# Tibial eminentia avulsion fracture in children – a systematic review of the current literature

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## ABSTRACT

**INTRODUCTION:** Tibial eminentia avulsion fracture is the paediatric equivalent to a midsubstance anterior cruciate ligament injury. It is most common between the ages of 8 and 19 years of age. The incidence is three per 100,000 per year. We explored the clinical evaluation and classification of the fracture, indications for and methods of surgery and the possible sequelae.

**METHODS:** We performed a systematic search in the PubMed database and retrieved 127 articles. A total of 16 articles met the defined inclusion criteria and were reviewed. Only studies on adolescents were included.

**RESULTS:** No prospective studies were found. The Meyers & McKeever and Zaricznyj classifications were commonly used, also when evaluating fractures for surgery. X-ray in three views is often sufficient to establish a diagnosis, but computed topographies can be necessary to further evaluate the type of fracture. There is disagreement as to whether a type II-fracture needs surgery. The method of fixation varies greatly between different kinds of suture techniques and screw fixations, but arthroscopic surgery is preferred in the most recent literature. Whether to cross the physis when fixating the fracture is also a matter of disagreement, but there is a lack of literature on the subject. All authors describe low rates of subjective sequelae.

**CONCLUSION:** Arthroscopic surgery is less invasive and allows for earlier mobilisation than other techniques. Pull-out suture seems to be a recommendable technique. There is a lack of literature on transphyseal fixation and a need for prospective studies evaluating the many different surgical techniques described and the indications for surgery.


The tibial eminentia avulsion fracture (TEAF) is an injury most commonly seen in skeletally immature patients, and it is the paediatric equivalent to a midsubstance anterior cruciate ligament (ACL) injury. TEAF arises because the tibial epiphyseal bone has not yet been ossified and is thus the weakest part of the ACL structure [1-8].

The tibial spine or intercondylar eminence is the bony prominence between the medial and the lateral tibial plateaux. It is where the anterior cruciate ligament attaches to the anterior ligamentous parts of the medial and lateral menisci. It is non-articular, but the eminentia avulsion fracture should still be considered an intra-articular fracture because of the consequences of a loose fragment in the knee joint and the damage to the ACL structure.

TEAF is a relatively rare injury compared to other paediatric fractures and therefore has a higher risk of being overlooked. Moreover, treatment can be difficult since multiple treatment techniques are described and there is a lack of consensus with regard to the choice of treatment. Untreated TEAF can result in knee instability. The objective of this review was to provide an overview of the mechanism of injury that causes TEAF, appraise clinical evaluation and classification, study indications for and methods of surgery and appraise the possible sequelae to surgical fixation.

## METHODS

### Search strategy and study selection

A systematic search was conducted in the PubMed database using the following keywords individually and combined: “ACL”, “arthroscopic fixation”, “open physes”, “cruciate ligament injuries” and “intercondylar eminence”. The following MESH terms were used: “anterior cruciate ligament”, “child”, “adolescent”, “fracture fixation” and “tibial fracture”. The search strategy also included crosschecking of the reference lists of the included articles. This resulted in the identification of a total of 127 articles.

The abstracts were then assessed and 59 full-text articles were retrieved. These articles were then reviewed systematically for inclusion of studies concerning patients being younger than 19 years of age because the adolescents were considered not fully skeletally mature and because TEAF in adults is often associated with other serious injuries to the knee [9]. When studies included adults as well as adolescents, data from the two groups had to be separate, and only data from the adolescent group were extracted.

The surgical method had to be described to ensure reproducibility, and the articles had to include a description of the follow-up results to appraise any complications and sequelae. A minimum sample size of five patients was chosen. Only articles published in English were included. We found 16 studies eligible for this review (**Figure 1**).

Publications not meeting the inclusion criteria are cited in this article for supplementary information.

SYSTEMATIC REVIEW

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FIGURE 1

Flow diagram of article selection.

