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Pediatric Ankle Fractures: Concepts and Treatment Principles

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Synopsis

Current clinical concepts are reviewed regarding the epidemiology, anatomy, evaluation and treatment of pediatric ankle fractures. Correct diagnosis and management relies on appropriate exam, imaging, and knowledge of fracture patterns specific to children. Treatment is guided by patient history, physical examination, plain film radiographs and, in some instances, CT. Treatment goals are to restore acceptable limb alignment, physal anatomy, and joint congruency. For high risk physal fractures, patients should be monitored for growth disturbance as needed until skeletal maturity.

Keywords

ankle fracture; Salter-Harris; growth plate injury; physis; transitional fracture; pediatric sports injury; ankle trauma; leg length discrepancy; ankle angular deformity

Scope of Review

The present review discusses pediatric ankle fractures, defined as tibia and fibula fractures distal to the metaphysis in patients with open physes. The majority of these fractures are caused by sports injuries or low-energy trauma¹. The pediatric ankle with open physes and incomplete ossification presents distinct mechanical and biological properties compared to skeletally mature patients. Thus, children have unique ankle fracture patterns and require specific treatment to preserve and monitor the physis.

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Epidemiology

Ankle fractures represent around 5% of all fractures and 15–20% of all physeal injuries in children and are the most common physeal injury in the lower extremity.^{2–5} Ankle fractures also occur in adolescents and more frequently require surgical management than distal radius fractures and other common fractures. There is a higher incidence of ankle fractures in children with increased BMI.^{6, 7} Basketball, soccer, football, and scooters are the most common activities associated with ankle fractures.^{8–10,11}

Pediatric Ankle Anatomy

Of all physeal injuries, fractures of the distal tibial physis have among the highest rates of complications, including premature physeal arrest, bar formation, angular deformity, and articular incongruity^{12, 13}. The physis contains four zones, from the epiphysis to the metaphysis with decreasing mechanical strength due to decreasing matrix-cell ratio: reserve zone, proliferative zone, hypertrophic zone and the provisional calcification zone. Fracture typically occurs through the hypertrophic zone, which has the largest cells and less extracellular matrix than the other zones. For most fractures, this in turns preserves the reserve zone, which is located on the epiphyseal side of the fracture and contains the progenitor cells for physeal growth^{14, 15}. Fractures which cross the physis into the epiphysis (Salter Harris III and IV types), however, may damage the reserve zone and thus are at higher risk of causing physeal growth disturbance.

The distal tibial physis provides 40% of the growth of the tibia and 17% of lower extremity growth, with 3–4 mm of growth per year in childhood. Distal tibial growth occurs proportionately to the proximal tibia in young patients, but in adolescents the proximal tibia growth becomes more rapid and distal tibial growth tapers off¹⁶. Thus, injury to the physis at a young age can result in significant leg length discrepancy. The distal tibial ossification center appears around 6 months of age and the distal fibula around 1 to 3 years of age. Distal tibial and fibular physeal closure occurs around 12 to 17 years in females and 15 to 20 in males^{17, 18}. In contrast to other physes, tibial physeal closure occurs slowly and eccentrically, beginning around Poland's hump, and then anteromedially, posterolaterally, and finally anterolaterally. This pattern of closure explains the specific tibial physeal fracture patterns seen in adolescent triplane and Tillaux fractures. Physeal arrest is generally not a concern for triplane and Tillaux fractures, since the physis is already closing in these fracture patterns. Abundant blood supply is provided to the distal tibial physis, so post-traumatic avascular necrosis of the plafond is very rare.

The distal fibula is contained in a groove on the lateral distal tibia with significant ligamentous constraint with the anterior and posterior tibiofibular and calcaneofibular ligaments. Ligamentous structures in children are quite robust, whereas the physis is biomechanically vulnerable to shear and rotational forces. Thus, the same injury mechanism which may result in an ankle sprain in adults can present with physeal or avulsion fractures in children. The distal fibula physis becomes undulating during childhood, which does provide it with additional stability¹⁸. The distal fibula frequently has a secondary center of ossification which can mimic an avulsion fracture on radiograph. The medial os subtibiale is

more prevalent than the lateral os subfibulare.^{19, 20} Thus, clinical exam findings may be used to distinguish a nondisplaced avulsion fracture from an ossification center.

