Acute fractures of the pediatric foot and ankle

Mansur Halai, Bilal Jamal, Paul Rea, Mobeen Qureshi, Anand Pillai
Glasgow, UK

Background: Injuries around the foot and ankle are challenging. There is a paucity of literature, outside that of specialist orthopedic journals, that focuses on this subject in the pediatric population.

Data sources: In this review, we outline pediatric foot and ankle fractures in an anatomically oriented manner from the current literature. Our aim is to aid the emergency department doctor to manage these challenging injuries more effectively in the acute setting.

Results: These injuries require a detailed history and examination to aid the diagnosis. Often, plain radiographs are sufficient, but more complex injuries require the use of magnetic resonance imaging. Treatment is dependent on the proximity to skeletal maturity and the degree of displacement of fracture. Children have a marked ability to remodel after fractures and therefore mainstay treatment is immobilization by a cast or splint. Operative fixation, although uncommon in this population, may be necessary with adolescents, certain unstable injuries or in cases with displaced articular surface. In the setting of severe foot trauma, skin compromise and compartment syndrome of the foot must be excluded.

Conclusion: The integrity of the physis, articular surface and soft tissues are all equally important in treating these injuries.

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Key words: ankle;
            foot;
            fractures

Introduction

Injuries around the juvenile foot and ankle constitute a complex problem for a number of reasons. This group of injuries are common and have been reported to account for 14% of attendances at the outpatient department.[1] The anatomical differences between the pediatric and adult populations predispose the former to an entirely different set of injuries than adults. Therefore, a sound understanding of the bony, ligamentous and developmental anatomy of the skeletally immature foot and ankle is crucial when treating these injuries. Normal anatomical variants, when unrecognized, can cause undue anxiety to both the clinician and family. Furthermore, children can prove difficult to glean a succinct history from, especially in the context of pain, which will impact on diagnostic accuracy.[2] We do not include the myriad of overuse injuries, which present in a more chronic manner. In this article, we describe the pertinent anatomy, history, physical examination, diagnosis and basic treatment guidelines of the common acute foot and ankle injuries, in an anatomically oriented fashion. Our aim is to aid the emergency department doctor to manage these challenging acute injuries more effectively.

Anatomy

The ankle is a synovial hinge joint comprising of the tibia and fibula which articulate around the central talus. Its role is to transfer force from the foot to the rest of the axial skeleton (and vice versa), allow stability when mobilizing and to allow foot movements.[3] This complex is frequently referred to as the ankle mortise. Movement occurs in dorsiflexion and plantar flexion. The commonly used terms of supination (plantarflexion with inversion and adduction) and pronation (dorsiflexion with eversion and abduction) refer to triplanar composite ankle movements.[4] Stability of the ankle joint is offered by the bony and ligamentous anatomy. The talus is wider anteriorly such that the ankle is more stable in dorsiflexion. Static stability is provided by the lateral ligamentous complex (anterior talofibular, calcaneofibular and posterior talofibular ligaments) and the medial deltoid ligament complex (superficial and deep). Dynamic stability is offered by the peroneal tendons laterally and by the tibialis posterior medially. The distal tibio-fibular joint also accounts for some minor movement at the ankle joint. The bony and ligamentous anatomy of the foot and ankle joint are

Author Affiliations: Department of Trauma and Orthopedics, University Hospitals of South Manchester, Manchester M23 9LT, UK (Halai M, Jamal B, Rea P, Qureshi M, Pillai A)

Corresponding Author: Mansur Halai, MRCS, Department of Trauma and Orthopedics, Southern General Hospital, Glasgow, G51 4TF, UK (Email: mansurhalai@googlemail.com)

summarized in Figs. 1 and 2 from specimens taken from our anatomy laboratory.

Moving distally, the hindfoot comprises the talus and the calcaneus. They articulate with each other at the subtalar joint. The midfoot contains the tarsal bones (navicular, cuboid and three cuneiforms). The articulation between the talus and navicular and the calcaneum and cuboid (chopart joint) forms a functional unit referred to as the transverse tarsal joint. Finally, the forefoot consists of the metatarsals and phalanges. The hind, mid and forefoot collectively function to support the body, dissipate forces from impact and to provide a rigid base for ambulation. The LisFranc joint merits special attention as injury here is often missed.[5] It refers to the articulation involving the 1st and 2nd metatarsals with the medial (1st) and middle cuneiforms. The keystone wedging of the 2nd metatarsal into the middle cuneiform forms the focal point that supports the entire tarsometatarsal articulation. Transverse ligaments connect the bases of the lateral four metatarsals; however, no such transverse ligament exists between the base of the first and second metatarsals. The LisFranc ligament primarily connects the plantar base of the 2nd metatarsal to the plantar surface medial cuneiform (Fig. 1A).

