Forefoot problems in athletes

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ABSTRACT

HOCKENBURY, R. T. Forefoot problems in athletes. *Med. Sci. Sports Exerc.*, Vol. 31, No. 7(Suppl.), pp. S448–S458, 1999. Athletes who participate in high-impact sports involving running, jumping, or contact are at risk for forefoot injury. These injuries occur as a result of acute trauma or chronic overuse. Some athletes may be predisposed to injury because of preexisting foot deformity, such as cavus, hallux valgus, or Achilles contracture. This article reviews the common causes of forefoot pain in the athlete. The most common causes of forefoot pain in the athlete are metatarsal stress fracture, interdigital neuroma, sesamoid pathology, metatarsalgia, hallux rigidus, hallux valgus, and turf toe. The pathophysiology, clinical presentation, and treatment of these conditions are discussed. **Key Words:** STRESS FRACTURE, INTERDIGITAL NEUROMA, SESAMOID PATHOLOGY, METATARSALGIA, HALLUX RIGIDUS, HALLUX VALGUS, TURF TOE

Injuries to the foot can be divided into those that involve the hindfoot, midfoot, or forefoot. Forefoot injuries include any injury distal to the tarsometatarsal joint, or Lisfranc's joint. The most common conditions that produce forefoot pain in the athlete are metatarsal stress fracture, interdigital neuroma, sesamoid pathology, metatarsalgia, hallux rigidus, hallux valgus, and turf toe. This article will discuss the anatomy and biomechanics of the forefoot, as well as the diagnosis and treatment of common causes of forefoot pain in the athlete.

ANATOMY AND BIOMECHANICS

The forefoot consists of 5 metatarsals, 14 phalanges, and 2 sesamoids. Each toe has a metatarsophalangeal (MTP) joint and a distal and proximal interphalangeal joint, except for the great toe, which has only one interphalangeal joint. The medial, or tibial, and lateral, or fibular, sesamoid each articulate with the plantar aspect of the first metatarsal head.

During the normal gait cycle, the foot spends 62% in stance phase and 38% in swing phase. Stance phase is subdivided into heel strike, foot flat, heel rise, and toe off. The foot is in its maximum position of flexibility at foot flat and then becomes rigid at heel rise as the subtalar joint inverts and the transverse tarsal joint becomes locked. It is during this period of forefoot rigidity in late stance phase that the forefoot experiences most of its stresses. During heel rise and toe off, the hallux and lesser toes reach their maximum dorsiflexion. Toe dorsiflexion places traction on the plantar fascia and helps to elevate the medial longitudinal arch through the windlass mechanism of the plantar fascia. Normal motion of the lesser metatarsophalangeal joints is 90° extension to 50° flexion. Normal motion of the first metatarsophalangeal joint is 90° dorsiflexion and 30° plantarflexion (47).

The foot supports loads that are truly impressive. Peak vertical forces reach 120% body weight during walking, and they approach 275% during running. It is estimated that an average 150-lb. man absorbs 63.5 tons on each foot while walking 1 mile and that the same man absorbs 110 tons per foot while running 1 mile (29). During the normal gait cycle, the center of pressure progresses along the plantar aspect of the foot from the heel at heel strike to the toes at toe off. The center of pressure is initially located in the central heel, then accelerates rapidly across the midfoot to reach the forefoot, where the center of pressure is located under the second metatarsal head. At toe off, the center of pressure is located under the hallux. Studies of plantar pressure distribution in runners has documented that most of the pressure is located in the distal-most 20–40% of the shoe, indicating most time is spent on the forefoot (8).

METATARSAL STRESS FRACTURE

In 1855, a Prussian Army doctor named Breithaupt reported painful, swollen feet in soldiers after long marches (6). These symptoms were due to metatarsal shaft stress fractures and were commonly called "march fractures." Stress fractures have plagued military personnel throughout history but have now become more common in the civilian population with the increasing popularity of long-distance running, aerobics, and jumping sports. In the foot, the two most common locations for stress fractures are the metatarsal shaft and the calcaneus (35).