Growth of the fibula is evenly distributed between the proximal and distal tibia physis in childhood, although the proximal tibia growth becomes predominant in adolescents.²¹ Isolated physeal arrest of the fibula is rare, but can lead to ankle valgus and an external foot progression angle.

Patient Evaluation and Diagnosis

History

Patients frequently present following a twisting injury to the ankle. It is important to distinguish an ankle fracture from an ankle sprain. Hallmark findings include inability to bear weight, bony tenderness, swelling, or deformity.

Physical Exam

The skin should be evaluated for open wounds, ecchymoses, or abrasions. Edema and discoloration may develop over the first 24–48 hours after injury. Neurovascular status should be assessed, including a sensory exam, palpation of pulses, and testing of capillary refill. Then a focused exam should evaluate the site of maximal tenderness, specifically examining the distal tibial and fibular physes, medial and lateral malleoli, tibial and fibula shafts, the base of the 5th metatarsal and the peroneal tendons. A 5th metatarsal fracture or peroneal tendon subluxation may present as an ankle fracture. Ligamentous structures should be evaluated as well, including anterior and posterior talofibular ligaments, calcaneofibular ligaments, and anterior tibiofibular ligament. Maximal tenderness over the ligaments distal to the malleoli may indicate sprain rather than fracture. If the patient's condition will tolerate, a squeeze test can be performed proximally and stress test of the medial ligamentous complex with passive flexion and external rotation of the foot to assess for a ligamentous or syndesmotic injury.

Atypical Fractures

The treating physician should always assess for atypical presentations, such as absent or inadequate trauma history, antecedent pain, or constitutional symptoms. Small children are particularly at risk for misdiagnosis, as they may not be able to recount an episode of trauma and can develop hematogenous osteomyelitis with no associated risk factors which can mimic a fracture. Less common causes of atypical fractures include nonaccidental trauma or leukemia. Radiographs should always be evaluated for a lytic lesion or periosteal reaction adjacent to the fracture site. In addition, a history that does not match the presenting injury pattern should alert the physician of possible child abuse. Nearly half of the child abuse cases present with solitary fracture alone.²²

Radiographs

Ankle radiographs with three views should be used to selectively evaluate for fracture in patients with ankle injuries. The Ottawa Rules (bony tenderness along the malleoli, inability to bear weight) were developed for adults to help determine when radiographs are

necessary²³ and have been validated for children^{24, 25}, but have been criticized for having a high false negative rate in adults.^{26, 27} The Low Risk Ankle Rule has also been developed specifically for children to determine when a radiograph is needed and has been shown to reduce the number of radiographs and result in cost savings in the emergency department²⁸. Low risk ankle injuries are defined as sprains, nondisplaced Salter-Harris 1 and 2 fractures, and avulsion fractures of the distal fibula. X-rays are not required if there is only tenderness of the distal fibula or adjacent lateral ligaments²⁹.

Radiographic images should be evaluated for physeal widening, which may indicate a Salter Harris 1 fracture. The plafond and mortise should be carefully examined for evidence of an intra-articular fracture pattern, such as a Tillaux or triplane fracture, as these findings can be quite subtle. A Salter Harris 2 fracture of the fibula may only be visible on the lateral view and will be superimposed on the image of the lateral tibia. If displaced, this may result in a growth arrest.

