

Common Injuries of the Foot and Ankle in the Child and Adolescent Athlete

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One of the most commonly injured parts of the body in adolescent athletes is the foot and ankle. It can account for up to 30% of visits to sports medicine clinics [1,2]. Ankle sprains alone account for 10% of all injuries seen in the emergency room [3]. Different sports can cause different types of injuries in the foot and ankle. In basketball, for example, foot and ankle injuries have been shown to account for 44% to 45% of all injuries in adolescent athletes, and in the adolescent football player, the foot and ankle make up 13% to 16% of all injuries [4–6]. Most of these injuries are lateral ankle sprains. Long distance runners report foot injuries as the most common injury they sustain [7–9], and adolescent runners are susceptible to overuse type of injuries [10]. Young dancers and gymnasts also have a high percentage of foot and ankle injuries, with their specific sports mechanics often predisposing to acute fractures and fatigue fractures [11,12]. It is important that physicians feel comfortable with the common injuries that can occur in the foot and ankle and be able to identify these injuries in the young athlete.

When treating young athletes, physicians must keep in mind the anatomic developmental differences that exist between the skeletally mature and the skeletally immature foot and ankle. These anatomic differences predispose young athletes to an entirely different set of injuries than the adult athlete. A thorough understanding of general bony, ligamentous, and muscular

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anatomy of the foot and ankle is also valuable to be able to accurately devise a differential diagnosis based on symptom location.

In this article we first address, define, and explain the types of injuries and injury patterns germane to the developing skeletally immature athlete. Next, before discussing all the common injuries, we present a brief anatomic review of the basic bony anatomy of the ankle and foot for reference purposes. In an anatomically oriented fashion, we outline the most common injuries noted in the pediatric and adolescent ankle and foot. There is emphasis on history, physical examination, diagnosis, and basic treatment guidelines. We look at the lateral ankle, the medial and anterior ankle, and the hindfoot, midfoot, and forefoot.

Injury patterns in the developing athlete

The presence of a growth plate, known as the physis or the epiphyseal plate, is a major difference in developing musculoskeletal structures that is not seen in the fully mature skeleton. The long bones of children contain the physis between the metaphysis and the epiphysis (Fig. 1). Bone is laid down for growth in the physis; however, this area is not a stable and strong area because it is constantly changing and remodeling. There is relative weakness at the growth plate and its surrounding bony structures as compared with the ligamentous structures about the pediatric and adolescent foot and ankle [1]. The epiphyseal plate is also less resistant to shear and tensile forces than the adjacent bony structures [13]. In adults, the opposite is true. The bone is strong, and the sites of injuries are in the ligamentous and muscular structures because they are the weaker points [14]. For example, where an inversion rollover injury would cause ligamentous injury in an adult, it is much more likely to cause injury at the growth plate in a child, possibly leading to a fracture of the physis or epiphyseal plate.

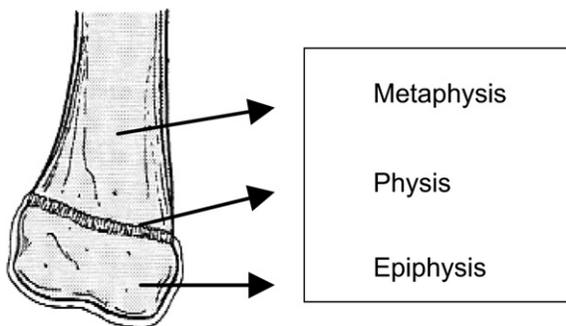


Fig. 1. A pictorial depiction of the metaphysis, physis, and epiphysis of the developing bone. (Adapted from Canale ST. Physeal injuries. In: Green NE, Swiontkowski MF, editors. Skeletal trauma in children. 3rd edition. Philadelphia: WB Saunders; 2003. p. 17–56; with permission.)

Generally, the injuries seen in skeletally immature athletes can be divided into three main categories: (1) injuries related to growth, (2) overuse injuries, and (3) acute presentations [13–15]. Pain related to growth stems from bony coalitions or accessory ossification centers that may be abnormally developing. Overuse injuries include osteochondroses, apophysitis, and stress fractures. Acute injuries include the full spectrum of ligament, tendon, and muscle injuries and acute fractures. Epiphyseal injuries can be from overuse and acute traumatic events. An overview is provided, and a more comprehensive discussion of the specific injuries follows.

Growth-related problems: coalitions and accessory ossicles

A coalition is a connection or fusion of two or more bones. It can be a bony, cartilaginous, or fibrous connection [16–18]. Endochondral ossification is the formation of new bone from tissues such as cartilage, and there are two ossification centers in bone. The primary ossification center is located in the diaphysis, and the secondary ossification center is the physis (physeal plate, epiphyseal plate, or growth plate) located between the diaphysis and the epiphysis [19]. Because coalitions are composed of bony, fibrous, or cartilaginous tissues, they can act as their own ossification centers. When they ossify, they become painful where the tissues are placed under stress, particularly in highly active adolescent athletes [1,16]. The most common coalitions are talocalcaneal and calcaneonavicular coalitions.

Accessory ossicles are separate ossification centers located extrachondrally. They differ from coalitions because they do not form a connection between two bones but exist at the end of certain bones. Accessory ossicles usually appear at age 8 to 10 years and usually fuse approximately 1 year after their formation. When they do not fuse, they become symptomatic [16]. The most common sites for accessory ossification center formation are at the posterior talus, known as os trigonum, the medial malleolus, and the navicular. The navicular ossification center sometimes can form an entirely new bone known as an accessory navicular.

Overuse injuries: apophysitis and osteochondroses

Overuse injuries in sports have been defined as chronic injuries related to constant repetitive stress without adequate recovery time [20]. The cause is believed to be repetitive application of a submaximal stress to normal tissue that overwhelms the normal repair process [15,20–22]. These types of injuries can develop in one of three ways in the adolescent athlete population [20]. First, they can occur in athletes who increase their activity level rapidly without adequate training, as in individuals who begin preseason workouts without having practiced the sport for long periods. Second, they can occur in ill-prepared children who lack good mechanical sport-specific skills. Third, they can occur in vigorous athletes who do not provide their body with

adequate rest from activity. Overuse injuries in the adolescent foot and ankle can present at (1) the insertion of the tendon to the bone, which is known as the apophysis, (2) the articular cartilage, which causes what is known as an osteochondrosis injury, and (3) the growing bone itself, which presents as a stress fracture [15,23].