A stress or fatigue fracture is a break that develops in bone after cyclical, submaximal loading. According to Wolff's law, bone remodels along lines of stress (38). Bone is constantly being resorbed and replaced as the resorption

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of circumferential lamellar bone is accomplished by osteoclasts and replaced with dense osteonal bone by osteoblasts. This process occurs in a histological structure known as a "cutting cone." In states of increased physical activity, bone is resorbed faster than it is replaced, which results in physical weakening of the bone and the development of microfractures. With continued physical stress these microfractures coalesce to form a complete stress fracture. A "stress reaction" occurs when the microfractures are attempting to heal and a complete fracture has not yet developed (15). A recent cadaveric biomechanical study found the simulation of fatigue of the toe plantar flexors resulted in an increase in second metatarsal strain. Therefore, muscular fatigue of the foot may play a role in the etiology of metatarsal stress fractures (52).

Athletes who abruptly increase their training, whether it be training mileage, time spent in high impact activities, or training intensity, are susceptible to stress fractures. A study of 320 athletes with bone scan positive stress fractures found the following distribution among sports: runners (69%), aerobics (8%), racket sports (5%), basketball (4%), and the remainder in football, hockey, gymnastics, and soccer (34). Military studies have found stress fractures to be more common in women, older aged individuals, and Caucasians (7,44). Although numerous studies have attempted to correlate foot shape to the incidence of stress fractures, none have conclusively shown a direct relationship between pes planus or cavus and stress fracture incidence (43).

Amenorrhea is present in up to 20% of vigorously exercising women and may be as high as 50% in elite runners and dancers (33). Women long-distance runners, ballet dancers, and gymnasts are notorious for dieting despite rigorous training schedules to achieve low body fat. Athletes with amenorrhea for greater than 6 months' experience the same bone loss as after menopause (42). Whole body bone mineral density is significantly lower in amenorrheic athletes, which predisposes them to stress fracture (42).

Do shoewear modifications or orthotics affect the incidence of stress fractures? Three studies of military recruits using shock-absorbing or semirigid orthotics failed to show a decrease in the incidence of metatarsal stress fractures (17,37,48). One study showed a decrease in the incidence of metatarsal fractures in low-arched feet by using a semirigid orthotic (53).

The athlete with a metatarsal stress fracture usually reports mild forefoot discomfort for days to weeks. There is often not a discrete injury, although an abrupt increase in pain may occur after one episode of particularly vigorous activity. The pain may not begin until a few minutes into activity. The athlete may be able to exercise through the pain early in the course of the injury. The discomfort may be relieved by rest, but as the stress fracture worsens, pain is experienced while walking and even at rest. An abrupt increase in activity level, whether in mileage or intensity, is reported. Even a well-conditioned runner who abruptly increases mileage or starts interval training or hill running is a candidate for stress fracture. A change in equipment or running shoe may lead to injury. Symptoms usually present 4–5 wk after a change in training regimen (38).

Figure 1—A stress fracture of the second metatarsal neck. Note the transverse sclerotic line, which correlated clinically with the site of the patient's maximum tenderness.

Local point tenderness of the involved metatarsal is present. Erythema of the dorsal foot may also be present. Anteroposterior, lateral and oblique radiographs of the foot may not show a fracture for 3–6 wk. A thin sclerotic line may be seen in a stress fracture of metaphyseal bone (Fig. 1). A break in the diaphyseal cortex may be very subtle and seen only on one view. Later in the course of the injury subperiosteal bone formation is seen. Although initial radiographs may be negative, a technetium bone scan is positive as early as 48–72 h after onset of symptoms. A triple phase bone scan (angiogram, blood pool, and delayed image phases) may improve specificity by showing increased uptake in all three phases. The bone scan initially shows diffuse increased uptake, which becomes more sharply marginated and fusiform in more advanced stages of the fracture (Fig. 2). In some studies, only 10–25% of bone scan positive fractures had radiographic evidence of fracture (38). In up to 50% of athletes with positive bone scans, asymptomatic sites are visualized, which may represent subclinical sites of bone remodeling known as stress reactions.