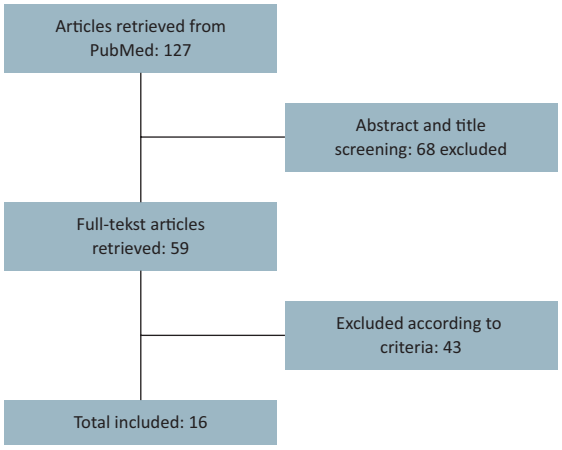


FIGURE 2

The Zaricznyj classification of tibial eminetia avulsion fractures [19].

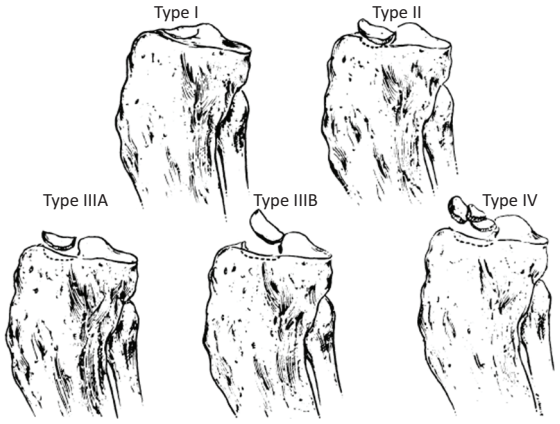


FIGURE 3

**A** and **B**. Eight-year-old boy with a tibial eminentia avulsion fracture. On conventional X-rays a type II-fracture was suspected. **C**. Computed tomography confirmed posterior contact of the fragment. **D**. 13-year-old boy with tibial eminentia avulsion fracture, arthroscopic fixation with a single Arcumed screw, 2 mm × 30 mm.


## RESULTS

The results are summarised in **Table 1**. All the studies were retrospective with follow-up periods ranging from eight months [7] to 37 years [10] and sample sizes ranging from five [4, 11, 12] to 47 [10].

### Incidence and causes

The prevalence of TEAF is highest between the age of eight and 19 [7, 13-15]. According to Fehnel & Johnson [16], 80% of injuries to the ACL structure in patients younger than 12 years of age are TEAFs. Kendall et al [9] reported a 14% incidence of TEAF in ACL injuries, but did not differentiate between adults and adolescents. An incidence of isolated TEAF of three per 100,000 per year [17, 18] has been reported.

Ten articles described the activity during which the TEAF was sustained (see Table 1), but only two articles described the mechanism of injury [9, 17]. In children, TEAF is due to less violent injuries than in adults and in adults it is therefore often associated with other severe injuries to the knee [1, 11].

### Classification

The most commonly used classifications were the ones by Meyers & McKeever [1] and Zaricznyj [19]. Meyers & McKeever divided TEAF into three types; type I-fractures with no displacement, type II-fractures where the anterior third or half of it is displaced and hinged, and type III-fractures with complete displacement [1]. Later, a subdivision of type III-fractures was introduced; type IIIA-fractures with a completely displaced fragment, and type IIIB-fractures with a completely displaced and rotated fragment. Zaricznyj introduced type IV-fractures in 1977 in which the fragment is completely displaced and comminuted [19] (**Figure 2**).

