REVIEW

Tibial tubercle avulsion fractures in children

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Purpose of review

To summarize and discuss the fundamentals of pediatric tibial tubercle avulsion fractures (TTAFs) including preferred imaging modalities, systems for fracture classification, frequently associated injuries, treatment options, outcomes, and common complications.

Recent findings

Although TTAFs amount to fewer than 1% of all physeal injuries in children, the incidence is increasing, likely because of greater participation in high-level athletics.

Summary

TTAFs tend to occur in adolescents nearing skeletal maturity who engage in sports with repetitive jumping. The most popular classification system was proposed by Ogden, which defines five fracture types based on the fracture pattern and extent of fragment displacement. Treatment can be nonsurgical or surgical, and indications depend on fracture type. Most fractures are surgical candidates and can be repaired with open reduction and internal fixation (ORIF) or arthroscopy. Arthroscopic approaches can reveal associated soft tissue injuries, such as meniscal tears, and confirm articular reduction. The most common postoperative complication is irritation because of hardware. With proper treatment, both nonsurgical and surgical outcomes are excellent. TTAFs have high rates of union and patients typically return to sports.

Keywords

anterior tibial tuberosity fracture, pediatric, tibial tubercle avulsion fracture

INTRODUCTION

Tibial tubercle avulsion fractures (TTAFs) are uncommon, amounting to fewer than 1% of all physeal injuries and 3% of all proximal tibial fractures [1]. The incidence of these fractures is 0.25–2.7 cases per year [2], and they typically occur in adolescents nearing skeletal maturity.

The pathophysiology of TTAFs is closely tied to the pattern of ossification in the knee joint. The proximal tibia has two ossification centers, a primary site at the proximal tibial physis and a secondary site at the tibial tubercle or apophysis (Fig. 1). Physeal closure proceeds from posterior to anterior and proximal to distal aspects of the knee. The tibial tubercle is the last part to fuse. Notably, whereas most growth plates mature under compressive forces, the growth plate of the tibial tuberosity fuses under extensive forces [3]. The ossification center at the tibial tuberosity is connected to the metaphysis primarily by fibrocartilage, which is gradually replaced by columnar cartilage during skeletal maturation [3]. The newly formed cartilage is weak, and this is where injury occurs in TTAFs.

TTAFs often occur during sports after abrupt contraction of the quadriceps, which pulls the tibial tuberosity underneath the patellar tendon. Contraction of the quadriceps can be indirect, because of eccentric contractions that resist knee flexion while landing, or by a direct mechanism of concentric quadricep contraction to produce powerful knee extension while jumping [4]. Male individuals are thought to be at higher risk because they tend to have greater quadriceps strength than female individuals [5], which puts more stress on the cartilage, a higher percentage of male individuals play sports during adolescence, and physiodesis of the proximal tibial tubercle occurs at later ages in male individuals compared with female individuals [6]. Basketball, high jumping, football, and sprinting are the sports most frequently associated with TTAFs [7].

It has been postulated that Osgood Schlatter disease (OSD) predisposes patients to TTAFs, yet this association is unclear. In a 2016 systematic review,

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KEY POINTS

- TTAFs are rare injuries but the incidence is increasing, likely because of increased participation in high-level sports.
- Plain X-rays are the standard imaging modality; CT angiograms are essential if vascular damage is suspected; MRI is best for visualizing soft tissue involvement.
- The Ogden system is the most commonly used tool for classifying TTAFs.
- Nonoperative and operative treatment (both ORIF and arthroscopy) can produce excellent results.
- The most common postoperative complication is irritation because of hardware.

25% of patients who presented with this injury had preexisting OSD symptoms [8], but whether this was a causative relationship remains unknown. Ogden described OSD and TTAFs as resulting from different disease processes [3], reporting that OSD affects the anterior part of the epiphysis or ossification center of the tuberosity, whereas TTAFs are fractures through the physis that involve separation of the entire tuberosity, including the physis [9]. However, he also suggested that the histological changes of OSD could modify the biomechanical qualities of adjacent cartilage and predispose the tissue to TTAFs [3].