Metatarsal stress fractures should be treated with rest from the offending activity and cross-training in a low-

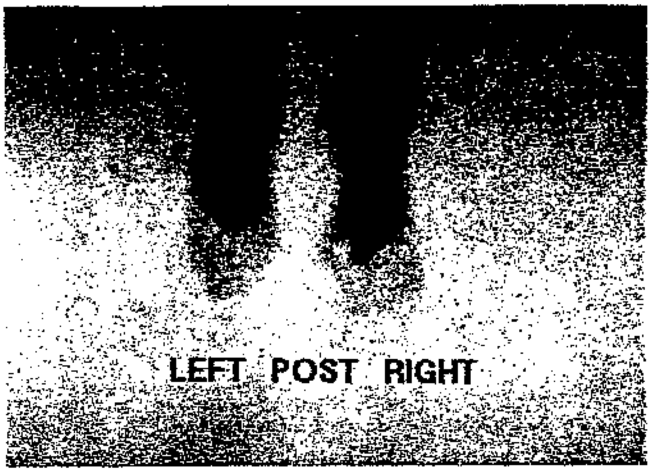

Figure 2—The delayed phase of the technetium bone scan demonstrating increased uptake in the second metatarsal neck. This is the bone scan of the patient whose plain radiographs are seen in Figure 1.

impact sports. Weight bearing to tolerance may be allowed in comfortable shoes of choice or a wooden shoe. If the fracture is diagnosed late and is associated with marked antalgia and pain, a short leg walking cast or functional cast-brace should be prescribed for 5–6 wk until healing callus is seen radiographically. After 6 wk, weight-bearing exercise can usually begin.

A stress fracture of the proximal diaphysis of the fifth metatarsal should be differentiated from the acute fractures of the metatarsal base. Fractures of the proximal fifth metatarsal have all been indiscriminately labeled a "Jones' fracture." A true Jones' fracture is an acute fracture of the proximal fifth metatarsal at the diametaphyseal junction involving the fourth-fifth metatarsal articulation caused by forefoot adduction. The most common fifth metatarsal base fracture is an avulsion fracture of the tuberosity caused by traction of the peroneus brevis and lateral band of the plantar fascia during hindfoot inversion (26). A stress fracture of the proximal fifth metatarsal base occurs distal to the fourth-fifth metatarsal base articulation, usually 1.5 cm distal to the tuberosity. The proximal fifth metatarsal has a poor blood supply and is at significant risk for delayed union or nonunion. A long history of prodromal symptoms, a widened fracture line, intramedullary sclerosis, and periosteal reaction are hallmarks of this stress fracture (12). These fractures should be treated with nonweightbearing short leg cast immobilization for 6–8 wk or until healing is seen radiographically. If an established nonunion develops, screw fixation and/or bone grafting may be required (57).

INTERDIGITAL NEUROMA

An interdigital neuroma, or Morton's neuroma, is a mechanical entrapment neuropathy of the interdigital nerve. The interdigital nerve courses under the transverse intermetatarsal ligament and is vulnerable to traction injury and compression by the distal edge of the ligament (Fig. 3). The injury occurs during the toe off phase of running or during repetitive positions of toe rise. The condition is a misnomer, as a true neuroma does not exist. Rather, the nerve undergoes pathologic changes of perineural fibrosis, fibrinoid degeneration, demyelination, and endoneural fibrosis (19). The most commonly involved nerve is the third interdigital nerve, between the third and fourth metatarsal heads, followed in incidence by the second interdigital nerve and, rarely, the first and fourth interdigital nerves (62). Although commonly a result of chronic compression of the interdigital nerve, this condition may also arise as a result of an acute dorsiflexion injury to the toes with injury to the collateral ligaments of the metatarsophalangeal joint (49). In a study of 91 patients with interdigital neuromas, the male:female ratio was 1:9 (62). Symptoms are exacerbated by poorly fitting narrow shoes, which compress the forefoot. Poor shoe selection, such as a firm cross-training or racket shoe for long-distance running may increase the impact forces on the forefoot and contribute to neuroma symptoms. High-heeled shoes increase forefoot pressure and will also exacerbate symptoms of interdigital neuroma.