The history

A complete account of the preceding events is important with an emphasis on the mechanism of injury (high/low velocity, twisting, compression, direct blow) and the characteristics of the pain. The location of pain, in our opinion, is the most important factor in aiding diagnosis from the history. A pertinent question is to ask about a previous fracture to the area as old fractures can often

masquerade as fresh injuries on radiographs.[6] Consistency and plausibility of the story is vital to determine, as these may be the early clues to a non-accidental injury.[7] The effect of the injury of the child should be noted. For example, is the child limping? Analgesia usage can give an insight to the severity.

The clinical examination

Examination is tailored to according to the history provided by the patient and other witnesses. General orthopedic examination relies upon examination of the joint proximal and distal to the zone of injury. The ankle is inspected for open wounds. Wounds overlying a fracture site constitute an open fracture and are an orthopedic emergency. These have been ably described by Gustilo and Anderson.[8] Similarly, any pressure on the skin from a displaced fracture necessitates urgent reduction as the soft tissues can rapidly become compromised. The injured extremity should be examined for swelling and ecchymosis. Palpation should be systematic and include palpation of the deltoid ligament posteromedially, the medial malleolus, tibialis anterior, the syndesmotic ligaments, the lateral ligamentous complex and the lateral malleolus. The calcaneum and the midfoot bones should then be palpated in a similar stepwise manner. Each metatarsal should be examined proximal to distal. Tenderness along the course of the Achilles tendon, the peroneals laterally or tibialis posterior will alert the clinician to an overuse tendonitis.

The ankle plantar-flexes to 40°, but only dorsi-flexes to 10°. Other movements to note are: subtalar eversion (15°-20°), subtalar inversion (35°-40°), forefoot adduction (20°), forefoot abduction (10°), 1st
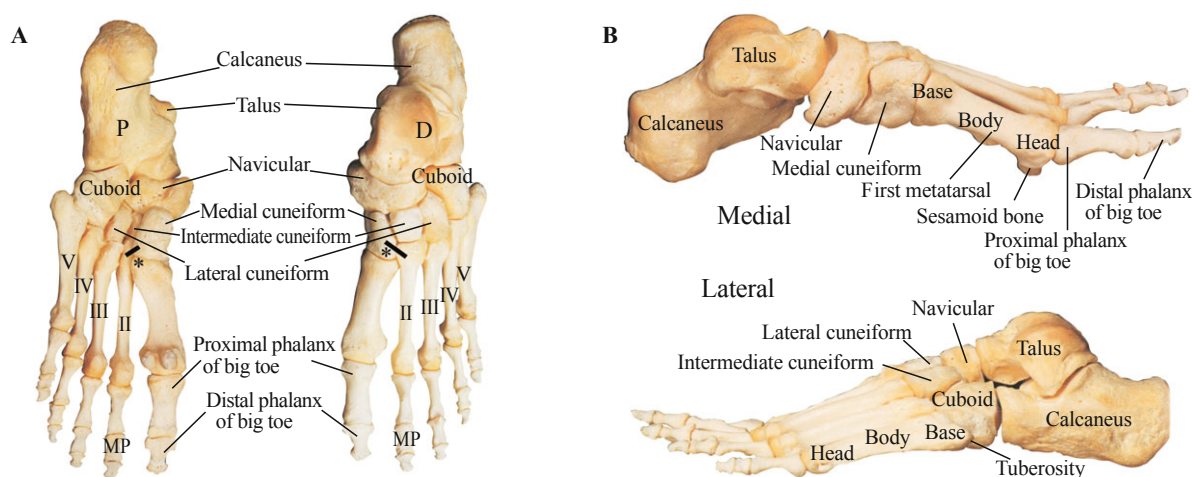
Fig. 1. The bony anatomy of the foot and ankle in cadaveric samples from our laboratory. Pictures are from plantar and dorsal (A), medial and lateral aspects (B). MP: middle phalynx; P: plantar; D: dorsal. *: LisFranc ligament.