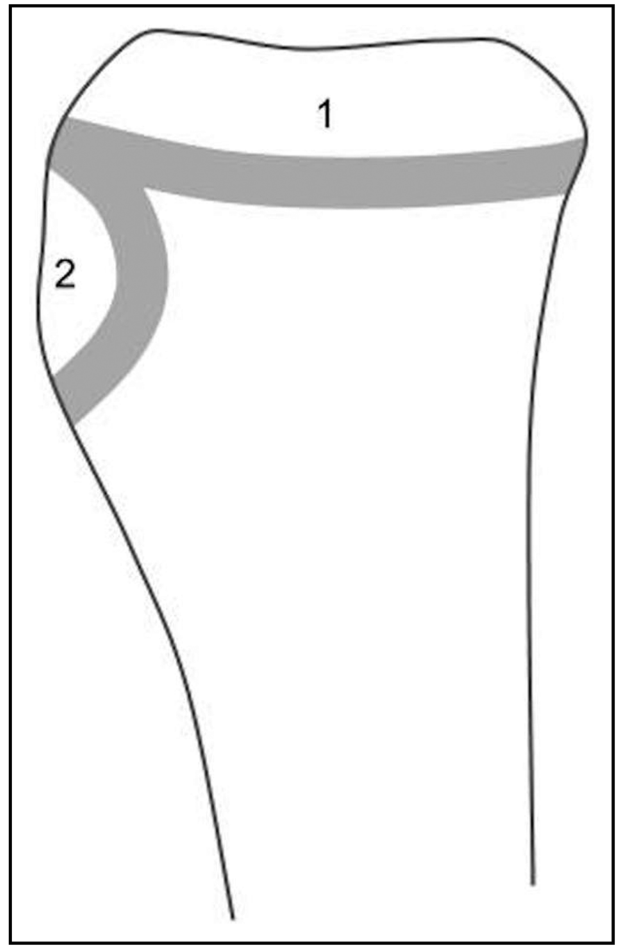

FIGURE 1. The two ossification centers of the proximal tibia: the primary site (proximal tibial physis) and the secondary site (tibial tubercle or apophysis), pictured in the lateral view.

EVALUATION

TTAFs typically present with the sudden onset of pain, especially during the initiation of a jump or sprint, and the inability to bear weight on the joint, move the knee, or ambulate. Common physical exam findings are swelling, effusion, and ecchymosis at the injury site. Pain is usually highly localizable as the tibial plateau and tibial tubercle are not covered by much soft tissue [10].

On physical exam, it is important to evaluate the extensor mechanism competence by asking the patient to perform a straight leg elevation against gravity. Importantly, retinacular fibers and strong periosteal coverage may allow active extension despite the presence of a TTAF. Physicians must also examine the stability of the knee in order to rule out concomitant ligamentous injuries, even though these injuries are rare. It is also critical to evaluate neurovascular structures, particularly the popliteal artery, which lies adjacent to the posterior capsule and descends between the two muscular bellies of the gastrocnemius, ending at the level of the distal-most aspect of the tibial tubercle before dividing into the anterior and posterior tibial branches. The anterior tibial recurrent artery, a branch of the anterior tibial artery that is located near the lateral border of the tibial tubercle, is prone to laceration and entrapment [11]. One study reported that injury to this artery occurs in 20% of cases [12]. Injury to anterior tibial recurrent artery branches may lead to compartment syndrome because of excessive bleeding within the anterior compartment. Pandya *et al.* [13] reported this complication in around 10% of cases. Patients at risk for compartment syndrome should be closely monitored since without prompt treatment, patients face potentially devastating consequences. Some authors go as far as suggesting prophylactic fasciotomies to prevent compartment syndrome [12].

ASSOCIATED INJURIES

Associated injuries occur in approximately 4% of TTAF cases [5,8]. The most common associated injuries are patellar tendon avulsions and meniscal tears. The majority of meniscal tears occur with fractures with intra-articular involvement. Meniscal tears are best repaired simultaneously with fracture treatment, and as a result these injuries should be ruled out with MRI prior to surgery or investigated arthroscopically during TTAF repair.