If radiographs are suspicious for an intra-articular fracture pattern, a CT may be obtained to evaluate articular congruity, assess the need for surgical management, and assist in preoperative planning. This is most commonly indicated for Tillaux and triplane fractures, as most Salter Harris fractures can be assessed and treated without axial imaging. After viewing CT imaging, surgeons more frequently recommend surgical treatment for Tillaux and triplane fractures due to significant intra-articular step-offs that are difficult to appreciate on plain films³⁰. An MRI may provide similar information but has increased costs and at most centers is not as readily obtained as CT. Several reports show magnetic resonance imaging (MRI) specifically does not change in the treatment plan for acute pediatric ankle fractures.^{31, 32} It may however provide information for surgical planning, characterize suspected osteochondral injury, or rule out underlying tumor or infection.

Routine ankle stress views are not recommended for most pediatric ankle fractures. However, for adult ankle fracture equivalents (supination external rotation, SER pattern), a gravity stress view may be a useful tool to assess whether surgical management is indicated and whether weight-bearing can be initiated immediately.^{33, 34} Gravity stress views are well-tolerated and less painful than the traditional manual-stress radiograph.^{33, 34}

Fracture Classification

The Salter-Harris Classification is the most widely recognized system to describe physeal injuries.^{13, 35} This system is easy to apply, has good inter- and intra-observer reliability, and provides valuable prognostic information regarding growth arrest and subsequent complications.

The Dias-Tachdjian classification categorizes pediatric ankle fractures based on the applied traumatic force to the foot and the position of the foot when it sustains such force. If the pattern is recognized correctly, this system can potentially help on fracture reduction by reversing the applied force. However, the low inter-observer reliability and its complex nature render the system less popular. The Peterson classification has also been described.^{36, 37}

Salter-Harris Classification

The most common physeal ankle fracture is the Salter-Harris Type II (SH-II), which account for 32–40% of pediatric distal tibial fractures, then followed by SH-III (25%), SH-IV (up to 25%), SH-I (3–15%) and SH-V (less than 1%).^{8, 38} The prognosis of SH-I and SH-II is the best, followed by SH-III then SH-IV. This is believed to correlate with the magnitude of initial traumatic force and the resultant physeal injury. The strength of the physis is weaker at the metaphysis junction than at the epiphysis junction, therefore making SH-II the most common physeal fracture type. Salter-Harris Type VI has also been proposed as an open fracture with partial physis loss.³⁷

- a. SH-I (Fig. 1A): only involves the physis, with slight physeal widening or translation that may not be obvious in plain films
- b. SH-II (Fig. 1B–C): the fracture line extends from the physis into the metaphysis
- c. SH-III (Fig. 2A–B): the fracture line extends from the physis into the epiphysis
- d. SH-IV (Fig. 3A–E): the fracture line extends from the physis into both the metaphysis and the epiphysis
- e. SH-V: crush injury to the physis – rarely seen.

Transitional Fractures

Patients between 12 and 15 years of age with closing physes are susceptible to specific distal tibial fracture patterns. The Tillaux fracture (Fig. 4A–B) is a variant of SH-III fractures and represents avulsion of anterolateral distal tibia epiphysis at the insertion site of anterior inferior tibiofibular ligament. This accounts for less than 5% of pediatric ankle fractures, and may present together with a distal fibula fracture. Triplane fractures (Fig. 4C–D) are complex, three-dimensional SH-IV fractures, occurring in younger children than the Tillaux fractures. In younger adolescents, more of the distal tibial physis open and vulnerable to mechanical failure through multiple planes. By definition, there are fracture lines in three planes: coronal, sagittal and axial (transverse). The classical ones are lateral and medial triplane fractures. Lateral triplane fractures are the most common, with fracture lines in tibia metaphysis (coronal), epiphysis (sagittal) and the physis (axial), resulting in three parts: a spiky fragment in the medial epi-metaphysis, the tibia shaft, and a rectangular fragment in the lateral epiphysis. This can present as a 2-part fracture if the tibia shaft is not separated with the epi-metaphysis fragment. Medial triplane fractures are less common, with fracture lines in tibia epiphysis (coronal), metaphysis (sagittal) and the physis (axial). Intramalleolar fractures are triplane variants and can be subcategorized into intra-articular and extra-articular types.³⁹ A CT may be helpful to determine whether the fracture is intra-articular or displaced.

