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Reviewing Current Concepts in Distal Tibial Physeal Injuries: New Twists and Old Turns?

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Abstract

Distal tibial physeal injuries are common in children accounting for a significant proportion of the paediatric trauma. They are commonest between the years of 10-16, temporally related to the timing of physeal closure. They are strongly associated with sporting activities where there are significant sudden changes in direction with resulting force applied through the distal physis. This article reviews the anatomy, pathophysiology, imaging, classification systems and management of these injuries. Salter Harris, Tillaux and triplanar fractures are discussed. This article, in addition to informing the reader of the above, we hope will also update the reader of relevant new twists in management strategy as well as re-visit the old turns that have provided the main stay of orthopaedic surgical understanding of these injuries.

Keywords: Paediatric trauma; Salter Harris; Physical injury; Tillaux fracture; Triplanar fracture; Growth arrest

Introduction

Ankle injuries are very common in children and adolescents and second only to wrist and hand injuries. Pediatric ankle fractures are commonest between 10-16 years of age, due to physeal closure, which begins around the pubescent phase lasting over an 18-month period. Recent evidence in the literature suggests that distal tibial physeal fractures represent 11% of all physeal injuries but Dias et al. original work states that the actual rates lie between 25-40% [1-4]. Studies in the United States show a strong association between sports such as football, rugby, and basketball having an increased risk for physeal ankle injury due to sudden changes in direction. Also the use of skateboards and scooters has an association with these injuries [5-7].

Further evidence by Ogden et al. and others state that obesity in children is also associated with a higher risk of these injuries due to the forces that the joint encounters [8-10]. In 2008, more evidence highlighted the importance of body mass index (BMI) as an important risk factor for non-contact ankle sprains in high-school American footballers [11,12].

Anatomy

The ankle joint is a hinge joint that consists of a medial malleolus, lateral malleolus, tibial plafond and the talus. The joint reaction forces are five times that of actual body weight on flat surfaces. Motion primarily occurs in two planes with plantar and dorsiflexion and also inversion and eversion with some rotation. The ankle joint is surrounded by a complex array of ligaments that attach medially (deltoid and calcaneonavicular ligaments) and laterally (anterior and posterior talofibular, calcaneofibular and the lateral talocalcaneal ligaments) (Figures 1-3). Further to this the syndesmosis stabilizes the ankle joint in the anterior-posterior plane. It consists of the anterior, posterior and transverse tibiofibular ligaments and the interosseous ligament [13-15]. Figure 4 demonstrates that the distal tibial growth plate closure starts centrally, and medially, progresses to posteriorly and laterally and finishes anterolaterally [13].

This occurs over an 18 month period and commences in girls at 14 years and 16 years in boys [14]. It is well established teaching that the weaker physis fails prior to the stronger ligaments getting injured, thus it is important to understand the stages of physeal closure [15-17].

Pathophysiology

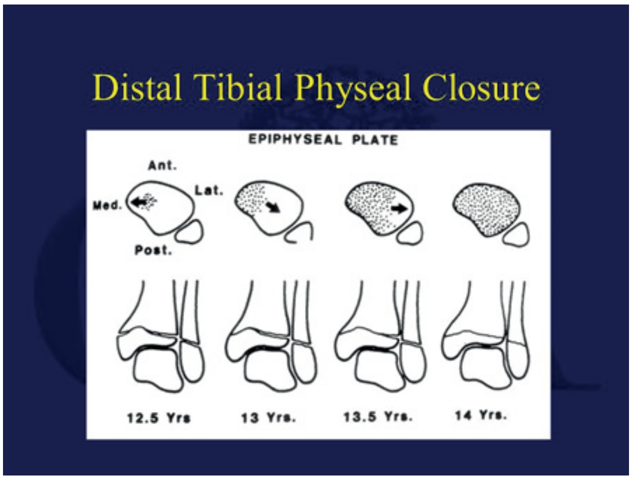

Figure 1: Distal tibial physeal closure.