IMAGING

Lateral and frontal plain X-Rays of the knee provide important information about the type of fracture, the extent and magnitude of the displacement, and signs of associated tendinous injuries. The lateral view is best for visualizing the position of the patella and comparing it to the contralateral knee. Preoperative CT scans are very useful for visualizing the extent of the fracture, especially intra-articular involvement and posterior extension, and for assessing fracture fragmentation [11]. If vascular injury is suspected, it is imperative to rule out damage with CT angiography. The disadvantages of CT scanning are radiation exposure, particularly in pediatric patients, and the inability to identify soft tissue injuries. MRI is the preferred modality for evaluating soft tissue injuries, such as ligamentous or meniscal tears. The disadvantages of MRI are the lack of bony details about the fracture pattern, cost, and the long duration of the scan.

CLASSIFICATION

There are several systems for classifying TTAFs. The first was proposed by Watson-Jones in 1955 and defines five fracture types: type I fractures are avulsions of the tibial tubercle distal to the proximal tibial physis; type II fractures extend across the physis but did not enter the knee joint; type III fractures are avulsions, which extend proximal to the physis, into the knee joint; type IV fractures extend through the entire proximal tibia; and type V fractures are periosteal avulsions in the secondary ossification center [13,14].

The most popular classification system was described by Ogden. This system categorizes fractures similarly to Watson-Jones but adds the subtype A for nondisplaced fractures and B for displaced fractures (Fig. 2).

Further types were defined by Ryu and Debenham [15], who described a type IV fracture that extends posteriorly along the proximal tibial physis, creating an avulsion of the entire proximal epiphysis. In 1990, Frankl *et al.* [16] proposed a type C subcategory for fractures with patellar ligament avulsions. McKoy and Stanitski describe another type IV, which is a type IIIB fracture with an associated type IV fracture joined in a ‘Y’ configuration. In 2012, Pandya *et al.* proposed a new classification with four types: type 1 are isolated fractures of the ossified tip, type 2 occur when the epiphysis and tubercle fracture as a unit off the metaphysis without intra-articular involvement, type 3 fractures extend to the intra-articular surface of proximal tibia, and type 4 fractures involve the distal aspect of the tubercle (Fig. 3).

TREATMENT

The goal of treatment is to restore the extensor mechanism of the knee, achieve an anatomic reduction of the joint surface, and address associated injuries. Treatment can be nonoperative or operative.

NONOPERATIVE TREATMENT

The indications for nonoperative treatment are displacement less than 2 mm or displacement less than 2 mm after closed reduction and cast immobilization [9]. In terms of fracture type, Chow *et al.* [17] recommend nonoperative management for Ogden

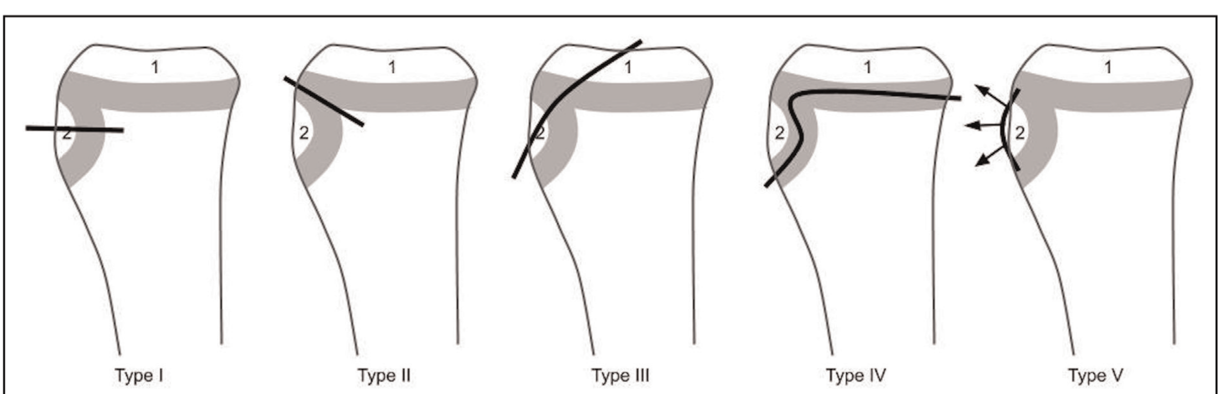

FIGURE 2. Adapted depiction of the Ogden classification system, where white represents bone, grey areas are physes, and black are fracture patterns.