The athlete with an interdigital neuroma will complain of symptoms of forefoot burning, cramping, tingling, and numbness in the toes of the involved interspace. Occasionally the pain radiates proximally in the foot and may be somewhat relieved by removing the shoe and massaging the

Figure 3—The most common site of an interdigital neuroma is between the third and fourth metatarsal heads. The neuroma runs plantar to the transverse intermetatarsal ligament.

forefoot (49). Physical examination reveals tenderness in the web space plantarly between the metatarsal heads. Squeezing the forefoot with one hand while carefully palpating the involved interspace with the thumb and index fingers of the other hand is usually successful in eliciting marked discomfort (Fig. 4). This compression may produce a painful audible click, known as a Mulder's sign (41). Careful palpation of the metatarsophalangeal joint, metatarsal head, and proximal phalanx should be performed to rule out localized joint or bone pathology such as MTP joint synovitis, stress fracture, or Freiberg's infraction, which can also cause symptoms of forefoot pain. A positive Tinel's sign over the tarsal tunnel or multiple symptomatic web spaces should alert the examiner as to the possibility of a more proximal nerve compression or underlying peripheral neuropathy. Electromyographic studies and nerve conduction velocity testing should be performed in these cases (49).

Treatment initially entails avoiding the offending activity, cross-training in lower impact sports and modification of shoewear. A switch to wider, more accommodating shoes with better shock absorption will often improve symptoms. A metatarsal pad, such as an adhesive backed felt pad, placed proximal to the symptomatic interspace is helpful (Fig. 5). The metatarsal pad can also be incorpprated into a custom made full length semirigid orthotic. A trial of nonsteroidal antiinflammatory drugs (NSAIDS) is indicated in an attempt to decrease inflammation around the interdigital nerve. A trial of vitamin B6 50 mg. p.o. BID has been used successfully in the treatment of carpal tunnel syndrome and may also be useful in the treatment of interdigital neuritis (55).

Recalcitrant cases that fail to respond to 2–3 months of the above conservative measures may benefit from an injection of corticosteroids into the involved interspace. A mixture of 0.5 cc. corticosteroid, 1 cc 1% Xylocaine, and 1 cc 0.5% bupivacaine is injected into the interspace through a dorsal approach utilizing a 25-gauge needle. The needle is introduced in a dorsal to plantar direction as the examiner's hand palpates the plantar skin of the interspace. The mixture is injected when the needle is palpated under the plantar skin

Figure 4—Method of palpating the foot for an interdigital neuroma. The interspace is palpated both plantarly and dorsally. Symptoms may be exacerbated by simultaneously squeezing the forefoot.

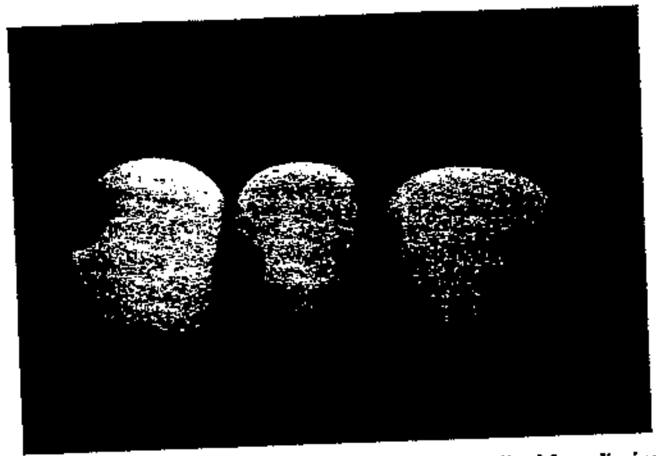

Figure 5—Commercially available wool felt pads utilized for relieving forefoot symptoms. Each pad is backed with adhesive so it can be positioned in the insole of the shoe. Left, a "C' or "J" pad is place just proximal to the lesser metatarsal heads with the cut out "C" portion under the symptomatic sesamoids to relieve pressure on the sesamoids. Middle, a metatarsal pad is placed just proximal to the symptomatic metatarsal head or interspace. Right, a larger metatarsal bar is used in cases of generalized pain in all metatarsal heads.