Treatment Strategies

General Concepts and Principles of Treatment

The long-term treatment aims are to minimize angular deformity and leg length discrepancy, to avoid post-traumatic arthritis, and to achieve normal ankle function. Intra-articular fractures should be reduced anatomically to restore joint surface congruency and to correct angular limb deformity. Articular step-off should be less than 1–2 mm.⁴⁰ In growing children with open physes, efforts should be made to achieve an anatomic reduction of the physis to facilitate physeal growth. Repeated or delayed manipulation of physeal fractures should be avoided, so as to avoid additional damage to the physis with incurrent risks of premature closure.^{38, 41}

Non-displaced fractures can be treated with a cast. Weightbearing status and duration of the immobilization depends on fracture type and stability. Low risk ankle fractures such as distal fibular avulsion fractures, nondisplaced fibular SH-I fractures, or lateral talus avulsion fractures may be treated in an air splint or walking boot.^{42–44} SH-I distal fibular fractures may be far less common than previously thought. A recent report of 18 SH-I fracture cases who underwent research MR imaging revealed intact physis in 100%, and ligament injury in 90% of all cases⁴⁵. Physeal arrest after nondisplaced fibula fractures has not been reported in the literature, furthering the support for expectant management of these fracture patterns with immediate weightbearing as tolerated and immobilization as needed for comfort⁴⁶.

Simple displaced tibia and fibula fractures can be managed with closed reduction (CR) and casting. Unstable fracture patterns may require percutaneous fixation or open reduction if a satisfactory closed reduction cannot be maintained. A long leg cast with the knee flexed will add rotational stability and may prevent displacement after successful closed reduction. Open reduction and internal fixation (ORIF) is recommended for displaced intra-articular fractures. Partially threaded cannulated screws or smooth pins are used for internal fixation, although adolescents with extensile fracture pattern may occasionally need a plate-screw construct. Percutaneous insertion of screws and pins is used when possible. Implants which cross the physis should be avoided when possible in skeletally immature patients, as they may result in growth arrest. If fixation across the physis is inevitable in children with open physes, use only smooth pins instead of screw or threaded wires and plan for early removal postoperatively.

Screw removal may be offered for symptomatic implants, but delayed removal of partially threaded screws may be difficult. Some authors favor the use of bioabsorbable screws for epiphyseal fixation, which obviates the need for removal and may have less effect on joint contact forces and articular pressures compared to metal implants^{47, 48}. In our clinical practice, however, we favor metal implants for ease of use and perceived improved purchase. Screws are removed electively as indicated by patient symptoms.

Management of Displaced Physeal Fractures

Significant physeal fractures are typically managed with 6 weeks of nonweightbearing. Anatomic alignment should be restored with closed or open reduction as needed if there is interposed periosteum or a block to reduction. Closed reduction may be successful for SH-I

and SH-II fracture patterns. Displaced SH-III and –IV fracture patterns benefit from anatomic reduction, internal fixation, and restoration of joint space congruity. Surgical fixation has been associated with lower rate of physeal arrest following these fractures compared to closed reduction alone.⁴⁹ In the case of open reduction, it is important to avoid extensive dissection or periosteal stripping at the physis, as this may contribute to premature physeal arrest.

Displaced Tillaux and triplane fractures may be treated with attempted closed reduction. Closed reduction for a Tillaux fracture entails plantarflexion and internal rotation and manual pressure over the displaced fragment. Triplane fractures may be reduced with axial traction and internal rotation. A long leg cast is applied with the foot internally rotated. A CT is best obtained after closed reduction to assess the adequacy of alignment and whether surgical management is necessary. If the reduction is satisfactory, weekly radiographs should be obtained to ensure maintenance of alignment for three weeks, at which point the child can be transitioned to a short leg nonweightbearing cast for an additional three weeks. If the articular alignment is not anatomic, open reduction and internal fixation is recommended.

