

Management of Tibial Spine Avulsion Fractures: From MRI-Based Classification to Arthroscopic Repair

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Abstract

Tibial spine fractures (TSFs) are avulsion injuries of the anterior cruciate ligament (ACL) attachment, predominantly affecting the pediatric population between 8 and 14 years of age. This article provides a comprehensive review of TSF management, highlighting the shift from traditional radiographic classification systems, to modern MRI-based systems. Preoperative MRI is emphasized as crucial for identifying associated intra-articular injuries, including meniscal entrapment and ACL lesions, which occur in a significant percentage of cases. While conservative treatment remains the standard for non-displaced fractures, surgical intervention is indicated for displaced Type II and III injuries. We describe an all-arthroscopic trans osseous suture-bridge technique utilized at the C. Poma Hospital in Mantua. This approach employs high-strength sutures secured over a cortical bridge, providing stable anatomical reduction without the need for intra-articular hardware. Clinical outcomes demonstrate that this technique is reliable, cost-effective, and reproducible, allowing for early mobilization and a full return to pre-injury sports activities while minimizing risks in skeletally immature patients.

Keywords

Tibial Spine Avulsion Fractures; Arthroscopic Repair; Anterior cruciate ligament; Intra-articular injuries.

Introduction

Tibial spine fractures (TSFs), also referred to as intercondylar eminence fractures, are avulsion injuries occurring at the tibial attachment of the anterior cruciate ligament (ACL) [1]. Although relatively rare, with an estimated annual incidence of approximately three cases per 100,000 individuals, their frequency has increased in recent years, likely reflecting greater participation in organized sports and evolving training patterns among pediatric patients [2]. TSFs predominantly affect skeletally immature individuals between 8 and 14 years of age and occur more commonly in males [3-5]. The injury mechanism typically involves forced knee trauma associated with external rotation of the tibia while the foot remains fixed to the ground, closely resembling the mechanism responsible for ACL injuries in adults. In the adult population, similar tensile forces usually result in mid-substance ligament rupture [6], whereas in children they more often lead to avulsion fractures, as the partially ossified tibial spine represents the weaker biomechanical structure compared with the ACL [7]. Less frequently, TSFs may arise from hyperextension combined with valgus stress, rotational loading, or direct impact trauma [8,9]. Athletic activities such as soccer and basketball are commonly implicated, although injuries related to bicycle or skateboard falls and skiing accidents are also frequently reported.

Classification

Tibial spine fractures have traditionally been classified according to the Meyers and McKeever (MM) system [Figure 1], which is based on findings from conventional radiographs [10]. The original classification described three fracture types according to the degree of fragment displacement, with a fourth type subsequently introduced by Zaricznyj [11]. Type I lesions are nondisplaced fractures of the tibial eminence. Type II injuries involve anterior elevation of the fragment while the posterior portion remains attached to the tibial plateau, creating a hinged configuration. Type III fractures are characterized by complete displacement of the fragment, whereas Type IV fractures are both displaced and comminuted.

These injuries are often associated with concomitant meniscal or osteochondral lesions. Consequently, preoperative magnetic resonance imaging (MRI) has become increasingly important for detecting associated injuries, evaluating fragment size and orientation, and identifying possible intrasubstance ACL damage.

With the broader adoption of MRI in preoperative assessment, Green et al. proposed a modified classification system [Figure 2] based on MRI findings [12]. In this system, grade I fractures are defined as nondisplaced or minimally displaced lesions (less than 2 mm). Grade II fractures consist of posterior-hinged injuries with anterior displacement greater than 2 mm and posterior displacement of 2 mm or less. Grade III fractures include those with posterior fragment displacement exceeding 2 mm, meniscal entrapment, or fracture extension into the weight-bearing portion of the tibial plateau. Compared with the traditional MM classification, this MRI-based system modifies both fracture grading and treatment recommendations in approximately 32.5% of cases.

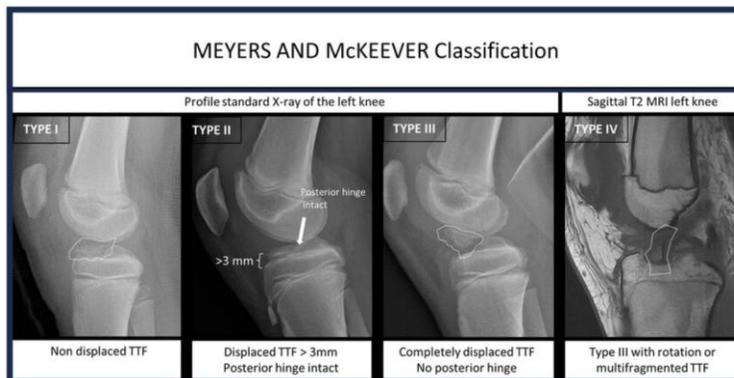


Figure 1: Meyers and McKeever classification system grades tibial spine fractures as type i (non-displaced, <3 mm), type ii (hinged, >3 mm), type iii (completely displaced without rotation of the fragment) and type iv (completely displaced with rotation) [10].