### Diagnostics

The patients' symptoms were pain, swelling, a sensation of locking of the knee and limited range of motion [1, 7, 9, 14, 15, 18-30]. A proper clinical examination can only be done in universal anaesthesia [4, 17, 18, 22] where conventional tests can be used; a positive Lachman's test [4, 9, 12, 15, 18, 22, 26, 28, 30-32], anterior drawer test [4, 9, 15, 26, 28, 31] and Pivot Shift [4, 29, 30]. Most studies used roentgenograms in three views (lateral, antero-posterior and tunnel view) to validate the clinical findings (**Figure 3**). Senekovic & Veselko found that diagnostics by X-ray was generally correct, but 28% of type III-fractures were classified as type IV when seen arthroscopically [33]. Some authors preferred to use magnetic resonance imaging (MRI) as supplemental diagnostic imaging [5, 20] to confirm the diagnosis and also to evaluate associated soft tissue injuries. Otherwise, arthrosco-

py [4, 9] was used as a diagnostic tool with or without subsequent surgical intervention although three authors abstained from arthroscopy and proceeded directly to fixation by arthrotomy or conservative treatment [8, 10, 17]. Iborra et al even discouraged the use of arthroscopy as a diagnostic tool [17].

**Treatment**

At the time of the publication of their paper in 1959, Meyers & McKeever described that the common treatment of TEAF was manipulation of the knee into hyperextension and immobilisation in this position, but they renounced this technique based on the anatomic fact that the fragment is in an empty space in the knee and therefore cannot be manipulated by manipulating the knee joint and the fact that the ACL is stretched tight in the hyperextended position and therefore will pull the fragment away from the fracture bed [1]. Instead they recommended immobilisation without manipulation with the knee flexed for type I- and II-fractures and surgical treatment of type III-fractures.

**Table 2** outlines the preferred treatment for various types of fractures. All type I-fractures were treated conservatively [8-10, 17, 34, 35], type II fractures were treated arthroscopically by some [5, 20, 33, 34, 36], whereas other authors preferred conservative treatment [8, 10, 35], which could be preceded by closed > reduction [17]. One preferred open surgery [9]. However, in type III-fractures, the majority of studies recommended surgical treatment. Nine studies described arthroscopic methods [5, 11, 12, 20, 31, 33, 34, 36, 37], six described open surgery [4, 7, 9, 10, 17, 35], whereas three treated type III-fractures conservatively [8, 17, 35]. Only four studies included type 4-fractures which were all treated surgically; half of them arthroscopically [8, 12, 17, 33].

In the articles reviewed for this paper, there is a lack of consensus regarding the treatment of type II-fractures. Senekovic & Veselko recommended surgical treatment of type II-fractures because they found that the intermeniscal ligament was interposed in the fracture and blocked reduction in 62% of type II-fractures [33]. Hunter & Willis also advocated for surgical treatment of type II-fractures because of the possibility of early mobilisation [20]. Reynders et al also recommended surgical treatment of type II-fractures, finding that fractures often involve a big part of the medial tibial plateau [34].

**Conservative treatment**

Most of the reviewed articles concentrate on surgical treatment. Iborra described a conservative regime for type I-fractures with the leg immobilised in a long leg cast in slight flexion for four weeks [17]. Iborra et al also recommended conservative treatment for type II-fractures preceded by closed reduction and haemarthrosis aspiration [17]. Molander et al were the only ones to confidently recommend conservative treatment of type

**TABLE 1**

Data extraction from eligible articles.