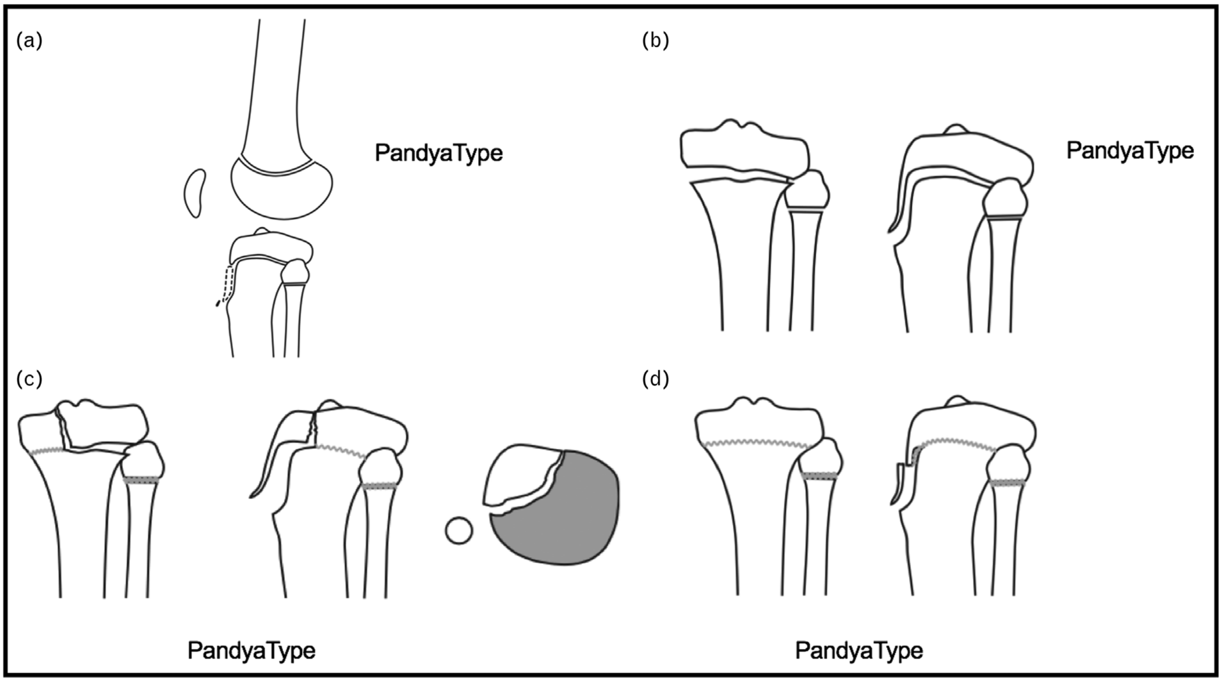

FIGURE 3. The Pandya classification system. Data from [13].

type IA and type IIA fractures as long as the extensor mechanism is intact. Henard *et al.* [18] recommend closed reduction and casting for Ogden type II fractures.

Conservative treatment involves immobilizing the knee in extension for 6 weeks using either a knee brace in extension or a long leg cast [6]. Outcomes are generally good. Christie *et al.* [1] reported excellent results; in their study of eight patients whose Ogden type I fractures were treated with casting, only one experienced mildly decreased flexion.

Interestingly, there is some evidence that nonoperative treatment can even benefit patients who would have historically been indicated for surgical management. Checa Betegón *et al.* [19▪] report a series of five type IV fractures that were treated conservatively and all five returned to sports in fewer than 25 weeks. In their analysis, they report that the choice of treatment depends more on the degree of reduction achieved in the emergency room and the patient's ability to extend the knee than the fracture classification.

OPERATIVE TREATMENT

Fractures classified as Ogden types II–V are typically indicated for surgical treatment (Figs. 4 and 5) [4,20].

Approximately 88% of TTAF cases are surgical candidates [8]. Surgical options include ORIF with compression screws or closed reduction and percutaneous pinning. Arthroscopy can be used to achieve anatomic reduction of the articular surface, diagnose and treat associated meniscal injuries, and decrease incision size. During arthroscopy, surgeons should be mindful of the risk of compartment syndrome, and minimize it by using as short a scope time as possible, either dry or with a low pressure bomb. Arthrofibrosis is a potential postarthroscopy concern [8].

ORIFs are performed through a midline incision in the knee, which provides direct access to the fracture site [8]. Direct observation and debridement of fracture site and the removal of interpositional soft tissue is crucial for obtaining anatomical reduction. Cancellous partially threaded 4.0 screws are recommended for optimal compression during internal fixation. Screws must be placed parallel to the joint surface, avoiding the growth plate and remaining attached to the posterior cortex.