The apophysis is the area of junction between a tendon/musculotendinous unit and the epiphysis. Sometimes these sites of attachment also cross the physal growth plate. These areas are constantly placed under stress from repeated contractions and traction at the site, which can lead to irritation or inflammation at the physis, known as apophysitis [1,24]. The most common sites for the occurrence of apophysitis that we discuss are at the calcaneus (Sever's disease) and at the base of the fifth metatarsal (Iselin's disease).

Osteochondroses refer to lesions thought to be related to overuse, although it also believed that osteonecrosis may play a role in their development [15,25]. What is known is that they are lesions of the ossification centers that eventually undergo recalcification [1]. The two most common lesions that we discuss are osteochondrosis of the tarsal navicular, known as Kohler's disease, and osteochondrosis of the second or third metatarsal heads, known as Freiberg's infarction. It is worth noting that an osteochondral lesion of the talus—a complication of lateral ankle sprains—is not technically considered an osteochondrosis or overuse injury, although the pathology is located in the talar dome articular cartilage. These injuries can occur with up to 6.5% of ankle sprains and are discussed as a chronic presentation of an acute injury [26].

Overuse injuries: stress fractures

A stress fracture can occur anywhere in the pediatric and adolescent foot and ankle and is believed to be the ultimate overuse injury [16,27]. It has been referred to as a process that leads to fatigue or insufficiency failure of bone that occurs when the bone's reparative abilities have been surpassed [13,16,28] and the bone is unable to withstand chronic repetitive submaximal loads [29]. These injuries account for up to 15% of all athletic injuries in young athletes [30]. Stress fractures are most commonly seen in adolescent runners [10,20] but are associated with almost any sport in which repetitive running and cutting movements occur [29,31].

Multiple risk factors exist for the development of stress fractures, including sudden increases in training, poor mechanics, improper or worn-out footwear, young age, and poor nutrition with low bone mineral density [1,20,32–36]. Recently there has been an increase in stress fractures in young female athletes, and a connection has been made between anorexia, amenorrhea, and osteoporosis and the incidence of stress fractures [10,15]. This population is also at increased risk. In the foot and ankle, stress fractures can occur anywhere, but the most common sites are the metatarsals and the tibial diaphysis [20]. Stress fractures of the medial and lateral malleolus

can occur in adolescents but are more common in adult athletes. Tarsal navicular stress fractures are also common and difficult to treat.

In a study on military recruits, the occurrence of stress fractures was most prominent in the first month of training, when the increased training and repetitive loads led to increased osteoclastic activity and the osteoblastic activity had not caught up with the remodeling process [36]. Research indicated that bone mineral content increased after 14 weeks of training, possibly acting to prevent continued occurrence of stress fractures. This finding argues in favor of evidence that accelerated bone remodeling during the time when overuse is occurring is directly associated with stress fracture development.

Patients who have stress fractures commonly present with insidious onset of pain that worsens with increased activity and dissipates once the activity is stopped [37]. There is usually a history of an increase in the amount of training that coincides with the onset of symptoms; therefore, they are thought to be overuse injuries [13]. On physical examination, palpation can recreate symptoms depending on the location of the fracture. There may be point tenderness with no history of acute discrete traumatic event.

Radiographs often do not show evidence of the fractures initially [38]. It has been reported that only 10% of initial radiographs showed abnormalities [29,39]. It may take 3 to 4 weeks for the reactive process associated with stress fractures to become visible on radiographs, and often the first sign of this reactive process is subperiosteal new bone formation [13]. Results of radiographs also may remain normal if athletic activity is decreased [38]. In cases in which the diagnosis is suspected, a three-phase bone scan is most sensitive in detecting the stress fracture [38].

Proper treatment of stress fractures, as with most overuse injuries, requires a period of 2 to 4 weeks of relative rest, with temporary cessation of running. Usually partial weight bearing is tolerated, unless the symptoms are present during walking and light activity. During this period of modified rest, the osteoblastic activity catches up and restores balance [1]. It is important to maintain some level of cardiopulmonary fitness program, including non-land-based training, such as pool activities or cycling. Progression to running depends on symptoms and is individualized. Please note that these specifications do not apply to navicular stress fractures, whose management is somewhat different.

Acute problems: epiphyseal fracture classification

Acute fractures of the ends of long bones in children are common because of the relative weakness of the epiphysis in relation to the surrounding soft tissues. The literature is full of different ways to attempt classify these fractures. Some systems attempt to define the position of the foot with relation to the leg, whereas other systems attempt to define the fracture patterns in terms of the direction of the force placed on the leg [15,40–45]. These

systems can be useful, but unless one is communicating with specialists, there is not good communication regarding the injury.

One system that is widely used by specialists and primary care physicians to communicate about growth plate fractures is the Salter-Harris classification system (Fig. 2) [46]. It is essential to have a grasp on this way of referring to physal plate fractures. This system not only gives an anatomic and radiologic way of describing these injuries unique to the child and adolescent population but also provides useful prognostic implications that may affect treatment and the potential for growth disturbances [47,48]. For example, Salter-Harris type I fractures of the distal fibula are rarely complicated by growth arrests, whereas Salter-Harris type II fractures of the distal tibia do have a significant incidence of growth arrest [14,49].

Salter-Harris fractures of the foot and ankle most commonly are seen in the distal tibia and distal fibula and the phalanges [15]. The most common acute injury of the adolescent foot and ankle is a Salter-Harris type I