| Reference | Study design | Sample size, n /age, range, yrs | Follow-up period | Physical activity | Trauma mechanism | Surgical method stated |
|---|---|---|---|---|---|---|
| *Kim et al,* 2007 [1] | Retrospective | 5/13-19 | 15-36 months | Not stated | Not stated | Yes |
| *Ahn & Yoo,* 2005 [12] | Retrospective | 5/6-13 | Average 51 months | Not stated | Not stated | Yes |
| *Hunter & Willis,* 2004 [20] | Retrospective | 8/7-16 | Average 33 months | Ski, sports, traffic | Not stated | Yes |
| *Owens et al,* 2003 [7] | Retrospective | 12/10-12 | 8 months | Bicycling | Not stated | Yes |
| *Senekovic & Veselko*, 2003 [33] | Retrospective | 15/8-16 | 16-69 months | Bicycling, skiing, soccer, traffic | Not stated | Yes |
| *Reynders et al*, 2002 [34] | Retrospective | 26/13-18 | > 24 months | Falling, sports, traffic | Not stated | Yes |
| *Binnet et al,* 2001 [5] | Retrospective | 8/9-14 | Average 27.3 months | Not stated | Not stated | Yes |
| *Doral et al,* 2001 [36] | Retrospective | 10/9-14 | Average 49 months | Not stated | Not stated | Yes |
| *Iborra et al*, 1999 [17] | Retrospective | 25/8-15 | Average 42 months | Traffic, sports, skiing | Lat. valgus-flex-rotation and jolt on dist. femur | Yes |
| *Mulhall et al,* 1999 [4] | Retrospective | 5/10-15 | 1-20 yrs | Falling, bicycling, sport | Not stated | Yes |
| *Bale & Banks*, 1995 [31] | Retrospective | 8/4-12 | 12 months | Not stated | Not stated | Yes |
| *Janarv et al*, 1995 [10] | Retrospective | 47/6-16 | 11-37 yrs | Not stated | Not stated | Yes |
| *Kendall et a*l, 1992 [9] | Retrospective | 12/8-16 | Average 31 months | Sports, falling, traffic | Jolt on dist. femur and hyperext. with rotation | Yes |
| *Wiley & Baxter*, 1990 [8] | Retrospective | 45/8-16 | 3-10 yrs | Traffic, bicycling | Not stated | Yes |
| *Mah et al, 1988* [37] | Retrospective | 11/9-15 | 42 months | Sports, traffic | Not stated | Yes |
| *Molander et al,* 1981 [35] | Retrospective | 28/6-14 | 42 | Sports, traffic | Not stated | No |

TABLE 2

Data on diagnostics, treatment and outcome.

| Reference | Diagnostics | Type I-fracture | Type II-fracture | Type III-fracture | Type IV-fracture | Fixation | Immobilisation of knee |
|---|---|---|---|---|---|---|---|
| *Kim et al,* 2007 [11] | Not stated | | | AS | | PS | Extended knee |
| *Ahn & Yoo,* 2005 [12] | Not stated | | | AS | AS | PS | Not stated |
| *Hunter & Willis*, 2004 [20] | X-ray | | AS | AS | | PS/SC | Extended knee |
| *Owens et al,* 2003 [7] | X-ray | | | AS with "mini AT" | | PS | Extended knee |
| *Senekovic & Veselko,* 2003 [33] | X-ray | | AS | AS | AS | S/SW | None |
| *Reynders et al*, 2002 [34] | Not stated | CT | AS | AS | | SW | Not stated |
| *Binnet et al,* 2001 [5] | X-ray, MRI | | AS | AS | | SS | Allowed passive flexion to 90° |
| *Doral et al*, 2001 [36] | X-ray | | AS | AS | | SC | Not stated |
| *Iborra et al*, 1999 [17] | X-ray + EAU/MRI | CT | CR | CT/ AT | AT | S/SS/SC | Light flexion |
| *Mulhall et al*, 1999 [4] | X-ray, EAU, a-scopy | | | AT | | SW | 20° flexed |
| *Bale & Banks*, 1995 [31] | EUA | | AS | AS | | Kirschner wires | Extended knee |
| *Janarv et al,* 1995 [10] | X-ray | CT | CT | AT | | S | Not stated |
| *Kendall et al*, 1992 [9] | X-ray, a-scopy | CT | AT | AT | | S | Extension for two weeks, followed by increased flexion |
| *Wiley & Baxter*, 1990 [8] | X-ray, EAU | CT | CT | CT | AT | S, Kirschner, SC | Not stated |
| *Mah et al,* 1988 [37] | A-scopy | | | AS | | S | Not stated |
| *Molander et al,* 1981 [35] | X-ray | CT | CT | CT/AT | | S | Not stated |

III-fractures with the leg in a long cast for 4-6 weeks. It made no difference in the long term whether the leg was in extension or flexion [35].