(49). One to two injections can be tried, but multiple injections should be avoided as corticosteroids may cause atrophy of the plantar fat pad. A retrospective study of 65 patients who underwent interdigital corticosteroid-Xylocaine injections found that 80% of patients had complete relief or significant relief of pain at 2-yr follow-up. Only 11 of 65 patients required eventual surgery in this study (20). Another study showed less successful long-lasting results with conservative measures, with 70% of patients electing to have the surgery (32).

Surgery in the athlete is the treatment of last resort. The surgical procedure is performed through a dorsal longitudinal incision over the distal aspect of the interspace. The intermetatarsal ligament is sectioned and the interdigital nerve is excised. Some surgeons feel that the intermetatarsal ligament should be left intact if possible. Another method of surgical treatment is release of the intermetatarsal ligament while leaving the interdigital nerve intact in order to remove the offending compressing structure on the nerve (60).

SESAMOID PATHOLOGY

The tibial (medial) and fibular (lateral) sesamoids are important components of the first metatarsophalangeal joint complex. Situated under the first metatarsal head, they are prone to injury in repetitive high impact and contact sports. The sesamoids are contained within the tendon of the flexor hallucis brevis and serve to increase the lever arm for flexion of the MTP joint, analogous to the function of the patella in knee extension. The sesamoids are connected distally to the base of the proximal phalanx by extensions of the flexor hallucis brevis called the plantar plate. The abductor hallucis inserts into the medial sesamoid and the adductor hallucis inserts into the lateral sesamoid. The sesamoids are separated on the plantar aspect of the first metatarsal head by a crista, or ridge. They are connected to one another by the intersesamoidal ligament. The flexor hallucis

TABLE 1. Causes of sesamoid pain.

Acute sesamoid fracture
Sesamoid stress fracture
Osteochondritis of sesamoid
Sesamoiditis (chondromalacia)
Arthritis of sesamoid-metatarsal articulation
Seasamoid bursitis

longus pierces the two heads of the flexor hallucis brevis muscle to run just plantar to the intersesamoidal ligament. The sesamoids bear up to three times body weight during a normal gait cycle and the tibial sesamoid bears the majority of the force (23,36,45,46,51,59,61).

Although direct trauma or forced dorsiflexion of the great toe can acutely fracture the sesamoids, most sesamoid injuries are overuse injuries. Table 1 lists the various etiologies of sesamoid pain. Twelve percent of injuries to the great toe complex are sesamoid injuries (36). According to McBryde and Anderson (36), the etiologies of sesamoid injuries are stress fracture (40%), acute fractures (10%), chondromalacia, synovitis, sesamoiditis (30%), osteochondritis (10%), arthritis (5%), and bursitis (5%). Bipartite or multipartite sesamoids occur in 5–33% of the population and are bilateral in 25% (50,51). The smooth contour of the partite sesamoid differs from the usually indistinct jagged fracture surface of the fractured sesamoid. Because the tibial sesamoid bears most of the force under the first metatarsal head, it is most commonly injured.

Athletes with sesamoid injuries complain of acute or chronic pain and swelling under the involved sesamoid. Passive dorsiflexion of the MTP joint exacerbates the pain. Sesamoidal bursitis presents with swelling, erythema, and tenderness with side-to-side pinch. A plantar fullness or fluid-filled bursal cyst may be palpated under the sesamoids. Plain radiographs in anteroposterior, lateral, and standard lateral oblique views are helpful. The axial sesamoid view is taken with the beam angled from the heel to the toes down the long axis of the foot parallel to the plantar surface of the foot. The axial sesamoid view is excellent in diagnosing arthritis of the metatarsosesamoidal articulation. The tibial sesamoid view is taken with the foot in a lateral position with the x-ray beam angled 15° cephalad, and the MTP joint extended 50°. This view profiles the tibial sesamoid nicely (Fig. 6).

Technetium bone scans are helpful in diagnosing occult stress fractures of the sesamoids because plain films may be negative for the initial 3 wk after injury. The bone scan is positive within 48–72 h after onset of symptoms. Bone scans are sensitive but nonspecific, as increased uptake is seen in acute fractures, stress fractures, osteochondritis, or sesamoiditis. CT scans or magnetic resonance imaging (MRI) may also be helpful, although these tests are expensive and usually not required to make a diagnosis.