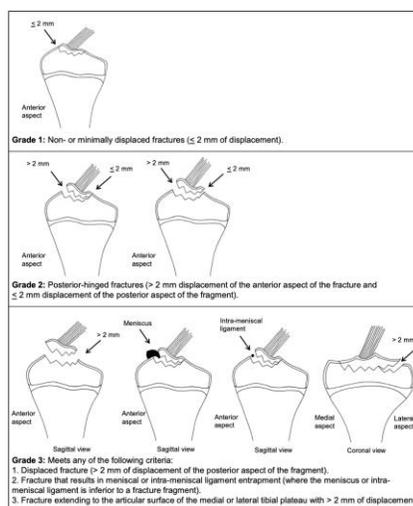


Figure 2: MRI-based system for classifying TSFs described by Green et al [12].

Associated Lesions

Tibial spine fractures are frequently associated with concomitant intra-articular injuries, including meniscal tears, intrasubstance ACL lesions, chondral damage, bone contusions, and fractures of the tibial plateau [13,14]. Meniscal involvement has been reported in 32% to 59% of cases, with incidence increasing in parallel with fracture severity from type I to type III lesions [15]. Precise identification of soft-tissue pathology is crucial, particularly when interposed structures become trapped between the avulsed fragment and its tibial bed, as this may prevent successful closed reduction and necessitate surgical management [16].

Kocher et al. described entrapment of the anterior horn of the medial meniscus, the intermeniscal ligament, or the anterior horn of the lateral meniscus in 26% of type II fractures and in up to 65% of type III injuries [17]. Similarly, Feucht et al., in a series of 54 patients, reported associated meniscal lesions in 37% of TSFs, most commonly involving the lateral meniscus [18]. Longitudinal tears of the posterior horn

of the lateral meniscus represented the predominant pattern, followed by detachment of the anterior root.

Concomitant ACL injuries have also been documented. In a 2019 study, Mayo et al. identified ACL lesions in 20% of patients with TSFs [19]. Among 129 patients analyzed, 25 ACL injuries were observed, including one in 27 type I fractures, 16 in 59 type II fractures, and eight in 43 type III fractures; five patients (20%) subsequently required ACL reconstruction. Residual anterior knee laxity of up to 5 mm was reported, with postoperative Lachman test positivity ranging from 64% to 87%. Despite these findings, subjective instability remained uncommon, likely owing to preserved ACL mechanoreceptor function and maintained neuromuscular feedback [15].

Given the high prevalence of associated injuries that may require concomitant treatment, preoperative MRI evaluation is recommended to optimize surgical planning in patients with TSFs.

Treatment

Early diagnosis and appropriate management of tibial spine avulsion fractures are essential to achieve optimal clinical outcomes [20]. Conservative treatment, consisting of immobilization in slight knee flexion or full extension, is generally recommended for type I fractures, with periodic radiographic evaluation to confirm maintenance of fragment stability [21].

The optimal management of type II fractures remains controversial. In cases of minimal displacement without associated meniscal injury, closed reduction may be attempted. When satisfactory reduction is achieved, immobilization using a cast or hinged knee brace for four to six weeks is recommended, with serial radiographic monitoring to detect possible re-displacement [22,23]. Surgical treatment is indicated when reduction is incomplete, re-displacement occurs, initial displacement exceeds 5 mm, or concomitant lesions require operative repair [24,25].

Type III fractures typically require surgical fixation because conservative management is associated with a high risk of treatment failure [15,26,27]. Fixation can be performed through either open or arthroscopic techniques. A recent multicenter study reported comparable clinical outcomes and nonunion rates between arthroscopically assisted reduction and internal fixation (ARIF) and open reduction and internal fixation (ORIF) in pediatric TSFs; however, ARIF enabled intraoperative identification of a greater number of associated injuries [28].

At our institution, arthroscopic fixation is the preferred approach, as it allows smaller incisions, reduced soft-tissue disruption, improved postoperative pain control, and earlier recovery of range of motion [15,24,29]. Furthermore, arthroscopy facilitates the detection and treatment of concomitant intra-articular pathology, including meniscal tears and loose bodies [15].

Multiple fixation strategies have been described, such as trans osseous sutures, suture anchors, trans osseous tunnels with cortical button fixation, cannulated or solid screws (metallic or bioabsorbable, headed or headless), and Kirschner wires [15,24,30,31]. For larger fragments, arthroscopically assisted fixation using cannulated screws has proven reliable and reproducible, providing satisfactory clinical and radiographic outcomes [15,32]. Potential limitations include anterior impingement and cartilage injury,

occasionally requiring hardware removal, whereas bioabsorbable screws may eliminate the need for secondary surgery.