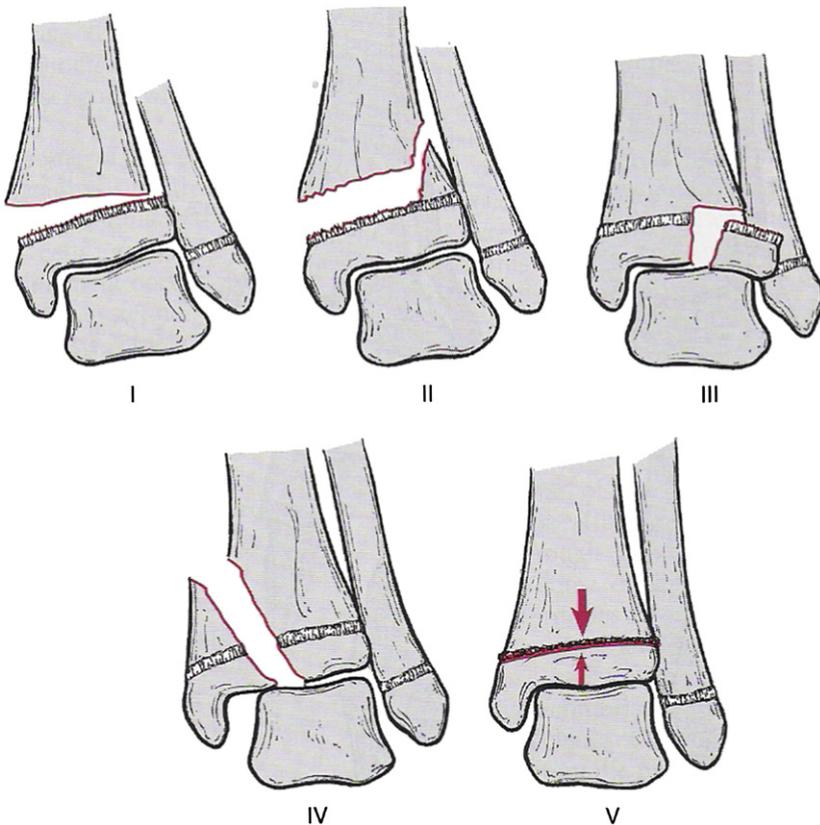


Fig. 2. Salter-Harris classification of physal injury. (Adapted from Canale ST. Physal injuries. In: Green NE, Swiontkowski MF, editors. Skeletal trauma in children. 3rd edition. Philadelphia: WB Saunders; 2003. p. 17–56; with permission.)

fracture of the distal fibula, which has been called the childhood equivalent of the lateral ankle sprain in skeletally mature patients [14]. Type I Salter-Harris fractures are confined to the growth plate, and they do not involve either the metaphysis or the epiphysis. Salter-Harris type II fractures involve the growth plate and usually a margin of the metaphysis. The epiphysis is not involved. These fractures are by far the most common types of growth plate fractures seen [15]. Salter-Harris type III fractures occur when a fracture line extends vertically or obliquely through a section of the epiphysis and proximally to reach the growth plate. In these fractures, the metaphysis is not involved. Salter-Harris type IV fractures extend vertically through the epiphysis, into the physal growth plate, and into the metaphysis. Type V Salter-Harris injuries usually result from a compressive or crushing force. They are rare and often have no radiographic abnormality.

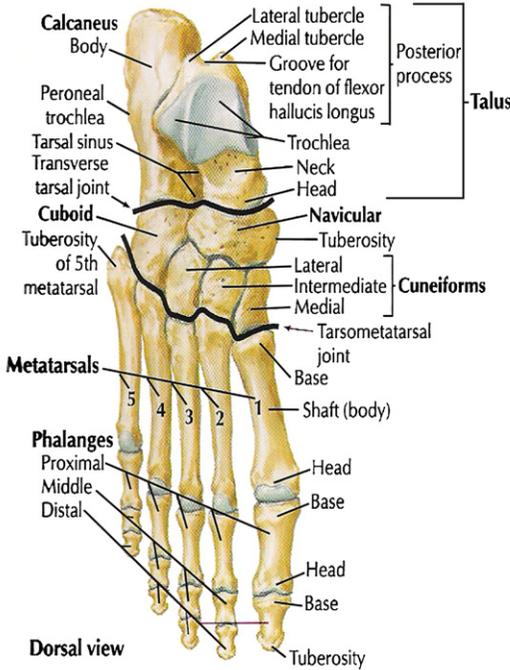
Treatment of physal growth plate fractures depends on multiple factors, including the location of the injury, the Salter-Harris classification, the age of the child, and the potential pitfalls and complications of each injury [48]. The age of the child is particularly important because the growth plate may be fully open if the child is young or may be closing if the child is older. In the latter case, there is less concern for growth arrest and significant leg-length discrepancy because there is likely little growth remaining. If the child is younger, premature physal closure is a concerning complication. These fractures usually heal within 4 to 6 weeks [50].

General guidelines state that for Salter-Harris type I and II fractures, closed reduction and cast immobilization with a short leg walking cast for 3 to 4 weeks are usually the initial treatments of choice, unless there is any level of displacement of the fracture, in which case maintenance of reduction must be undertaken, sometimes necessitating wire placement [14,15,50]. The patient is followed with serial radiographs to ensure that no complications occur. These fractures have been thought to be fairly uncomplicated. Recently, however, studies illuminated that premature physal closure may be more common than previously thought [51]. Salter-Harris types III and IV always require closed reduction, but if their displacement is more than 2 mm, usually open reduction with internal fixation is favored. Two specific kinds of Salter-Harris fractures are presented later in this article: the Tillaux fracture and the triplane fracture.

Brief anatomic review of foot and ankle

The most pertinent bony anatomy is as follows: the ankle joint is a synovial joint composed of three bones: the tibia, fibula, and talus (Fig. 3). The proximal articulating surface of the ankle is composed of the concave end of the distal tibia and its medial malleolus and the lateral fibular malleolus [52]. This proximal articulating surface extends more distally in its posterior and lateral borders. It forms a mortise-type shape into which the distal articulating surface of the ankle—the talus—articulates; there is inherent stability in

A



B

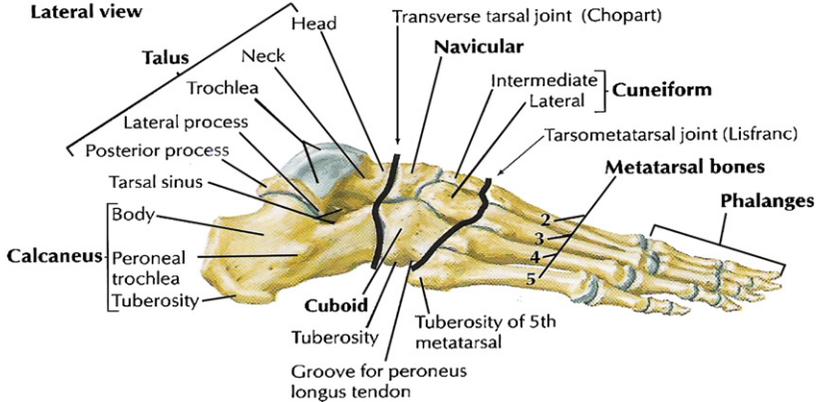


Fig. 3. (A) Dorsal views of the foot and ankle bony anatomy. (B) Lateral view of the ankle and foot bony anatomy. (Reprinted with permission from Netter Anatomy Illustration Collection, © Elsevier Inc. All rights reserved.)