Ares *et al.* described a surgical technique using cannulated screws to fix the intra-articular fragment with one or two screws depending on the size of the fragment. They fixed the fragment between the physis and metaphysis, placing screws through the tubercle physis but not through the proximal tibial physis [21]. They emphasized that avoiding implant prominence was a key way to mitigate the risk of hardware removal.

Kirschner wires are also an option for patients with more than 3 years of potential growth remaining, but biomechanical studies have demonstrated that cannulated screws provide better fixation [10]. The most common postoperative complication is

FIGURE 4. Images from the course of treatment of a 14-year-old boy with a tibial tubercle avulsion fracture. Mechanism of injury: kicking a rugby ball. Fracture type: Ogden type IIIB. (a) anteroposterior (AP) and (b) lateral view X-rays of right knee. (c) Sagittal view of computed tomography (CT) of right knee with (d and e) 3D model reconstruction. Postoperative (f) AP and (g) lateral X-rays taken 4 months after ORIF with cannulated screws. The patient achieved consolidation and returned to baseline activity level 6 months after surgery.

bursitis, with one study reporting a cohort in which 56% of candidates developed bursitis, and 7% of the 56% subsequently underwent hardware removal [8].

Surgical outcomes are typically good. In a study of 19 patients with 20 TTAFs in which all but one knee underwent fixation using cannulated screws, physical therapy was started an average of 4.3 weeks postoperatively and return to sports took an average of 3.9 months [12]. In a large cohort of 325 patients of which 88% underwent surgery, 98% had ORIF and the authors reported that 99% of patients achieved consolidation, 98% returned to normal activities at 29 weeks, and 97% regained complete range of motion, regardless of fracture type [8].

Postoperatively, patients should be nonweight-bearing and wear a long leg cast or brace in

FIGURE 5. Images from the course of treatment of a 16-year-old boy with a tibial tubercle avulsion fracture. Mechanism of injury: jump landing. Fracture type: Ogden type V. (a) Anteroposterior (AP) and (b) lateral view X-rays of the right knee. (c and d) Sagittal view computed tomography (CT) scans of right knee with (e) 3D model reconstruction. Postoperative (f) AP and (g) lateral X-rays after ORIF with cannulated screws. The patient achieved consolidation and returned to baseline activity level 6 months after surgery.

extension for 4–6 weeks. In terms of physical therapy, progressive strengthening of the extensor mechanism and resistance training is recommended starting 6 weeks after surgery. Patients with Ogden type I and II injuries are able to return to sports in 8 weeks. Patients with type III–V fractures may return to sports after 6–8 months, as long as they can tolerate a full quadriceps load and have full range of motion in the joint [6].

COMPLICATIONS

The complication rate of TTAFs is as high as 28%. TTAFs with intra-articular involvement or a posterior metaphyseal component are associated with the highest complication rates [8]. Anterior knee pain because of implant irritation or bursitis is the most frequent patient-reported concern, yet hardware removal is infrequent, in one representative study occurring in only 7% of patients [8]. Refracture is associated with types III, IV, and V fractures and has been reported in up to 6% of cases. Recurvatum deformity has been reported in less than 2% of cases [8]. Arthrofibrosis is associated with arthroscopy. TTAFs in preadolescents (8–12 years) have been associated with growth arrest of the tibial tuberosity physis, but as this fracture occurs most commonly between ages 12–17 years, when the physis is nearing normal closure, growth disturbances are infrequent [22].

CONCLUSION

Although TTAFs are uncommon, the incidence is rising as children increasingly participate in a greater number of sports, and the sports themselves are of higher intensity. There are several systems for classifying these fractures, and the Ogden classification is the most common. The assessment of fracture type guides treatment. Treatment can be nonoperative or operative, though most cases are treated surgically with either ORIF or arthroscopic approaches. It is critically important to rule out compartment syndrome as an early complication of these injuries as well as assess for associated soft tissue injuries. With adequate and timely treatment, TTAFs have a high rate of union and return to sports is generally successful.

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Conflicts of interest

There are no conflicts of interest.

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▪ of special interest
▪▪ of outstanding interest

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