The forces that produce these physeal injuries are slight variations of that described by Lauge-Hansen in their cadaveric studies [14]. The injuries can be categorised into the more common Salter Harris (SH) I-II fractures, with the foot in a fixed position to the ground with external rotation or abduction forces through the physis resulting in a tibial metaphyseal spike either posteriorly, laterally or posteromedially. A second less common injury, results from supination and adduction of the foot that manifests as SH III-IV fractures. It is these injuries that were described by Dias et al. [4] as SH III (Tillaux fracture), SH IV (Triplanar fractures) and are generally associated with a worse long term outcome [4,16-18]. These fractures often involve the medial aspect

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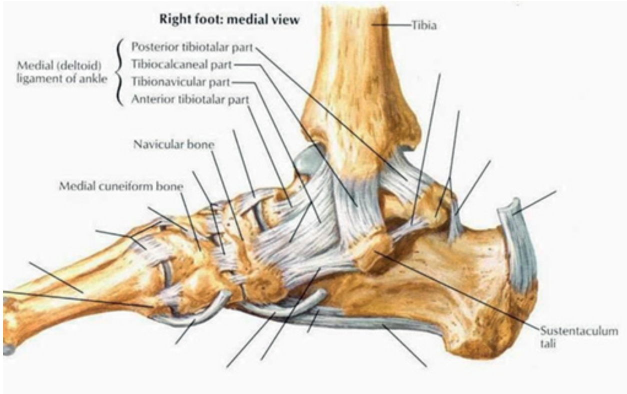

Figure 2: Ligaments of the medial ankle.

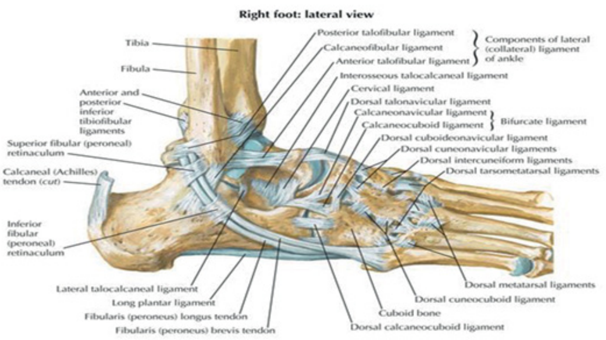

Figure 3: Ligaments of the lateral ankle.

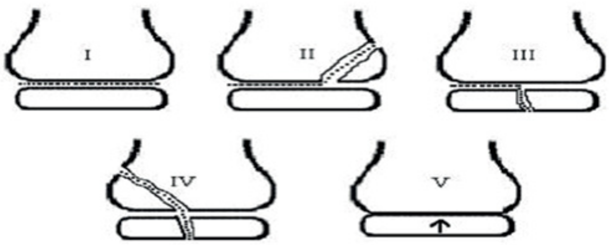

Figure 4: Salter Harris classification system.

of the tibial plafond and occur in a similar pattern to a supination injury. Studies performed analysing the adduction mechanism causing SH III and IV injuries results in greater physeal damage than the abduction and distraction forces that result in SH I and II fractures [19,20].

Imaging

The clinical history and examination should aid in directing the clinician towards the need for a formal trauma imaging for the patient. Appropriate imaging of the injured segment should follow the trauma imaging. We would support current convention starting with plain radiographs of the injured segment, namely orthogonal views including an ankle mortise. The mortise radiograph is crucial in evaluating these fractures as there may be minimal obvious deformity and the tibiofibular overlap might disguise a minimally displaced fracture [21,22]. The question of further imaging pertinent to the injury has been the source of discussion in contemporary literature. An interesting study compared computed tomography (CT) scans with plain radiographs in a cadaveric model of juvenile Tillaux fractures and reported that CT scans and radiographs are accurate to within 1 mm 50% of the time but that CT scans are more sensitive at detecting fractures displaced >2 mm. CT scans have been shown to be more sensitive and specific in diagnosing these fractures but the use of x-rays as primary imaging only misdiagnoses the severity of the injury in 7% of patients [23-25]. As well as diagnosis, CT scans have been shown to be useful tools in operative planning with advocates demonstrating that they significantly aid the surgeon's ability to accurately plan screw placement for the treatment of triplane fractures [26,27]. The current accepted practice states that plain x-rays in two planes and then a CT scan provide sufficient information regarding the fracture pattern and pre-operative planning.

The role of Magnetic Resonance Imaging (MRI) is contentious with protagonists stating it does not involve radiation, can provide more detailed anatomical delineation of soft tissue structures and may be more sensitive for bone and physeal injuries than other modalities. A study by Carey et al. compared radiographs against MRI scans, stating that MRI scans led to a change in management of 35% of patients [23]. Larger studies comparing plain radiographs with MRI scans have disputed this showing that although approximately 15% of fractures were under diagnosed by plain radiographs, MRI scanning did not ultimately change the treatment plan [23-25]. The role of MRI remains unclear, but it may be useful to identify occult fractures, assess ligamentous and soft tissue injury, assess for premature physeal closure and ongoing postoperative complications [25].