Acute fractures of the sesamoids are rare but can occur with hyperdorsiflexion injuries or dislocations. An acute fracture appears as a sharp radiolucent line with occasional wide separation of fragments (Fig. 6). Stress fractures are the most common cause of sesamoid pain. The differentiation between a sesamoid stress fracture and a fractured bipartite sesamoid is sometimes difficult to make. An established nonunion of a sesamoid and a fractured bipartite sesamoid have essentially the same radiographic appearance, as in both cases the separated surfaces of the sesamoid have a rounded appearance. Some authors feel that some bipartite sesamoids may actually be fracture nonunions (10). The treatment of a sesamoid fracture is initially rest from the offending high impact activity and a wooden-soled shoe or short leg cast for 6–8 wk. An alternative treatment is the use of a "C" or "J" pad, which unloads the injured sesamoid. Pads with adhesive backing may be fixed to the insole of the shoe or may be incorporated into a custom molded orthotic to unload the sesamoid (Fig. 5). A failure of several months of conservative management of a sesamoid stress fracture or nonunion may leave no alternative but surgery. Surgical choices include excision of the involved sesamoid or bone grafting in an attempt to achieve union and preserve the sesamoid.

Sesamoid osteochondritis is characterized by pain, tenderness to palpation, and radiographic osseous mottling or fragmentation (10). The etiology is unclear, although it is thought to be due to an acute or chronic traumatic injury, which may result in aseptic necrosis of the sesamoid (23). A bone scan will document increased uptake in the involved sesamoid early in the course of the disease. An axial sesamoid view will eventually show mottling and fragmentation later in the course of the disease. Conservative treatment involves rest from impact sports and nonsteroidal antiinflammatory medication. The appearance of fragmentation usually indicates that surgical excision will be necessary to relieve symptoms.

The diagnosis of sesamoiditis is one of exclusion. This condition has been defined as inflammation and swelling of the peritendinous structures of the sesamoids (13). Sesamoiditis is associated with local trauma, pain on weight bearing, and plantar soft tissue swelling (10). This condition may be associated with degeneration, or chondromalacia, of the sesamoidal articular cartilage (1). Plain radiographs are normal, but bone scan may show increased diffuse uptake of the plantar region of the first metatarsophalangeal joint. Again

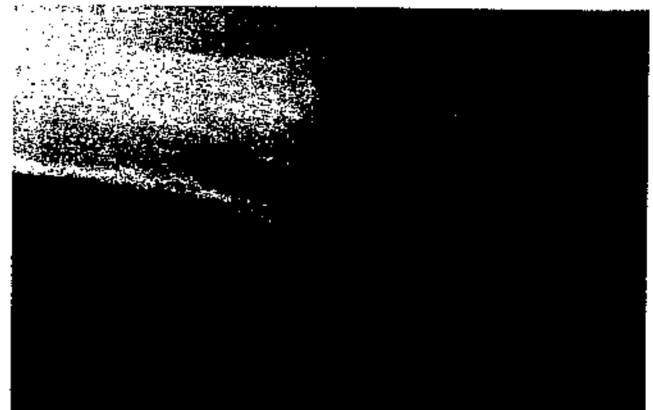

Figure 6—A tibial sesamoid view demonstrating a fracture of the tibial sesamoid. Note the wide separation between fragments and lack of sclerosis at the edges of the fracture.

conservative treatment involves rest from the offending activity, nonsteroidal antiinflammatory medication, and pads or orthotics to decrease the load on the involved sesamoid. One or two injections of corticosteroids into the region of the sesamoids may be helpful. Failure of several months of conservative care may result in the need for surgical excision of the offending sesamoid to alleviate symptoms.

