanism of injury, postoperative cast immobilization, and younger than 10 years old [52]. Longer surgical times have also been associated with a higher possibility of arthrofibrosis [30, 54]. Early mobilization is crucial to prevent arthrofibrosis stiffness; compared with patients who start ROM exercises within four weeks from surgery, those who start rehabilitation later are 12 times more likely to develop arthrofibrosis [56]. Postoperative immobilization in a cast should be avoided in favor of a hinged brace.

194 Residual laxity is typically the result of either damage to the ACL during the initial injury, a not anatomical bony/cartilage avulsion reduction, or the occurrence of a new injury in patients with ACL tear risk factors [22, 57]. Some degree of ACL instability of the knee has been described
in up to 70% of nonoperative displaced TSFs and 14% of surgical fractures by assessing Lachman and/or anterior drawer, pivot shift, and KT-1000 testing [36, 58]. A recent multicenter study concluded that the incidence of ACL tears following surgically treated pediatric TSFs was 21.7% in patients with at least 2 years of follow-up (median = 36.4 months). In this cohort of 385 tibial eminence fractures, the authors found a statistically significant association of concomitant ACL tears with higher-grade tibial spine avulsions (Myers and McKeever type III and IV) [59].

Nonunion of TSFs in children is a rare complication, with only few articles reporting such cases in the literature [60, 61]. The natural history of this event is persistent knee pain, a partial decrease of knee extension, and anterior knee instability, but asymptomatic cases have been described [62]. It is believed that the rare cases of nonunions may be caused by insufficient reduction, fixation, or soft tissue entrapment [1].

Growth arrest and resulting deformity or leg length discrepancy have been reported following transphyseal screw fixation [63]. More recently, a single case of ipsilateral limb overgrowth after tibial spine suture fixation has been described [64]. These complications, though rare, required additional surgery and could be avoided using physeal-sparing techniques. Therefore, preventing physeal damage is paramount in skeletally immature patients.

**REHABILITATION**

Early motion is paramount to avoid joint stiffness or arthrofibrosis in severe cases. Following stable fracture fixation, experts recommend immediate protected motion in a hinged brace; if necessary, a continuous passive motion device can be used [32]. In the first four weeks post-surgery, we initiate a physical therapy program for gentle ROM from 0-90° and muscle
strengthening. Four weeks after surgery, the patient can progress to weight-bearing as tolerated with the brace set to 0-50°, discontinuing crutches when gait is no longer associated with pain. Isometric exercises, active knee flexion with passive extension, and concentric and eccentric hamstring exercises are indicated [65]. More than 12 weeks after surgery, endurance activities are progressively increased to restore strength, function, and agility of the lower extremity. Initiation into an ACL injury prevention program is strongly recommended before returning to sports, which is typically allowed between four and six months after surgery following isokinetic and functional test assessments [32].

FUTURE PERSPECTIVES

Tibial spines are important structures that, together with the ACL, play a critical role in knee biomechanics. Proper treatment of TSFs is necessary to improve clinical outcomes and avoid progression to later complications. Most of the present evidence regarding the treatment of TSFs is based on small-number series of cases. New prospective, large-scale randomized control trials are needed to determine the superiority of one fixation method over the other. Given the relatively rare nature of these types of fractures, multicenter collaboration is fundamental for well-powered analyses [66].

The recent literature on pediatric patients has proven that simultaneous lateral extra-articular tenodesis augmentation diminishes the failure rate in patients treated with ACL reconstruction [67, 68]. Nevertheless, it is unknown whether performing a lateral extra-articular surgical procedure could benefit the outcomes in patients undergoing surgery for TSFs, especially in those with high risk of residual knee instability. Addressing the anterolateral complex provides a
secondary restraint to tibial translation and internal rotation. Future studies are required to
determine if concomitant anterolateral tenodesis is beneficial in the treatment of TSFs.
1. Key articles


2. Validated classifications

- Green et al. (2019), MRI-based.
3. Key issues of patient selection

- TSFs typically affect children and adolescents aged 8 to 14 years.
- TSFs represent up to 2-5% of knee lesions in children and adolescents evaluated for knee joint effusion.
- The higher occurrence of TSFs is related to organized sport, bicycle accidents, motor vehicle collisions, and outdoor sports.
- The mechanisms of injury are similar to those that cause ACL tears; however, the strength of the incompletely ossified tibial plateau in children and adolescents is inferior to that of the ACL and avulsion fractures more easily occur.

4. Essential surgical procedures

- Screws
  - Suitable for small or comminuted fragments
  - Fixed with anchors or through tibial tunnels
  - Reproducible technique
  - Caution must be taken not to damage the physis

- Sutures
5. Tips & tricks

- MRI imaging is the gold standard to evaluate TSFs characteristics and associated soft tissue injuries.
- The new MRI-based classification system is paramount for the decision making of TSFs treatment and surgical planning.
- The success of surgically treating tibial eminence fractures depends on stable fixation, early treatment, and early mobilization.
- Evaluation of ACL integrity is essentials to minimize the risk of residual laxity.
- Screws and sutures are the most commonly used techniques.
- Debride the fracture base with a shaver or curettes is crucial to get rid of any bony debris. Having contact between the fragment and its bed is essential to ensure healing.
- For the meniscal entrapment, a trick is to use an outside-in suture to pull the structure out of the way. This suture is useful to retract the meniscus anteriorly.
- When performing cannulated screw fixation, a superior medial portal is created with the knee bend at 80-90°, and two guidewires are placed across the fracture.
- Post-surgical early mobilization is crucial to prevent arthrofibrosis stiffness. Avoid cast immobilization.
6. Major pitfalls of classification and treatment

- The use of Meyers and McKeever's classification system fails in taking into account soft tissue injuries; these injuries can deeply affect the successful management of the patient.

- The presence of meniscal entrapment in type II MM fractures can lead to unsuccessful attempts of closed fragment reduction.

- The use of RX imaging only can result in misdiagnosis of non-displaced fractures, meniscal injuries and ligamental tears.

- If surgical treatment is pursued, post-operative immobilization is strongly associated with knee arthrofibrosis. Other risk factors are younger age, traumatic injuries not resulting from athletics, and concomitant ACL tears.
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Grade 1: Non- or minimally displaced fractures (≤ 2 mm of displacement).

Grade 2: Posterior-hinged fractures (> 2 mm displacement of the anterior aspect of the fracture and ≤ 2 mm displacement of the posterior aspect of the fragment).

Grade 3: Meets any of the following criteria:
1. Displaced fracture (> 2 mm of displacement of the posterior aspect of the fragment).
2. Fracture that results in meniscal or intra-meniscal ligament entrapment (where the meniscus or intra-meniscal ligament is inferior to a fracture fragment).
3. Fracture extending to the articular surface of the medial or lateral tibial plateau with > 2 mm of displacement.
Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Daniel W. Green reports a relationship with Arthrex Inc that includes: consulting or advisory. Daniel W. Green has patent with royalties paid to Arthrex.