this type of formation. The hindfoot is composed of the talus and the calcaneous bones. The articulation between these two is the subtalar joint. The midfoot is composed of the navicular, the cuboid, and the three cuneiforms: medial, intermediate, and lateral. The articulation of the distal talus and calcaneus with the proximal navicular and cuboid bones forms the midtarsal joint. The forefoot is composed of the five metatarsals and the 14 phalanges. The articulation of the three cuneiforms and the cuboid distally with the proximal metatarsals forms Lisfranc's joint. Note the following three articulations: (1) the talus with the calcaneous (ie, subtalar joint), (2) the talus with the navicular, and (3) the calcaneus with the cuboid. (Articulations 2 and 3 are known as the transverse tarsal joints.) These three joints are collectively known as the three-joint complex, and they are crucial structures for the dissipation of forces throughout the ankle and foot during gait mechanics [53].

Anatomic location of injury presentations

Lateral ankle

Acute injuries

Lateral ankle sprain. In the lateral ankle, developmental or overuse type of injuries are uncommon. The possibility exists of an ossification center in the fibular region or peroneal tendonitis overuse issues, but they are rare. The most common predominant injury in a child's lateral ankle, after the Salter-Harris type I physeal fracture of the distal fibula, which was discussed earlier, is the lateral ankle sprain. It is less common in younger children, because they are more apt to injure the fibular physeal plate for the aforementioned reason that the epiphysis and the growth plate are inherently weak points in the childhood ankle. In more mature adolescents, however, the bone is stronger and the growth plate is ossifying and closing, so injuries of the ligaments are common [14].

The main function of the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL) complex is the prevention of excessive lateral or varus translation of the ankle [52]. The typical mechanism of a lateral ankle sprain occurs when the ankle is subjected to an inversion and internal rotation force while in plantarflexion [54,55]. The ATFL is the first ligament injured, and the CFL is also at risk of injury, although it is more likely injured if the ankle is in dorsiflexion. One common method of injury involves landing on another athlete's foot while coming down from a jump. Patients complain of immediate pain and, depending on the severity of the sprain, may have swelling over the area. Depending on the severity of the injury, the patient may be unable to bear weight on it.

Physical examination usually reveals tenderness over the ATFL or the CFL with palpation. There may be ecchymosis and swelling and tenderness with active and passive range of motion of the ankle. Two maneuvers can be

performed to assess the integrity of the ATFL and the CFL, respectively: the anterior draw test and the talar tilt or varus stress test [56]. A positive anterior draw is more than 3 to 5 mm difference in anterior displacement of the ankle in side-to-side comparisons. Results of the talar tilt test are positive when there is more than 23° of angulation or more than 10° of difference side to side. The specificity and sensitivity for the anterior draw are 80%–94% and 74%–84% respectively. These have not been reported for the talar tilt [57]. Severity of injury is usually based on a three-point grading system. Grade 1 sprains are mild and involve a partial tear of the ATFL with intact CFL. There is usually tenderness to palpation, but only mild swelling. The anterior draw and the talar tilt tests usually have negative results. Grade 2 sprains are moderate and involve complete tears of the ATFL and mild tears of the CFL. There is diffuse swelling and ecchymosis and a large anterior shift on the anterior draw test. The talar tilt test usually has negative results. Grade 3 sprains are severe and involve tears of the ATFL and the CFL, with both tests producing positive results [58].

Radiographic imaging in lateral ankle sprain-type injuries in children is somewhat controversial. In adults, the Ottawa Ankle Rules (OAR) were devised by Stiell and colleagues because too many ankle radiographs were being obtained in emergency departments [59,60]. The sensitivity of the OAR is 100% and the specificity is 40% for the detection of ankle fractures. If a patient does not meet the rules, then no imaging is necessary [60]. With OAR, however, all patients were older than 18 years. In children younger than 18 years, there may be issues of weak growth plates and the possibility of physeal fractures. Some physicians have argued that nearly all children with ankle pain merit an evaluation with plain radiographs to assess the integrity of the bony structures and to look for congenital or developmental anomalies [61]. Clark and colleagues [59] tried to apply the OAR to children. They came up with a sensitivity of 83%, specificity of 50%, positive predictive value of 28%, and negative predictive value (NPV) of 93% and concluded that the OAR could not be applied to children.

In another prospective study, Boutis and colleagues [62] used a specific set of physical examination parameters for children and adolescents with ankle sprains who presented to the emergency department. Their low-risk clinical examination was defined as isolated tenderness, with or without edema or ecchymosis of the distal fibula below the level of the joint line and/or over the adjacent lateral ligaments (ATFL, posterior talofibular ligament, CFL). All other findings on examination were believed to be high risk. They stratified all injuries into low risk and high risk based on their examination and obtained radiographic views on all subjects to confirm their findings. It is worth noting that the diagnoses that they considered to be low risk included sprains, contusions, lateral talar avulsion fractures, and fractures of the distal fibula, including nondisplaced Salter-Harris I and II and epiphyseal avulsion fractures. These fractures were considered low risk because they are stable injuries that carry excellent prognosis and their management is usually based on

maximizing comfort, according to the authors. All other fractures were classified as high risk. They found that none of the 381 enrolled children with low-risk examinations had high-risk fractures (sensitivity 100% and NPV 100%). They concomitantly applied the OAR to all children and analyzed how the OAR would have fared as far as limiting the number of radiographs. They found that with their low-risk examination, 63% of radiographs could have been omitted, whereas only a 12% reduction in radiographs would have occurred with the OAR [62].

Proper treatment is essential for adequate return to competition in youth sports and to prevent future negative sequelae associated with improperly managed ankle sprains [63,64]. Some guidelines have been set forth in the literature, but much of the basic concepts are the same [65–67]. It also has been noted that early mobilization may promote better healing by producing better orientation of the collagen fibers when compared with an immobilized joint [1,68]. The basic guidelines of the PRICE acronym are used at first: *protection*, *rest*, *ice*, *compression*, and *elevation*. Patients may bear weight as tolerated with protective support and crutches. As patients progress from the acute to subacute phase of the injury and their pain at rest decreases, the goal should be to attempt to increase pain-free range of motion. Cardiovascular fitness comprised of upper extremity or non-weight-bearing aerobic work also should be undertaken. As the swelling and pain diminish, progressive weight bearing should be performed. Strengthening also should begin to progress from isometric to isotonic and isokinetic exercises based on patient symptomatology. Proprioceptive training also should be initiated to improve neuromuscular signaling and decrease future ankle instability. Once patients reach full range of motion with minimal or no pain on vigorous activity, sport-specific functional progression should occur [65]. The overall goal of the rehabilitative program should be to return athletes to full strength and range of motion and attempt to decrease the recurrence rates of sprains with improved proprioceptive neuromuscular control and confidence in the ankle.