METATARSALAGIA

Metatarsalgia refers to pain in the plantar aspects of the metatarsal heads. A common cause of metatarsalgia has already been discussed, interdigital neuroma. Table 2 lists the common causes of metatarsalgia. Any biomechanical intrinsic or extrinsic condition that increases stress on the metatarsal heads may result in metatarsal head pain and the development of painful plantar keratoses (4). Calluses under the metatarsal heads are known as plantar keratoses. Plantar keratoses may be diffuse and large, or small and discrete. A rigid cavus foot with plantar flexed first and second rays is prone to diffuse painful calluses under the first and second metatarsal heads. A Morton's foot with a short first metatarsal and a relatively long second metatarsal may result in increased loading of the second metatarsal head and the development of a painful callus (40). Patients with abnormally lax first metatarsal-cuneiform joints resulting in a hypermobile first ray will experience increased weight bearing under the second and third metatarsals, which often results in painful diffuse calluses. A prominent lateral condyle of a lesser metatarsal will result in a smaller discrete plantar keratosis, which can be exquisitely tender to palpation. A tight Achilles tendon will increase forefoot load in late stance phase and may result in metatarsalgia. The use of high-heeled shoes extrinsically increases forefoot load and may lead to diffuse metatarsalgia. Patients with diffuse swelling, pain, and stiffness of multiple MTP joints should be evaluated for inflammatory arthropathy, such as rheumatoid arthritis, seronegative spondyloarthropathy, or crystalline-induced arthritis.

The treatment of all these above conditions initially is an orthotic device, such as a metatarsal pad placed proximal to the painful metatarsal heads. Adhesive-backed metatarsal pads of different shapes and sizes are available to unload one or several metatarsal heads (Fig. 5). Custom orthotics may also be molded specifically for the cavus foot to decrease load on the plantarflexed first and second rays in order to distribute weight evenly across the forefoot. A patient with a hypermobile first ray will benefit from a custom longitudinal arch support with medial forefoot post in an attempt to increase load on the first metatarsal head. A trial of Achilles stretching is helpful in the initial treatment of metatarsalgia. Of course, the wearing of high heels should be discouraged in patients with metatarsalgia. A discrete plantar callus under the lateral plantar condyle of a prominent metatarsal head may respond to periodic shaving and a metatarsal pad. If unresponsive to conservative treatment, surgical plantar condylectomy may be required for resolution of a discrete plantar keratosis. More generalized diffuse painful calluses such as those seen under the first and second metatarsal heads in the cavus foot may require dorsal closing wedge osteotomies of the metatarsal bases to achieve pain relief (4).

Idiopathic synovitis of the second or third MTP joint (MTPJ) is another cause of metatarsalgia. This condition results in painful distension of the joint, swelling of the second toe, warmth, and limited MTPJ motion (31). Second MTPJ synovitis probably occurs as a result of attrition of the plantar plate due to a long second metatarsal (16). Dorsal instability of the MTPJ may develop with joint subluxation or dislocation. A hammertoe or clawtoe deformity is common. Attrition of the lateral collateral ligament of the MTPJ may occur with resultant cross-over deformity as the second toe crosses over the great toe (11). Initially the patient develops pain on palpation in the plantar and dorsal aspects of the MTPJ. Joint instability can be diagnosed by grasping the proximal phalanx and attempting to translate it dorsally. This digital Lachman's test, or drawer test, will produce pain and palpable dorsal translation of the phalangeal base (56). Conservative treatment of second MTPJ synovitis is nonsteroidal antiinflammatory medication, a metatarsal pad, taping the toe in a plantar flexed position, and an accomodative shoe. An intraarticular corticosteroid injection in combination with a rocker-sole modification has been shown to result in improvement in 93% of 15 cases (58). Persistent pain in the second MTPJ despite conservative measures may necessitate operative synovectomy to avert toe dislocation or deformity. In the case of symptomatic toe instability or cross-over deformity, MTPJ arthroplasty, ligamentous release, and tendon transfer have been recommended (16).

Freiberg's disease is an osteochondrosis of congenital, traumatic, or vascular etiology leading to eventual collapse and deformity of a lesser metatarsal head. An osteochondrosis is a disease of the epiphysis, which predisposes it to traumatic injury (14). It is unlikely that an athletic injury is the sole cause of Freiburg's disease, although a mechanical stress to the forefoot may exacerbate a previously subclinical condition. This condition is most common in the second metatarsal head with a predilection of 68–82% (18,22). The typical patient with Freiburg's disease is a female adolescent aged 11–17 yr (25) The female to male ratio for this condition is 5:1. The condition may be asymptomatic early on and present in young adulthood to middle age. The patient presents with second MTPJ pain, which is worse with activity. Exam shows pain on palpation of the second

TABLE 2. Causes of metatarsalgia.