Displaced distal fibula fractures frequently accompany distal tibial fractures, but can also present in isolation. In contrast to isolated distal tibial fractures, there is a very low risk of isolated fibular growth physeal arrest⁴⁶. For displaced fibular fracture associated with a tibia fracture, reduction of the tibial fracture usually results in reduction of the fibula as well. Occasionally a greenstick or displaced fibula fracture will block reduction of the distal tibia fracture, in which case closed or open reduction of the fibula may be necessary. In cases with need for additional stability, pinning of the fibula usually provides sufficient fixation.

Complications

Maintenance of bony alignment, joint space congruency, and restoration of physeal anatomy are the primary concerns in the early follow-up period. During the mid-term to long-term follow-up periods, patients with growth remaining may require monitoring for growth arrest and subsequent angular deformity or leg length discrepancy.

For patients at high risk of growth arrest, a baseline scanogram and hand bone age may be helpful to confirm an arrest and to predict anticipated growth remaining and projected leg length discrepancy at skeletal maturity.

Growth Disturbance

The overall risk of premature physeal closure ranges from 2–67% for SH-I and SH-II fractures, and 8–50% for SH-III and SH-IV fractures.^{12, 38, 41, 49, 50} Fracture type, high energy trauma, higher initial displacement and multiple manipulation attempts are associated with growth arrest.³⁸ Barmada et al. found higher rates of physeal arrest (60% vs. 17%) if a residual gap > 3 mm was seen at the physis for SH-I and II fracture patterns,⁴¹ and recommended open reduction to remove entrapped periosteum in these settings.

High risk patients are followed for several years until normative growth of the physis is established. Symmetric Park-Harris growth resumption lines will show restoration of

physeal growth. (Fig. 1C) In contrast, Park-Harris growth arrest lines that are incomplete or tracked to the physis are indicative of physeal bar formation. (Fig. 3B). Complete growth arrest can result in leg length discrepancy without angular deformity, while partial growth arrest may cause progressive angular deformity.⁵¹ The treatment for complete growth arrest depends on the expected remaining growth of the distal tibia and the extent of physeal bar, typically measured on CT. If the remaining growth is less than 1 cm, nonoperative management may be fine. If the remaining growth is more than 1 cm or the child has more than 3 years of growth remaining, physeal bar excision can be performed if less than 50% of the physis is involved. If there is less than 3 years of growth remaining and a progressive leg length discrepancy and/or angular deformity, tibial and fibular epiphyseodesis may be performed to prevent progression of the deformity. Contralateral epiphyseodesis may be considered as well to prevent worsening leg length discrepancy until the completion of skeletal growth. If more than 50% of the physis is involved and the predicted leg length discrepancy is significant, future limb lengthening surgery may be discussed. Attempted physeal bar resection may be indicated in the very young child as it is significantly less morbid than a limb lengthening procedure.

Angular deformity from physeal arrest or malunion may alter the ankle joint biomechanics, ankle range of motion, and increase joint contact stress, resulting in early arthritis. Angular deformity from malunion remote from the physis can be treated with guided growth/temporary epiphyseodesis plates if the patient is skeletally immature with sufficient growth remaining. Guided growth should not be attempted in conjunction with physeal bar resection due to risks of excessive tethering of the normal growth plate. For severe angular deformity, corrective procedures such as osteotomy may be performed either in isolation or at the time of physeal bar resection. The acceptable range of angular deformity and indication for surgical correction has not been well established. Children with isolated or combined angulation of 5° in coronal or 10° sagittal plane,^{52,12} may remain clinically asymptomatic and fully functional in daily activities, but may be at increased risk of arthritis in adulthood.