Talar osteochondral defects. Talar dome injuries are common complications of lateral ankle sprains and occur in up to 6.5% of cases [26]. The mechanism by which the lesions develop is still not fully elucidated, but the belief is that poor healing after an ankle sprain or other ankle trauma leads to poor circulation to the subchondral bone of the talus, which in turn leads to these focal lesions of almost necrotic bone fragments [69,70]. The injury is most common in the second decade of life, and up to 100% of the lateral lesions are believed to be from previous ankle sprains or trauma, whereas 64% of patients with medial lesions had a history of trauma [69,71].

The typical history is an adolescent athlete with ankle pain and either a persistent effusion or the occurrence of intermittent swelling of the joint. There may be a history of the ankle catching or locking and some instability and episodes of giving way [72]. Inevitably, further probing detects a history

of ankle sprains at some point in the athletic career of the patient and usually one that was not properly rehabilitated. Along the same lines, when an ankle sprain does not respond to 6 to 8 weeks of conservative treatment, then talar dome osteochondral lesions must be highly suspected and ruled out [72].

Radiographs often demonstrate the lesions fairly clearly, particularly with mortise views. Berndt and Harty [73] developed a classification system for these lesions based on radiographic appearance, which helps to guide management of the lesions. Stage I lesions show localized trabecular compression. Stage II lesions are incompletely separated fragments. Stage III lesions are undetached, undisplaced fragments. Stage IV lesions demonstrate a displaced or inverted fragment floating free within the joint. When radiographs do not demonstrate the lesions but clinical suspicion remains high, MRI can serve as a valuable tool for diagnosis. MRI helps to distinguish among stable lesions, loose in situ lesions, and loose lesions [74]. Stable lesions correlate with Berndt and Harty stage I and II lesions that have healed. Loose in situ and loose lesions correlate with stages III and IV lesions in the Berndt and Harty classification system.

Treatment for the stage I, stage II, and medial stage III lesions is nonoperative, short leg cast immobilization with limited or non-weight bearing for 6 to 8 weeks, whereas surgery is indicated for lateral sided stage III lesions and all stage IV lesions [75]. The authors believe that the best treatment for this lesion is prevention of its occurrence, which may be accomplished if a comprehensive therapy and rehabilitative program for lateral ankle sprains (much like the one outlined previously) is performed, with a focus on early mobilization, range-of-motion training, proprioceptive training, and progressive strengthening.

Medial and anterior ankle

Growth-related problems

Medial malleolus ossification center. The medial malleolus ossification center is present in all children. It usually appears at 1 to 2 years of age and closes by age 12 [16]. This center occasionally persists into adulthood but is usually asymptomatic. It becomes a problem in adolescents when they are overly active athletically [16,76]. The usual presentation is pain, point tenderness, and swelling over the medial malleolus without a significant history of trauma or any acute injury to the area. Anteroposterior radiographs of the ankle demonstrate an irregular ossification center with an associated ossicle [14,16,76]. Treatment includes rest from athletic activities with at least 3 to 6 weeks of short leg cast immobilization [76]. If no improvement occurs with this regimen, surgery for removal of the ossicle may be indicated.

Overuse injuries

Anterior ankle impingement syndrome. Bony anterior ankle impingement is a painful condition seen in many young athletes. It is an irritation of the

periosteum on the talar neck that leads to bony exostosis, which in turn leads to impingement [14,16]. It is commonly seen in athletes, such as ballet dancers and gymnasts, who are constantly in extremes of dorsiflexion; it is considered an overuse type of injury. Patients present with pain in the anterior ankle and a history of participating vigorously in a sport or activity that lends itself to repeated dorsiflexion moments. Pain is usually exacerbated by dorsiflexion movements, such as pliés in ballet dancers. Dancers often complain of limited dorsiflexion range of motion in the affected ankle, which may be noted during the examination [11]. Radiographs demonstrate an anterior tibial or talar neck osteophyte that has developed from the exostosis from overuse [11]. Conservative treatment consists of stretching of the Achilles tendon to attempt to improve range of motion and strengthening of the dorsiflexors [14]. Rest from activity and icing may help. According to one author, however, by the time an adolescent dancer presents with this problem, it usually cannot be solved with conservative measures, and a surgical excision of the osteophyte is needed [11]. The dancer usually can return to full plié position in 3 to 4 months if adequate postsurgical rehabilitation is conducted.

Acute injuries

Tillaux fractures. A Tillaux fracture is the most common Salter-Harris type III fracture seen in adolescents [14,15]. It is an isolated fracture of the distal anterolateral tibial physis. During normal development, the medial and posterior tibial physeal plates close first, and then the anterolateral areas close. This fracture occurs late in the teen years in the period when the medial and posterior plates have closed and the anterior growth plate is still open [15]. The most common mechanism of injury is a forceful external rotation-type injury. As the ankle is stressed medially, the pull of the anterior tibiofibular ligament results in an avulsion fracture of the anterolateral aspect of the distal tibial epiphysis over the area of the physeal plate that is still not ossified [15]. Because that physeal plate is not yet closed, it remains a structural weak link. The medial and posterior parts of the epiphysis are not affected because the growth plate already has ossified and closed and it is not a weak point any more [15]. Patients present with anterior ankle pain and swelling in the setting of an external rotation trauma. Radiographs reveal a vertical line that extends from the anterior ankle joint proximally through the epiphysis to the growth plate. Treatment depends on the amount of displacement of the growth plate. If it is less than 2 mm, then closed reduction and a short leg walking cast for 4 to 6 weeks are favored, as noted in the discussion on Salter-Harris fractures. Fracture displacements that are more than 2 mm necessitate open reduction and internal fixation [15,77].