**Surgical treatment**

*Arthrotomy versus arthroscopy*

In the studies published before 2000, the preferred method was open surgery, and arthroscopy was seen as a diagnostic procedure [4, 9]. Owens et al were the last to use what he called a mini-arthrotomy, claiming that arthroscopy too often leads to insufficient fixation [7]. Mah et al published the first study using an arthroscopic technique and stated, like other authors, that arthroscopy leads to less scar tissue, less morbidity and a faster recovery [5, 13, 30, 37]. The disadvantage of arthroscopy is that it is technically more demanding, and it is more difficult to obtain a secure fixation [13, 36]. However, today arthroscopic knee surgery is widely used to treat a variety of conditions and hence more surgeons are trained and use arthroscopic surgery routinely.

*Method of fixation*

Different methods of fixation are described. They can be divided into two main categories; suture versus screw fixation.

In the most recent literature, the preferred method can be described as a pull-out suture where a suture is passed through the ACL just proximally to the avulsed bony fragment [7, 11, 12, 15, 16, 18, 20]. After placing the suture, a small incision is made just medial to the tibial tuberosity and the bone is exposed. Then two tunnels are drilled from the lateral and medial border of the fracture bed to the anterior tibia. The suture is pulled through these tunnels and tied on the anterior surface of the tibia. In another suture technique, the suture is tied to a screw placed in the anterior part of the tibia [5, 17]. The disadvantage of this technique is the need for hardware removal.

Another method of direct fracture fixation is to use one or two cannulated screws, with or without a washer [8, 17, 20, 33, 34, 36]. Reynders et al acknowledged the risk of a screw further fragmentising the fragment and used a technique in which a cannulated screw with a spiked washer was placed right next to and not through the fragment, the spikes fixating the fragment, but they did not achieve knee stability [34]. Doral et al used 1-2 cannulated screws through the fragment and crossed the physis. They concluded that the technique was not useful when the fragment was comminuted [36], as did Hunter & Willis, who instead used a suture technique for small or comminuted fragments [20]. Senekovic & Veselko stated that screws are more stable than sutures and successfully fixated small and comminute fractures with a cannulated screw and washer [33].

Two authors used Kirshner pins to fixate the fragment [8, 31]. This has an obvious disadvantage due to the need for hardware removal and due to the increased risk of infection.

In a more recent study from 2011, Sundararajan described an arthroscopic technique that included the use

TABLE 2 CONTINUED

| Duration of immobilisation, weeks | Weight bearing | Physis | Symptom at follow-up | Sequelae |
|---|---|---|---|---|
| 2 | Individual | Not stated | None | None |
| 2 | After 12 weeks | Crossed | None | A-P laxity, possible growth disturbance |
| 4 | After 1.5 weeks | Crossed | 5/17, (hardware removal needed) | None |
| 4 | Not stated | Not crossed | Not stated | Laxity |
| None | Limited by pain | Crossed | None | No growth disturbance |
| 1 | After 6 weeks | Not crossed | 7/26 Obj, 2/26 Subj | Extension deficit and recurvatum |
| 6-7 | After 6 weeks | Crossed | 3/8 | A-P laxity |
| Not stated | Not stated | Crossed | 3/12 Obj, 0 Subj | A-P laxity |
| 6-7 | After 6 weeks | Crossed | 5/25 | A-P laxity |
| 6 | No stated | Sometimes crossed | 3/7 Obj, 0 Subj | A-P laxity, Quadriceps weakness |
| 4-6 | Not stated | Not crossed | 1/8 Obj, 1/8 Subj | Loss of extension, pain |
| Not stated | Not stated | Not stated | 25/47 Obj, 18/47 Subj | Laxity, loss of extension |
| 2 | After 5 weeks | Not crossed | 0/12 | None |
| Not stated | Not stated | Not stated | 27/82 Obj, 2/82 Subj | Loss of extension |
| 2 | Not stated | Not stated | None | None |
| Not stated | Not stated | Not stated | 7/28 Subj | Minor discomfort |

A-P = anterior-posterior; AS = arthroscopic surgery; AT = arthrotomi; CR = closed reduction; CT = conservative treatment; EUA = examination under anaesthesia; MRI = magnetic resonance imaging; Obj = objectively; found during examination, patient does not necessarily state symptoms; PS = pulls-out suture; S = suture; SC = screw; Subj = subjectively; the patient states symptoms; SS = suture fixed to screw; SW = screw and washer.

of staples, but separate results for children were not described [38]. The advantage of this technique and of the suture mattress technique described by Mann is that that both techniques can be performed without an additional incision to access the anterior tibia [39].