metatarsal phalangeal joint (MTP) flexion (45°), 1st MTP extension (70°-90°) and free motion of lesser toes. It is usual practice to first perform active movements, followed by passive movements. As always, excessive disproportional pain with passive movement should alert the clinician to the possibility of compartment syndrome of the foot.[9]

The neurovascular status of the extremity should always be noted. In particular, we recommend that if a manipulation has been performed, neurovascular examination should be documented pre and post-manipulation, for medico-legal purposes. Broadly, the 2 pulses to check are the dorsalis pedis and posterior tibial arteries. The 5 sensory nerves to check are the saphenous (medial calf and hindfoot), superficial peroneal (dorsum of the foot), deep peroneal (1st dorsal webspace), sural (lateral foot) and posterior tibial nerve (plantar foot and heel). The achilles reflex tests the S1 nerve root.

Investigations

Laboratory tests are seldom required in the acute setting. However if there is a possibility of an infective etiology, inflammatory markers should be requested. Although originally described for adults, the Ottawa ankle rules have been shown to be useful in children over 10 years to decrease the number of unnecessary radiographs.[10] According to these Ottawa ankle rules, an ankle and foot X-ray is only required if there is bone tenderness at the posterior edge of the lateral or medial malleolus, 5th metatarsal or navicular. Also if the patient is unable to weight bear in the emergency department, an X-ray is recommended. A summary of these rules is presented in Table. In addition to the standard anteroposterior and lateral radiographs, the clinician should also request a mortise ankle view. This is performed with an affected leg lying in 15° of internal rotation to allow visualization of the tibio-talar joint line.[11] For further visualisation, we recommend magnetic resonance imaging (MRI) as it provides superior detail of the articular and physeal cartilage, periosteum and bone marrow, compared to computed tomography (CT), and avoids the radiation exposure.[12]

The physis

The presence of an epiphyseal growth plate (physis) is the crucial difference when comparing pediatric injuries to adult injuries. In long bones, this plate is located between the proximal metaphysis and the distal epiphysis. Due to the high turnover of bone at the physis, the plate is relatively weak and prone to injury.[13] Epiphyseal injuries can be as a result of developmental growth anomalies (bony coalitions or accessory ossification centers), chronic overuse (osteochondroses or apophysitis) or acute traumatic injuries.[14] We will elaborate on the latter.

Acute epiphyseal fracture classification

A review on acute pediatric foot and ankle injuries must commence with an explanation of the widely used 1963 classical description by Salter and Harris.[15] It also

Table. A summary of the Ottawa ankle rules[10] that assist the doctor when to request an ankle or foot X-ray in the acute setting

Indications for ankle X-ray:
Tenderness over the inferior or posterior pole of either malleolus, including the distal 6 cm;
Patient cannot weight bear 4 steps independently since the injury and at examination.
Indications for foot X-ray:
Tenderness along the 5th metatarsal base or the navicular;
Patient cannot weight bear 4 steps independently since the injury and at examination.
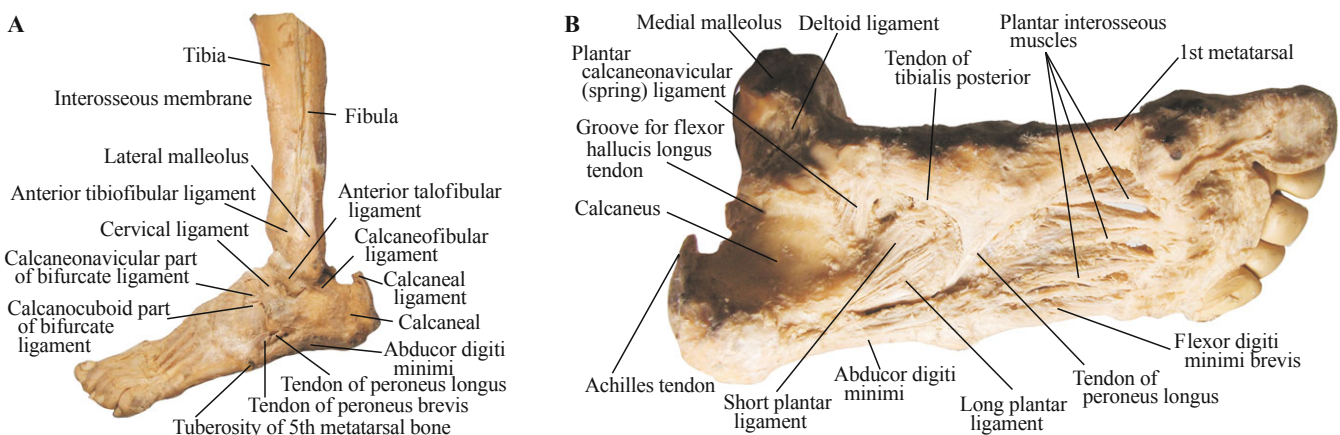