Triplane fractures. Triplane fractures represent yet another type of fracture of the distal anterior tibial epiphysis and physeal growth plate. These fractures are similar to Tillaux fractures in two main ways. First, they normally

occur in the period when the anterolateral plate is still open and other areas of the distal tibial growth plate have closed. The pattern of what has and has not been ossified is what determines the extent of the injury [78]. Second, the triplane fracture occurs from external rotation forces of the ankle, which cause shearing and avulsion. Some authors speculate that plantarflexion may contribute to their occurrence and to their irregularity in presentation and on radiographs [79]. They differ from Tillaux fractures in that the extent of involvement of the terminal bone is greater and involves the metaphysis, physis, and epiphysis. Triplane fractures are more difficult to diagnose on plain radiographs because their full extent may not be seen on regular views of the ankle. CT scans usually delineate the lesion well [15]. Treatment is same as for Tillaux fractures, and if surgery is performed, adequate visualization of all fracture fragments is paramount to successful outcomes [15,80].

Hindfoot

Growth-related problems

Talocalcaneal coalition. Tarsal coalitions are fusions of two or more of the tarsal bones [1,16]. The incidence of coalitions may be as high as 1% to 3% in the population and are bilateral 50% of the time [1,81]. The most common tarsal coalitions are the talocalcaneal and the calcaneonavicular coalitions, which account for 90% of all coalitions [1]. The subtalar joint, the talocalcaneal articulation, and the calcaneocuboid articulation form the three-joint complex. This complex is responsible for many foot motions during the gait cycle. The presence of a talocalcaneal and calcaneonavicular coalition severely affects the motion at the three-joint complex [81].

The typical presentation of a painful coalition occurs in the developing mid- to late teenage athlete who participates in vigorous activity. It is then that the presence of the congenital coalition first becomes evident. Increasing activity, combined with maturing ossification, leads to motion alteration and pain. Pain is usually located vaguely around the ankle based on the location of the coalition and based on which motion segment in the three-joint complex is mostly affected. There may or may not be a history of previous lateral ankle sprains [81]. Physical examination reveals findings associated with decreased motion of the hindfoot. The hindfoot is held in rigid valgus, and there is absence of heel varus on tiptoes. There is often rigid flat foot, and peroneal tightness and spasticity can be seen in their attempts to overcome the rigid flat foot. Pain is also present with foot inversion [1,81,82].

Radiographically, the talocalcaneal coalition is difficult to identify on plain radiographs, although the calcaneonavicular one is usually well visualized. CT is considered the gold standard imaging modality for the diagnosis of tarsal coalitions, however [83]. Treatment initially targets symptom control. If athletic activity worsens the symptoms, then the activity should be decreased or temporarily stopped. Orthotics can help control mild symptoms.

Cast immobilization for 6 weeks in a short leg walking cast is indicated, particularly with painful and stiff joints [81]. Failure of conservative therapy is marked by continued pain and inability to participate in sports. Surgical options include excision of the coalition, calcaneal osteotomy, and arthrodesis of the joint [1,81].

Os trigonum. A normal ossification center can often be located at the posterior aspect of the talus. It usually appears at 9 to 12 years of age and fuses 1 year after its appearance. When it does not ossify, an ossicle develops, which is known as the os trigonum [16]. It has been reported to be present in as much as 10% of the population, and it is usually unilateral [16,84]. It becomes symptomatic in young athletes who perform repeated ankle plantarflexion, such as ballet dancers, gymnasts, and ice skaters. One of the mechanisms by which it is believed to cause pain is from mechanical impingement of the posterior talus between the posterior tibia and the calcaneus when the foot is in plantarflexion [16,84]. The presentation is an active athlete who has pain in the posterolateral ankle that is reproducible on palpation and active plantarflexion. The os trigonum is usually seen on lateral plain radiographs as an ossicle located posterior to the calcaneus. It has been recommended that plantarflexion views also be obtained for verification [16]. Treatment is conservative. Plantarflexion must be avoided as much as possible. If the pain continues with resumption of the athletic activity, then surgical resection may be indicated. Some authors recommend early resection in competitive young athletes as the best way to resolve the symptomatology and expedite return to play safely [85].

Overuse injuries

Sever's apophysitis. Apophyses are bony attachment sites that develop as accessory ossification centers and mimic the maturation of an epiphyseal plate [1,24]. The calcaneal apophysis serves as the attachment site for the Achilles tendon superiorly and the plantar fascia inferiorly [16]. Inflammation of the calcaneal apophysis, known as Sever's disease, is one of the most common overuse injuries seen in the young athletic population, accounting for approximately 8% of all overuse injuries in this group [1,86]. It has been referred to as the ankle equivalent of Osgood-Schlatter's disease of the knee [16]. The typical presentation is that of an athlete who has just begun the season or has increased running activity recently. Pain is at the heel, particularly with running and jumping. Physical examination is often positive for tight Achilles' heel cord and weakness of the ankle dorsiflexors [1,87]. There also may be swelling and induration over the calcaneal apophysis. Diagnosis is usually clinical, and radiographs are usually not helpful. Treatment is multifaceted. First, causative activity should cease. Short-term icing and nonsteroidal anti-inflammatory drugs can be helpful for controlling the pain. A comprehensive program of heel cord stretching and dorsiflexor strengthening should be initiated. Barefoot walking should be avoided

because this prolonged traction is what leads to apophysitis. Occasionally, a heel insert or a heel lift is recommended to remove tensile forces on the tendon while the inflammation decreases [24,87].

Plantar fasciitis. The plantar fascia stretches from the calcaneal tuberosity and fans out to attach around the plantar aspect of the proximal phalanges [1]. Current literature has noted that this is not a true inflammatory condition but rather the result of repetitive microtrauma from continued athletic activity overuse [1,88,89]. Much like lateral epicondylitis, it seems that plantar fasciitis is not an “-itis” but rather an “-osis,” a loss of normal tendon integrity. Young athletes involved with speed work, jumping, or hill running are at increased risk of developing this condition [16]. In young athletes, plantar fasciitis usually coincides with calcaneal apophysitis, but in adolescent athletes with closed physes, it can exist by itself and presents as medial arch or heel pain. Patients give a history of heavy athletic involvement and medial arch or heel pain, particularly with the first step out of bed every day. Physical examination shows tenderness over the anteromedial aspect of the heel, particularly with the foot in dorsiflexion [1]. This, like Sever’s disease, is a clinical diagnosis, because radiographs are often not helpful. Treatment involves conservative measures, including relative rest, ice massage, arch supports, heel pads, and heel cord stretching and strengthening, both of which are paramount to successful rehabilitation. The decision to inject corticosteroids in the area is currently controversial in the literature, particularly in adolescent athletes. Evidence exists to support injection in adults, but complications such as tendon rupture and fat pad atrophy are real and must be monitored. Studies are not solid in adolescents [16].