Ankle Joint Problems

Intra-articular ankle fractures may predispose a patient to future ankle arthritis, stiffness and persistent pain. SH-III and SH-IV distal tibial fractures carry higher risks of post-traumatic arthritis. In a series of 68 patients with average 27 years of follow up, 11.8% of patients developed radiographic signs of ankle arthritis, most commonly associated with persistent varus or valgus angular deformity of five degrees or more.⁵¹ Overall, 29% of all SH-III and SH-IV patients developed radiographic signs of ankle arthritis.⁵¹ The risk of ankle arthritis is decreased by anatomical reduction.⁵³ Stiffness may be addressed with physical therapy and rehabilitation programs. MRI can be considered for persistent mechanical symptoms, which may indicate osteochondral lesions. Reflex sympathetic dystrophy (RSD), also known as complex regional pain syndrome (CRPS), is a rare but frustrating complication after ankle injury; the prevalence is higher in young girls than boys.⁵⁴ The treatment is limited to physical and psychological therapies, although most pediatric patients note symptom improvement over time.

Conclusions and Future Directions

The general concepts and principles of treatment for pediatric ankle fractures are similar to those for other pediatric physal injuries. Treatment for premature physal closure focuses on addressing the resultant angular deformity or LLD. Future direction may involve biological solution to salvage or resume the viability of the injured growth plate. Successful outcomes depend on early recognition and treatment of specific pediatric ankle fracture patterns.

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Key Points

- Pediatric ankle fractures account for 15% of all physeal injuries.
- The Salter-Harris Classification is the most widely adopted system.
- Salter-Harris Type III & IV fractures more frequently require operative treatment and may result in growth arrest.
- Local soft tissue swelling and inability to bear weight should prompt radiographs to assess for fracture.
- Tillaux and triplane injuries are specific fracture patterns which occur as the physis closes, may be missed on plain radiographs, and frequently require surgical management to restore congruency of the articular surface.

Fig. 1.

(A) Salter-Harris Type I fracture. Note the widening of the physis at the medial side of distal tibia (red arrows) and the adjacent soft tissue swelling (blue arrows), even though no obvious fracture lines were seen. (B) Salter-Harris Type II fracture. The fracture line extended into the metaphysis (red arrows) and was seen clearly in the lateral view. Casting resulted in satisfactory outcome in both patients. (C) Park-Harris line (blue arrows) symmetric to the uninjured ankle (yellow arrows) and parallel to the physis with longitudinal growth at one year follow-up, indicating restoration of normal physeal growth.

Fig. 2.

(A) Salter-Harris Type III fracture with a displaced medial tibial epiphyseal fragment (red arrows) was treated by open reduction with two parallel cannulated screws fixation. (B) CT scan excluded extension of the fracture into the tibial metaphysis and confirmed the SH-III diagnosis.

Fig. 3.

(A) Salter-Harris Type IV fracture with a displaced medial tibial epiphyseal fragment (red arrows) and a posteromedial metaphyseal fragment (blue arrows), treated by open reduction with cannulated screw fixation. Also note the widening and translation at the distal fibular physis (green arrows) implicating a SH-I fracture. (B) Follow up of the SH-IV fracture in (A) revealed progressive angular deformity, with Park-Harris growth arrest lines (red) that is not symmetric to the normal side (blue arrows). (C) Clinical photo showing varus deformity of the hindfoot on the right. (D) Physal bar resection and Cranioplast® interposition were performed with radiolucent bone markers to monitor growth. (E) One year following physal bar resection, a Park-Harris growth resumption line (green arrows) is now visible and the right distal tibial physis has grown.

Fig. 4.

(A) Juvenile Tillaux fracture with an avulsion of lateral tibial epiphysis (red arrows) was treated by open reduction with cannulated screw fixation. Also note the co-existing SH-IV distal fibular fracture (green arrows) (B) CT scan confirmed the diagnosis of Tillaux fracture and showed that the physis is closed in the medial side of distal tibia. The tibio-talar joint was visualized during surgery. (blue arrows) (C) Triplane fracture with coronal fracture line (red arrows) in both epiphysis and metaphysis, axial fracture line in the physis as well as metaphyseal fracture line in the sagittal plane (blue arrows), as clearly identified in (D) CT scan.