Classification

There are several methods of classification of distal tibial physeal fractures. The most commonly used remains the Salter-Harris system due to its reliability and reproducibility [16]. The system has 5 subtypes that focus on the physis and relate the injury to the metaphyseal or epiphyseal fragment of bone that is fractured (Figure 4). Further subdivisions have been developed; type VI that implies damage to the perichondral structures, type VII isolated injury to the epiphyseal plate, type VIII isolated injury to the metaphysis with a potential injury to endochondral ossification and type IX which represents injury to the periosteum that may interfere with membranous growth. The Dias-Tachdjian mechanism of injury classification is an abbreviation of the Lauge-Hansen based on the foot position at the time of injury and the direction of the force. This classification system aims to help understanding of the pathophysiology of the injury thus facilitating in fracture reduction during a manipulation and/or operative treatment [4,28-30] (Figure 5).

Tillaux and Triplane fractures represent special variants of distal tibial physeal injuries. A tillaux fracture is effectively a SH III fracture of the distal tibial (Figure 6). The lack of a coronal fracture component distinguishes it from a classic triplane injury.

The classic triplane fracture consists of three parts: a rectangular fragment of distal tibial epiphysis (sagittal plane), an injury to the physis (axial plane) and a large fragment that includes a metaphyseal spike and the tibial shaft (coronal plane) (Figure 7). Two, three, and four-part triplane fractures have also been described [31-33].

Management and Treatment

Generic management principles

The central philosophy of treating paediatric distal physeal injuries

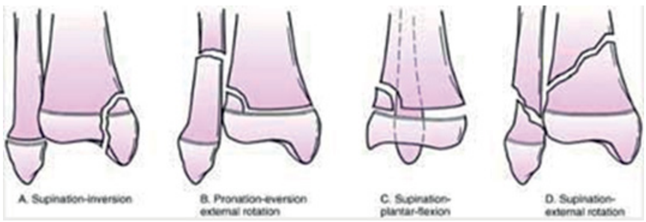

Figure 5: Dias- Tachdijian classification.

Figure 6: Tillaux fracture x-ray.

Figure 7: Triplanar fracture x-ray.

is anatomic reduction, restoration of joint congruity and preserve the integrity of the physis. A conservative approach can be used in situations where there is minimal displacement and a stable fracture pattern. If a fracture is displaced it can be manipulated via closed reduction techniques. A fracture that is displaced and unstable will require open reduction and internal fixation. With regard to conservative treatment and contrary to popular opinion, there is no evidence to support the concept that multiple reduction attempts cause physeal injury [34]. This divides surgeons with many stating that ideally, the reduction should be achieved in the fewest attempts as possible [33,35,36].

Specific fracture management

Salter Harris I: SH I distal tibial fractures represents approximately 15% of all paediatric distal tibial fractures. (1) Generally these fractures are low energy injuries and have a low risk of physeal arrest [3]. Consensus is that undisplaced (<2 mm step off) fractures can be immobilized in a below knee cast, or a walking boot for four weeks with NWB [19]. Displaced Salter-Harris type-I fractures will require closed reduction and immobilisation in a below knee cast. Regular radiographic follow-up is required in the first week following injury to ensure no displacement. Most patients can be transitioned to a walking cast at the month stage. A note of caution written by Barmada et al. showed that incomplete reduction may suggest interposed periosteum which further is a significant negative prognostic factor and may lead to premature physeal closure requiring open reduction and internal fixation [35-37].

Salter Harris II: Salter-Harris II distal tibial fractures are the commonest variant of distal tibial physeal injuries, comprising between 32%-38% of all physeal fractures [3,35]. Undisplaced Salter-Harris II distal tibial fractures can be managed in a short or long leg cast four weeks, followed by weight bearing in a cast. As stated with SH I fractures, all SH 2 fractures should be evaluated clinically and radiologically for rotational deformity. Concerningly, Phan et al. reported that 61% of treated distal tibial physeal fractures developed secondary external tibial rotation deformities [38-40]. With regard to displaced fractures, a large case series involving 91 SH I and II fractures was conducted by Phieffer et al. This determined that the mechanism of injury was related to premature physeal closure. It concluded operative treatment for fractures with >2 mm of displacement to remove interposed periosteum was necessary to achieve satisfactory outcome. Long-term results showed mal-reduction of these fractures which resulted in premature physeal injuries and varus or valgus deformity [3,20,40].

We note words of caution from Spiegel et al. who showed as age of the child increases the likelihood of inability to remodel angular deformities also increases [3]. The inability to anatomically reduce Salter-Harris type-I and II distal tibial fractures is often caused by interposed soft tissue, particularly the periosteum [3]. Studies of displaced Salter-Harris type-I and II distal tibial fractures have noted premature physeal closure occurred in 60% fractures with >3 mm of physeal widening and in 17% fractures with <3 mm of physeal widening post reduction; reiterating the need for anatomic reduction and stabalisation with the use of smooth K-wires across the growth plate [20,35,40].