Midfoot

Growth-related problems

Calcaneonavicular coalition. The two most common coalitions are the talocalcaneal and the calcaneonavicular coalitions. The calcaneonavicular coalition is a bony fusion between the talus and the calcaneus, and it is the second most common coalition behind the talocalcaneal coalition (Fig. 4). It has a similar presentation as the talocalcaneal coalition, with decreased range of motion across the hindfoot and the three-joint complex. Diagnosis and treatment are also similar.

Accessory navicular. An accessory navicular bone is the most common accessory bone in the foot [16]. It is an ossicle that develops like all other ossicles as a separate extrachondral ossification center, and it is located at the site of the tibialis posterior tendon insertion [14,16,90]. When it fails to ossify fully, it becomes an accessory navicular bone. It has been reported to occur in anywhere from 4% to 14% of the population [16]. It is not until adolescence, when athletes increase their participation, that these conditions

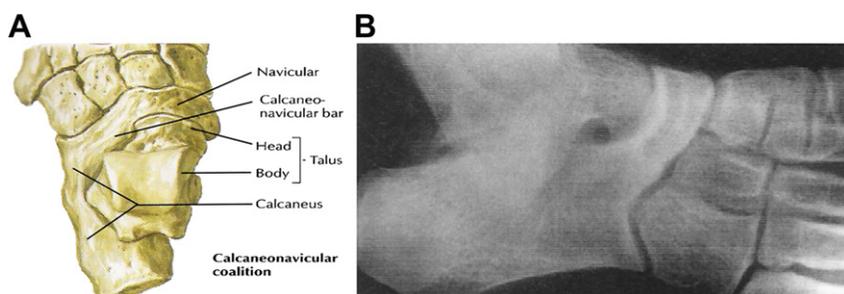


Fig. 4. (A) Pictorial of calcaneonavicular coalition. (B) Oblique radiograph shows the calcaneonavicular fusion. (Reprinted with permission from Netter Anatomy Illustration Collection, © Elsevier Inc. All rights reserved.)

actually become painful. Patients present with pain medially along the arch of the foot, and on physical examination there is often a prominence along the arch of the foot that is tender with shoe wear [14]. Also on examination there is often evidence of pes planus. One theory about the development of pes planus is that the tibialis posterior tendon, which is a dynamic stabilizer of the medial longitudinal arch of the foot, inserts onto the accessory navicular instead of into the native navicular. Because it is a weaker insertion point, there is a drop in the longitudinal arch, which causes the pes planus [16]. Radiographic imaging is often diagnostic, but in cases in which it is not, MRI can help elucidate the lesion and define the anatomic points of insertion of the tibialis posterior tendon [72,91]. Treatment involves conservative management initially, with orthotics and casting and doughnut cut-outs for the painful parts over the enlarged navicular. If these measures fail and an athlete continues to have pain, there are well documented surgical procedures for the excision of these ossicles with varying degrees of handling of the posterior tibial tendon [14,92].

Overuse injuries

Navicular stress fractures. Aside from the previous discussion on stress fractures in general, one stress fracture in particular must be emphasized: the navicular stress fracture, which has been documented to have an incidence anywhere from 0% to 29% in young track and field athletes [15,93]. Navicular stress fractures are difficult to diagnose. The presentation is usually vague onset of foot pain along the dorsomedial area [10]. History elicits risk factors such as overuse with an increase in exercise duration and intensity and poor nutrition. Examination reveals palpatory tenderness over the dorsomedial navicular and may show mechanical configurations that may increase the risk of these fractures, such as a tight gastrocnemius complex or a Morton foot with a long second ray [10]. As with all stress fractures, radiographs are frequently normal, and a bone scan is required for definitive diagnosis. There must be a high incidence of suspicion for these fractures

because the navicular has poor blood supply over the middle one third, and if the fracture is untreated, poor healing with delayed union or nonunion is a possibility [10]. Treatment is more aggressive than with other stress fractures. Non-weight-bearing cast immobilization for 6 weeks is recommended by most physicians to prevent malunion, and if no progress is made, then surgical internal fixation is recommended. The usual time to return to athletic activity can be as long as 5 to 6 months [15,94].

Kohler's osteochondrosis. Osteochondroses are overuse lesions of the osteochondral ossification centers that are idiopathic. Osteochondrosis of the tarsal navicular is termed Kohler's disease. It typically occurs in children aged 5 to 9 years, and patients present with pain over the midfoot region that worsens with weight bearing [1]. Swelling of the area also may be present. Bilateral lesions have been known to occur, and one such case of bilateral lesions in twins led those authors to speculate on the possibility of a genetic predisposition to its occurrence [95]. Radiographs may be difficult to interpret because many children have irregular-appearing navicular bones that are normal and asymptomatic [1], but because patients have such good outcomes, further imaging has little use and does not change management. Treatment is conservative, with the use of the RICE technique and shoe supports for mild cases. Casting may be necessary over a 4- to 8-week period for more severe cases [95]. Patients typically fare well with this conservative treatment. In one series in the literature, 100% of patients became asymptomatic after conservative treatment, and the navicular returned to its normal appearance on radiographs [96]. There have been a few reports of children with Kohler's abnormality persisting into adulthood clinically and radiographically [97].

Acute injuries

Lisfranc injury. Lisfranc's joint is the tarsometatarsal articulation of the three cuneiforms and cuboid with the proximal five metatarsals. The keystones of this joint are the first and second metatarsals articulating with the first and second cuneiforms. 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 second metatarsal proximally has small articulations with the three cuneiforms that support the tarsometatarsal articulation [1,98]. This is a precarious yet highly important anatomic location. Injuries at Lisfranc's joint can be in the form of sprains of the transverse ligaments or even fracture-dislocations. The most common mechanism of injury is an axial loading through the foot as the foot is forcefully plantarflexed and slightly rotated, which causes the proximal second metatarsal to dislocate dorsally [1,98,99]. Given this mechanism, many of the Lisfranc joint injuries seen in adolescents occur while playing football, with a large percentage of those injuries occurring in

linemen [1,100]. Linemen are often in situations in which other linemen step on their toes, which cause a heavy axial load while they are attempting to explode forward onto their toes.