A
- Tibia
- Interosseous membrane
- Fibula
- Lateral malleolus
- Anterior tibiofibular ligament
- Anterior talofibular ligament
- Cervical ligament
- Calcaneofibular ligament
- Calcaneonavicular part of bifurcate ligament
- Calcaneal ligament
- Calcaneocuboid part of bifurcate ligament
- Calcaneal
- Abducor digiti minimi
- Tendon of peroneus longus
- Tendon of peroneus brevis
- Tuberosity of 5th metatarsal bone

B
- Medial malleolus
- Deltoid ligament
- Plantar interosseous muscles
- Plantar calcaneonavicular (spring) ligament
- Tendon of tibialis posterior
- 1st metatarsal
- Groove for flexor hallucis longus tendon
- Calcaneus
- Achilles tendon
- Short plantar ligament
- Abducor digiti minimi
- Long plantar ligament
- Tendon of peroneus longus
- Flexor digiti minimi brevis

Fig. 2. The ligamentous anatomy of the ankle in cadaveric samples from our laboratory: lateral **(A)**, medial **(B)**.

gives information about the prognosis and implications for potential growth disturbance. Five types were originally described and are illustrated in Fig. 3; the most common being type 2, with type 5 having the highest likelihood of growth arrest.[16] However, in the foot and ankle, a type 1 fracture of the distal fibula is the most frequent fracture and usually corresponds to a lateral ankle sprain with no involvement of the metaphysis or epiphysis.

Salter-Harris type 1 involves only the growth plate and type 2 involves both the physis and part of the corresponding metaphysis. Type 3 fractures extend from the growth plate into the epiphysis, and type 4 fractures extend from the metaphysis to the epiphysis, through the growth plate. Salter-Harris type 5 presents with no acute radiographic abnormality, but the key is in the history of a crushing mechanism. These rare type 5 fractures are often seen retrospectively as they are a cause of premature growth arrest.[17]

The treatment of physeal injuries is pivotal on the patient's age. Accordingly, if the patient is near skeletal maturity, there is less cause for concern regarding premature physeal growth arrest and corresponding limb length inequality. The converse is also true. Generally, these fractures heal in 4 to 6 weeks. Reduction of the fracture is crucial. If the fracture is reduced in an aligned position, the fracture can be treated non-operatively in a below knee walking cast, and it is the usual treatment for type 1 and 2 fractures. The key is monitoring the fracture in the outpatient clinic at weeks 1 and 2 post injury. At these visits, a check radiograph is recommended.[18] Any initial or subsequent displacement merits closed reduction under anesthesia with the supplementation of a wire, or screws for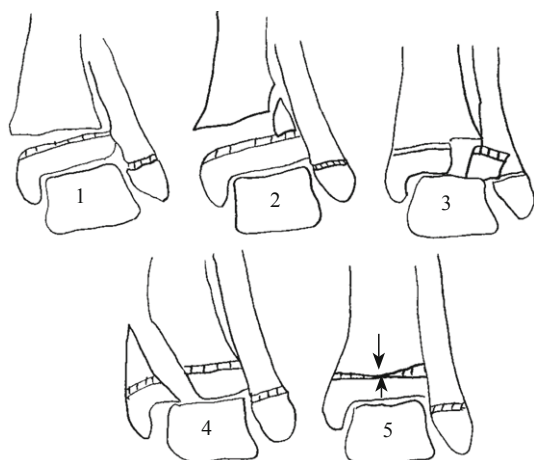 longer metaphyseal fragments, if necessary to maintain the reduction. The wire is then removed once healing has occurred both radiologically and clinically. Types 3 and 4 fractures require a closed reduction more often but if their displacement is more than 2 mm, an open reduction with internal fixation may be necessary. In those patients in whom closed reduction is not possible, one must remain aware of the possibility of soft tissue interposition at the fracture site, usually by the periosteum. If the treating doctor is unsure about the possibility of a physeal fracture (for example type 5), the options are either to immobilize the child in a cast and review in a week or to perform an MRI scan of the extremity. MRI may demonstrate associated soft tissue injury and subperiosteal bruising which are subtle signs of a fracture.[19] Two specific pediatric epiphyseal fractures that require separate elaboration are the triplane fracture and the juvenile tillaux fracture.