Salter Harris III: SH III fractures account for approximately 25% of distal tibial fractures. Fracture extends through the physis and exits through the epiphysis. SH III and IV distal tibial fractures are problematic as both articular incongruity and premature physeal closure must be considered. Undisplaced (<2mm) fractures can be treated with non-operative management. A short leg cast, is with careful radiographic surveillance, the gold standard in the first weeks following injury. Due to the risk of premature physeal closure current recommendations would include radiographic follow-up for at least two years after injury or to skeletal maturity [34].

Overwhelming evidence supports the belief that displaced (>2mm)

SH III fractures should be treated with open reduction and internal fixation [3,20,35,34,41]. Closed reduction and internal fixation has been compared to open reduction and internal fixation with the latter conferring significant advantage in terms of reduced risk of premature physeal closure [34]. Premature physeal closure has been quoted at 13% for displaced SH III and IV treated with open reduction and internal fixation [34,36].

The Tillaux fracture, a SH III variant, occurs in late teens at the end of distal tibial physeal closure. These account for 2.5% of all pediatric ankle fractures. Undisplaced and minimally displaced fractures may be treated with immobilisation in a short leg cast. For fractures with >2 mm of displacement, anterior capsular interposition should be considered and thus an open reduction and removal of the capsule may be necessary with stabilisation with either a screw or a K-wire which may or may not be arthroscopically assisted [41-46].

Salter Harris IV: Salter Harris IV fractures are significant injuries that involve axial and/or shear forces that damages the proliferative zone of the physis. The principles of treatment of SH IV fractures are similar to other distal tibial physeal injuries previously mentioned with open reduction for anatomical restoration paramount and internal fixation to convert unstable injuries into stable injuries. There is substantial evidence that within the SH III and IV patients, exist undiagnosed SH V injuries, which may contribute to the rate of growth disturbance [41,47].

Triplane fractures, representing a special variant of SH IV injuries, are rare injuries representing 6.3% of physeal injuries, with a two-part fracture pattern being most common, these have a low risk of growth arrest. Extra-articular medial malleolar fractures were seen in 24% of fractures, which is more common than previously reported [17,48-55]. Minimally displaced and extra-articular triplane fractures may be treated with reduction and long leg immobilization [56]. Evidence shows that triplane fractures with <2 mm of weight-bearing articular surface step-off, as seen on a CT scan, are best treated with a closed reduction and percutaneous screws/wires to maintain anatomical reduction whilst immobilized [57]. Recent literature supports open reduction and internal fixation for fractures with >3 mm of initial displacement or >2 mm of residual intra-articular step-off [57-59]. We recommend post-reduction CT scan if the surgeon is unsure of the articular reduction, as long-term outcomes are improved with a more accurately reduced articular surface [59,60].

Conclusion

Distal tibial physeal injuries are complex injuries, which can pose the treating surgeon with immediate and long-term management dilemmas. These types of injury tend to affect the teenage population between the years of 10-16 and are often a result of twisting and turning type mechanisms. Literature has not significantly advocated much beyond orthogonal and mortise x-rays plus CT scanning as the limits of radiographic investigation. We draw attention of the reader to the value of the Salter-Harris classification system in terms of reproducibility, reliability, clinical relevance and we feel it represents 'a must know' classification for any orthopaedic surgeon. Treatment largely centres around anatomic reduction and suitable fixation dependent on articular involvement and/or pattern of injury, which may or may not be augmented by a period of immobilization (Table 1) [49,50].

We would encourage orthopaedic surgeons to be following up patients, particularly those with SH III or IV injuries for up to two years post-injury in concordance with current opinion to rule out the possibility of an undiagnosed SH V injury and/or long-term sequelae to the physis. The current literature has deficiencies in two main areas. Firstly, most studies are poorly powered and/or have low numbers in case series and most studies do not sub-stratify different sub-groups of physeal injury often combining SH I and II and comparing this against SH III and IV. This review is based on available literature and we would suggest more detailed, higher-powered studies with longer-term follow-up would allow a more precise understanding of this complex topic.

Paediatric ankle fractures	Site of Injury	Management
Salter-Harris I	Tibia +/- Fibula	MUA +/- Plater +/ORIF
Salter-Harris II	Tibia +/- Fibula	MUA +/- ORIF
Salter-Harris III	Tibia (Tillaux)	ORIF
Salter-Harris IV	Tibia (Triplanar + translation)	ORIF

Table 1: Summary of treatment recommendations.

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