In our Sports Trauma Unit at C. Poma Hospital, Mantua, Italy, an all-arthroscopic trans osseous suture-bridge technique is routinely performed using high-strength sutures passed through two tibial tunnels. Patients are positioned supine with lateral support and a pneumatic thigh tourniquet. Standard anteromedial and anterolateral portals are established to allow joint inspection, identification of the avulsed fragment, evaluation of ACL integrity, and assessment of associated injuries. After preparation of the fragment and its tibial bed (figure 3a), anatomical reduction is achieved using an arthroscopic probe. A suture-passing device loaded with No. 1 PDS (Ethicon, Somerville, NJ, USA) is used to shuttle high-strength sutures through the fibrous portion of the ACL near its tibial footprint. The sutures are retrieved through 2.5-mm tibial tunnels drilled at 45° with an ACL tibial guide (figure 3b) and secured over a cortical bridge under arthroscopic visualization, confirming stable reduction and excluding notch impingement.



Figure 3a: TSFs identification and preparation of the fragment and its tibial bed.

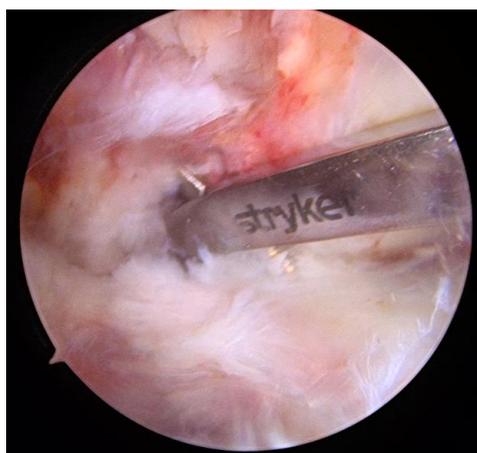


Figure 3b: tibial tunnels drilled at 45° with an ACL tibial guide under arthroscopic visualization.

Postoperatively, the knee is immobilized in full extension for the first two weeks, while quadriceps isometric exercises are initiated immediately. Controlled joint mobilization is introduced after two weeks. Partial weight-bearing (30%) is permitted until the fourth postoperative week, progressing to 50% thereafter, with full weight-bearing allowed at six weeks following radiographic confirmation of fracture healing.

Beginning in the second postoperative month, patients start functional strengthening exercises following rehabilitation principles similar to those used after anterior cruciate ligament reconstruction. Return to sports activity is determined based on clinical evaluation and isokinetic muscle testing.

At one-year follow-up, all patients had resumed pre-injury sports participation without functional limitations. No radiographic evidence of fragment displacement or clinical signs of ACL laxity were observed, and serial radiographs were obtained to monitor tibial growth.

Discussion

Surgical management of tibial spine avulsion fractures can be performed using either open or arthroscopic fixation techniques. Open procedures may be limited by restricted visualization and reduced ability to adequately address associated meniscal or chondral injuries. Current evidence does not clearly demonstrate the superiority of arthroscopic techniques over open approaches in terms of fracture healing, range-of-motion deficits, or residual laxity [33].

Nevertheless, arthroscopic fixation is favored at our institution because of its minimally invasive nature, improved visualization of intra-articular structures, and potential for faster functional recovery. Numerous arthroscopic fixation methods have been described in the literature; however, no definitive gold standard has yet been established [33]. Biomechanical investigations have suggested that suture-bridge constructs provide greater resistance to displacement compared with single- or double-screw fixation systems [34].

The technique used in our series employs high-strength sutures passed through two trans osseous tibial tunnels and secured over a cortical bridge, thereby avoiding intra-articular hardware and prominent screws that may irritate the immature knee. Sutures are tensioned with the knee in full extension to minimize the risk of postoperative extension deficit, and tibial tunnels are created with at least a 1-cm bone bridge to reduce the likelihood of iatrogenic fracture. In cases involving comminuted fragments, a more cautious postoperative mobilization protocol is adopted.

Overall, this technique is reproducible and cost-effective, while potentially reducing complications related to intra-articular fixation. Based on our experience, it represents a reliable arthroscopic treatment option for tibial spine fractures.

Future Perspectives

Current evidence regarding the management of tibial spine fractures is largely based on small case series and retrospective studies. Well-designed prospective randomized controlled trials are needed to better define the optimal fixation strategy. Owing to the relative rarity of these injuries, multicenter

collaboration will be essential to achieve sufficiently powered studies and generate more robust clinical evidence [35].

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