Triplane fracture

As the name suggests, this is a multiplanar fracture. Classically, the fracture extends through the sagittal (epiphysis), axial (physis) and coronal (distal tibial metaphysis) anatomic planes, disrupting the tibial plafond (Fig. 4). These fractures are similar to the aforementioned tillaux; they occur in adolescence with a partially fused physis (anterolateral plate is still open) and external rotation is the deforming force. Radiographically, these injuries appear as Salter Harris type 3 injuries on the anteroposterior (AP) radiograph and a type 2 injury on the lateral. True appreciation of the fracture pattern is difficult from plain X-rays alone. MRI is valuable in delineating fracture geometry with management, as always, depending upon displacement. Less than 2 mm of displacement can be accommodated in cast, but >2 mm of displacement merits open anatomical reduction and rigid internal fixation with screws, with care taken not to breach the physis.[20]

Juvenile tillaux fracture

This Salter-Harris type 3 injury is a fracture of the anterolateral tibial epiphysis (Fig. 5). It frequently presents in adolescence because the central and posteromedial segments of the physis have fused first, leaving the partially open anterolateral side. With external rotation of the foot, the strong anterior inferior tibiofibular ligament pulls off bone from the distal tibial epiphysis with the fracture line then propagating until it meets the fused physis and then passes through the epiphysis into the joint. Children present with anterior ankle pain and swelling in the setting of an external rotation injury. Occasionally, CT is required if the
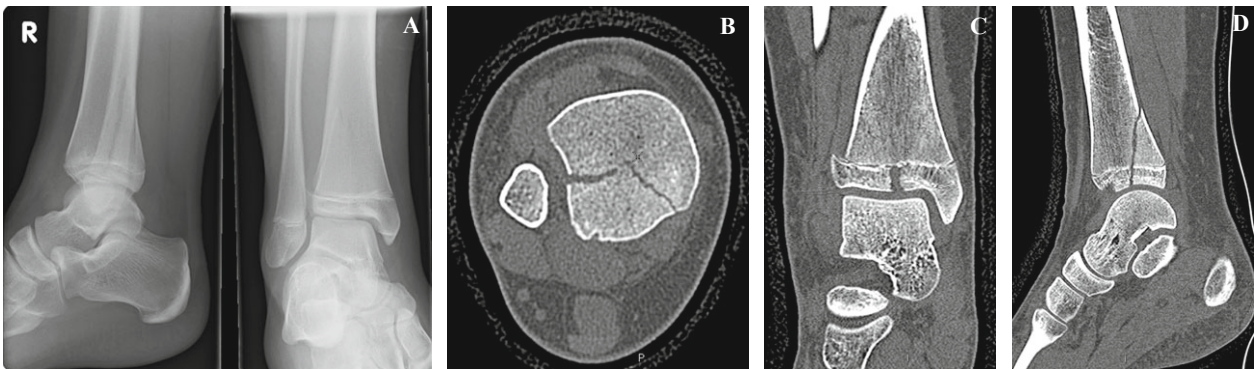

Fig. 3. The Salter-Harris classification of physeal injuries of a left ankle illustrated in the diagrams below, which were drawn by our artist. They are labelled 1-5 as per the original classification. Arrow: the crushing forces onto the growth plate (physis).

Fig. 4. Plain X-rays **(A)** and corresponding computed tomography slices illustrating a right triplane fracture in the axial **(B)**, coronal **(C)** and sagittal slices **(D)**.