In 2007, Eggers et al [6] conducted a biomechanical study on immature pigs in which TEAF was induced. They compared four different methods of fixation; a suture technique resembling the pull-out suture technique using either Ethibond or no. 5 FiberWire and fixation with one or two cannulated screws. The FiberWire suture appeared to be strongest both in single and cyclic load tests. Schneppendahl recently published a biomechanical study comparing Polydioxanone II (PDS II), Vicryl and FiberWire for fixation TEAFs. The strength of Vicryl was comparable to that of FiberWire and they suggested an advantage of using biodegradable material in children. The results for PDS II were inferior to those of Vicryl and FiberWire [40].

*Crossing the physis*

Larsen et al described tests performed on skeletally immature rabbits. They found that the size of the hole drilled through the epiphysis was crucial when it comes to growth disturbances. Holes representing approximately 3% of the cross-sectional area of the physes inflicted no growth damage, whereas holes representing 7% or more caused permanent growth disturbance [3].

Six out of 16 authors in this review described transphyseal fixation; only one reported growth disturbances [12]. Ahn & Yoo found a six-year-old patient with genu recurvatum of 10° and an 11-year-old patient in whom the affected limb was 1 cm shorter after surgery with a transphyseal pull-out suture technique. Five authors did not state if the physes were crossed during fixation. Available data on potential growth disturbance after transphyseal fixation are insufficient, and more research needs to be done before it can be determined whether transphyseal fixation is safe or not. Until then, using techniques that can be done without crossing the physes is recommended.

**Complications and sequelae**

At follow-up, the authors reported anterior laxity as the most common sequelae (see Table 2). Numerous authors explained the post-surgical laxity as a instance of traumatic elongation and not as a complication to surgery [7, 10, 17, 31, 34], leading to recommendation of recessing the fragment into the tibial plateau [26, 41]. However, Noyes et al found no evidence of traumatic elongation after inducing TEAFs in rhesus monkeys [42]. There seems to be a poor correlation between subjective and objective findings at follow-up, with the majority of patients reporting a satisfying outcome at follow-up despite the common findings of anterior laxity postoperatively.

## FACT BOX

**Tibial eminentia avulsion fracture**

Has the highest prevalence among children and adolescents and an incidence of 3/100,000/year.

Is classified by the Meyers & McKeever or Zaricznyj classification.

Arthroscopic treatment is the current choice of surgical method to fixate the avulsed fragment.

The open tibial physis complicates sufficient fixation, but data on growth alterations after transphyseal fixation is insufficient.

The most common sequelae are laxity of the knee.

## CONCLUSION

In most cases, TEAF can be diagnosed with conventional X-rays. When in doubt, a CT should be performed if it can be done without delay to further evaluate if surgery is needed.

Arthroscopic surgery is less invasive, allows earlier mobilisation and reduces morbidity compared with arthrotomy, but the surgeon should choose the method with which he or she is most comfortable. The same can be said when choosing the method of fixation. Our findings suggest that the fixation should be done arthroscopically. Pull-out suture seems to be a recommendable technique. The literature about transphyseal fixation and possible sequelae is limited. In order to recognise transphyseal fixation as a safe surgical intervention more research is therefore needed. Until then, care should be taken not to cross the proximal tibial physis when fixating the avulsed fragment.

Many surgical techniques are described. These techniques need to be examined in a prospective randomised manner, preferably in multicentre trials because of the low number of injuries.

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**CONFLICTS OF INTEREST:** none. The author's ICMJE forms are available along with the article at www.danmedj.dk.

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