The typical presentation involves an athlete with pain over the dorsum of the midfoot associated with swelling and an inability to bear weight through the midfoot, particularly on the tiptoes [1]. Plantar bruising often is associated with this injury, and if this sign is noticed, clinical suspicion should be raised. Radiographs are needed to make the diagnosis, particularly weight-bearing films (Fig. 5). There is a significantly high incidence of missed diagnoses [101]. One should look for malalignment between the first metatarsal and the first cuneiform or between the second metatarsal and the second cuneiform [99,101]. Severity grading is like other sprains, based on ligamentous tearing and amount of dislocation. Bone scans may help make the diagnosis in patients with negative radiographic results and continued high suspicion. Treatment of these injuries is based on the degree of severity. Stretch injuries or partial tears with less than 2 mm of malalignment should be treated conservatively with cast immobilization or a walking boot for 4 to 6 weeks [1,100]. Sprains that are more severe require operative reduction with internal fixation [1,102].

Forefoot

Overuse injuries

Iselin's apophysitis. Iselin's disease is an apophysitis that occurs at the tuberosity of the fifth metatarsal. The apophysis at this site appears at ages 9 to 14 and is located within the insertion of the peroneus brevis tendon



Fig. 5. Lisfranc injury. Note the malalignment between the metatarsals and the cuneiforms. (Reprinted with permission from Netter Anatomy Illustration Collection, © Elsevier Inc. All rights reserved.)

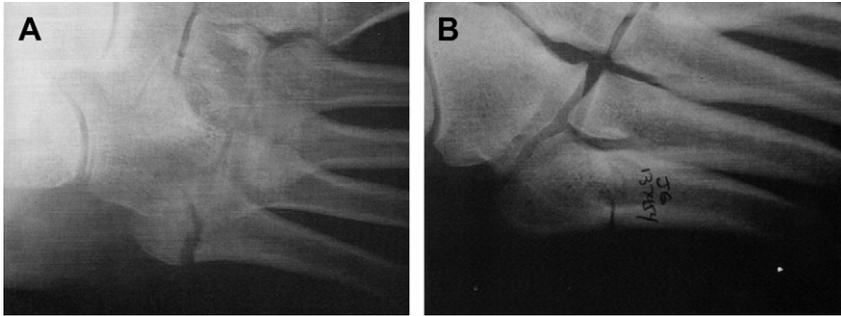


Fig. 6. (A) Fifth metatarsal avulsion fracture. (B) Jones fracture. Note how it extends to the metaphyseal-diaphyseal junction. (*Adapted from* Brodsky JW, Krause JO. Stress fractures of the foot and ankle. In: DeLee JC, Drez D, Miller MD, editors. *Orthopaedic sports medicine: principles and practice*. 2nd edition. Philadelphia: Saunders Elsevier; 2003. p. 2391–409; with permission.)

[16]. Presentation is similar to other cases of apophysitis in terms of history of overuse in athletically active older children. There is usually a presentation of insidious onset of pain over the lateral foot, with no history of trauma, in the setting of overuse-type activities. Radiographically, the apophysis appears as a diagonal or longitudinal line parallel to the long axis of the shaft of the fifth metatarsal, an important distinction from acute fifth metatarsal avulsion fractures, which are usually transverse in nature (see later discussion) [16]. Treatment is conservative, with decrease of activity and stretching and strengthening of the peroneal muscles. This treatment is usually effective until bony union eventually occurs [16].

Acute injuries

Fifth metatarsal fractures. Young child and adolescent athletes who present with pain along the lateral aspect of the foot near the fifth metatarsal present a challenging dilemma. History should be able to differentiate whether an acute or overuse injury has occurred; however, matters are not always that clear-cut. Three possible types of fractures are seen in the area of the base of the fifth metatarsal: include fifth metatarsal stress fractures, fifth metatarsal acute avulsion fractures, and Jones fractures. Metatarsal stress fractures are overuse injuries, which are the most common types of stress fractures seen in adolescent feet and ankles. Their management was reviewed previously. Most young athletes return to their sport in 4 to 6 weeks [16].

The fifth metatarsal acute fracture is the most common metatarsal fracture in children, accounting for 45% of all metatarsal fractures [16]. It occurs after an inversion-type injury, when the peroneus brevis tendon is avulsed from its attachment at the base of the fifth metatarsal [14]. Radiographs show the lesion, which can be distinguished from apophysitis because the fracture is transverse along the bone, whereas apophysitis of the fifth metatarsal (Iselin's

Table 1
Summary of common injuries of the foot and ankle in the child and adolescent athlete

	Lateral ankle	Medial & anterior ankle	Hindfoot	Midfoot	Forefoot
Growth problems		Medial malleolus ossification center	Talocalcaneal coalition Os trigonum	Calcaneonavicular coalition Accessory navicular	
Overuse injuries		Anterior ankle impingement syndrome	Sever's apophysitis Plantar fasciitis	Navicular stress fracture Kohler's apophysitis	Metatarsal stress fractures Iselin's disease
Acute injuries	Salter-Harris fractures Lateral ankle sprains Osteochondritis dissecans	Tillaux fractures Triplane fractures		Lisfranc injury	Fifth metatarsal avulsion fracture Jones fracture

disease) occurs along the diagonal plane from the bone (Fig. 6A) [16]. Treatment is usually conservative unless there is more than 2 to 3 mm of displacement, in which case surgical open reduction and internal fixation should be performed [14].

The Jones fracture is actually a fracture that occurs at the metaphyseal-diaphyseal junction of the base of the fifth metatarsal. The average age and demographics of occurrence of this fracture involve 15- to 21-year-old athletes [16]. Patients usually present with pain along the fifth metatarsal, particularly upon weight bearing, and give a history of an acute injury. Radiographs usually reveal the fracture (Fig. 6B). Similar to the navicular stress fracture, this lesion has higher rates of nonunion because it has poor blood supply to that area. Treatment involves a non-weight-bearing cast for 6 to 8 weeks and possible surgical screw fixation for nonhealing fractures [16].

Summary

Myriad problems in the foot and ankle are specific to child and adolescent athletes. The anatomy of young athletes with respect to the presence of a growth plate makes their injury patterns different from those seen in adults. The main general injury patterns seen in the feet and ankles of children are related to growth and development or occur from overuse syndromes or acute trauma. We have outlined in an anatomically oriented manner most of the common problems in this population. They are also summarized in Table 1.

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