Fig. 5. Computed tomography with 3-D reconstruction illustrating a right displaced juvenile tillaux fracture in the coronal plane.

fracture displacement is not clear on plain radiographs due to the oblique plane of the epiphyseal fracture.[21]

Non-operative treatment requires an attempt at closed reduction with internal rotation of the ankle and supination of the foot.[22] A long leg cast should be used initially. Open reduction and fixation may be required if >2 mm of displacement persists. Growth arrest seldom complicates a tillaux fracture because by the late teens, most of the physis has already fused. Nevertheless avoiding diastasis at the inferior tibiofibular joint and restoring of joint congruity is essential.[23]

Lateral ligament complex sprain

Anterolateral pain following an ankle injury is common, with inversion being the mechanism of injury in the majority. The most commonly injured ligament is the anterior talofibular ligament, with the calcaneofibular being involved less commonly (Fig. 2A). The usual complaint is pain over the lateral malleolus with difficulty weight bearing, accompanying anterolateral

bruising, swelling and/or tenderness of the lateral ligaments. The Ottawa ankle rules are applied regarding plain imaging and it must be noted that in the pediatric population, physeal fractures are more common than sprains due to the relative weakness of the developing growth plate which renders it more susceptible to injury. The principles of PRICE (protect, rest, ice, compression, elevation) are in general the treatment of choice for lateral ligamentous sprains. Rarely, cast immobilisation is required until the pain settles but a more effective method is functional bracing.[24] To prevent recurring injuries, it is recommended to wear a brace for 3 months following a return to activity. The differential diagnosis to consider includes interruption of the syndesmotic ligament between the tibia and fibula (which is palpated proximal to the ankle joint) and a fracture at the base of the 5th metatarsal.

Tarsometatarsal (lisfranc) injury

As described previously, this injury is challenging to manage as its spectrum is wide. The common mechanism of injury is rotation and axial loading through the plantarflexed foot causing the proximal 2nd metatarsal to dislocate dorsally. Thus, the injury is common in footballers or children jumping from a height. They present with midfoot pain, swelling, plantar bruising and an inability to bear weight.[25] Plantar bruising is present because the main part of the ligament runs from the plantar base of the 2nd metatarsal to the plantar surface medial cuneiform (Fig. 1A). Subtle clues on the AP radiographs include a widened distance between the 1st and 2nd metatarsal bases, an avulsion fracture from the base of the 2nd metatarsal, or in toddlers, there may only be minor buckling of the proximal 1st metatarsal cortex. It has been recommended to perform comparison radiographs of the unaffected contralateral foot to aid diagnosis.[26]

It is worth noting that by age 2.5 years, 2 ossification centers are calcified in the 1st metatarsal epiphysis. MRI in older children is often required to determine if fixation is needed or if the diagnosis is in doubt. Reports[27] suggest that up to 20% of these injuries are missed on initial presentation and this explains the low threshold for further investigation. While commonly treated operatively, these can be immobilized in a cast for 6 weeks if the malalignment is <2 mm.[28]

Metatarsal fractures

Certain trends have been documented by Singer et al[29] regarding metatarsal fractures in children. Over the age of 5 years, the 5th metatarsal is the commonest fracture but under 5 years, it is the 1st metatarsal that is the most commonly fractured foot bone. Another observation is that the 1st or 5th metatarsals usually occur in isolation but fractures of the 2-4th, are frequently accompanied by a neighbouring metatarsal fracture. These injuries typically present with pain and swelling over the corresponding dorsum of the foot.

The first ray is special with its short and strong profile and absence of an intermetatarsal ligament at its neck. Of all the metatarsals, displacement should be least tolerated here as it directly affects the weight-bearing biomechanics. Injuries to the 2-4th metatarsals are often managed non-operatively but more than 20° of angulation in any plane merits reduction as it can lead to shortening of the first metatarsal. This would cause the weight to be taken by the lesser metatarsals resulting in a painful gait. A useful manoeuver is to pull the toes upwards from the bed and use the weight of the leg to reduce the fractures and then apply the cast. Temporary fixation may be required for unstable fractures or multiple fractures that cannot be reduced closed. The 5th metatarsal, like the first, brings some unique challenges and sometimes these fractures do not heal at the proximal shaft. The reason for this is because it is a transition zone between two different blood supplies and therefore a fracture at the proximal shaft may disrupt the blood supply to the fracture and delay healing. These fractures merit a longer period of immobilization and protected weight-bearing (6-8 weeks) with follow-up radiographs to check for union. Clinicians should remember that there is an apophyseal growth center at the 5th metatarsal base, appearing at age of 9-12 years. It is sagittal in orientation whereas fractures typically are transverse here.

Conclusions

The presence of the growth plate makes the pediatric population's injury patterns different from those seen in adults. We have outlined, in an anatomically oriented manner, the most common presentations that will be relevant to the emergency department doctor.

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