Interdigital neuroma
Idiopathic MTPJ synovitis
Freiburg's disease
Inflammatory arthritis of MTPJs
Cavus foot with plantar flexed 1st and 2nd rays
Morton's foot (long 2nd ray)
Hypermobile 1st ray
Prominent lateral plantar condyle of metatarsal head
Tight Achilles tendon
High heeled shoes

MTPJ, limited range of motion, periarticular swelling, and occasionally a plantar callosity under the second metatarsal head (54). Radiographs initially show rarefaction of the metatarsal subchondral bone at the site of the subchondral fracture. Over time, flattening and collapse of the dorsal aspect of the metatarsal head is seen (Fig. 7). Later radiographic stages demonstrate the formation of loose bodies and, finally, marked flattening of the metatarsal head and joint space narrowing. Initial treatment of Freiburg's disease is rest from high-impact activities and possible use of a short leg walking cast or range of motion walking boot. Patients with severe antalgia should use crutches. As symptoms decrease, a phased return to activity is indicated with a metatarsal pad placed proximal to the involved MTP joint. Hoskinson (22) reported success with conservative treatment in 11 of 28 patients, although all had restriction of joint motion. The surgical treatment of Freiburg's disease involves debridement of the joint, removal of loose bodies, and removal of metatarsal head osteophytes with reshaping of the head (30). A dorsiflexion osteotomy of the metatarsal head has also been advocated in order to rotate the healthy plantar cartilage up into the articulation with the proximal phalanx. This treatment shortens and elevates the metatarsal head slightly, unloads it, reduces stress, and allows healing (18).

HALLUX RIGIDUS

Hallux rigidus is characterized by decreased dorsiflexion of the first metatarsophalangeal joint, pain, and swelling in the dorsal aspect of the joint. Attempted hallux dorsiflexion results in pain due to the impingement of dorsal osteophytes of the first metatarsal head and dorsal base of the proximal phalanx. Hallux rigidus results from degenerative arthritis of the first MTP joint. The cause of this degenerative process is unknown, but it may occur as a result of an intraarticular fracture, compression of the articular surfaces (turf toe), or an osteochondrotic lesion of the first metatarsal head (27). Repetitive dorsiflexion injuries to the first MTP joint could potentially lead to the development of hallux rigidus, although no studies have linked levels of physical activity to the development of hallux rigidus (27).

The athlete may experience difficulty walking or running up hills, climbing stairs, or during the toe-off phase of gait. Because 15° of hallux dorsiflexion is needed for normal gait, limited extension of the great toe will give the feeling of vaulting over the toe and may necessitate external rotation of the foot to allow for toe clearance. The dorsal metatarsal head osteophyte, or dorsal bunion, may rub against shoewear, causing an abrasion or ulceration (Fig. 8). The patient may experience tingling and numbness on the dorsum of the toe as a result of compression of the dorsomedial or dorsolateral cutaneous nerve. The dorsal metatarsal head osteophyte is palpable and is associated with periarticular soft tissue swelling. Tenderness is present on palpation of the dorsal, and especially lateral aspects of the joint. Radiographs demonstrate loss of first MTP joint space, the formation of dorsal and lateral osteophytes on the metatarsal head, and occasionally loose fragments about the joint. (24) (Fig. 9).

Initial treatment entails the use of shoe modifications, rest, and nonsteroidal antiinflammatories. A shoe with an extra-depth toe box is helpful to decrease dorsal pressure on the first MTP joint. A stiff-soled shoe or a rigid custom orthotic with a Morton's extension can be helpful in limiting toe dorsiflexion. A rocker bottom sole can also help to decrease the extension of the hallux during normal gait. An intra-articular corticosteroid injection may be considered as a temporizing measure. As symptoms increase, surgical intervention may provide the solution.

Surgical intervention is indicated when conservative measures fail. The most common procedure recommended is the cheilectomy, which is an excision of the dorsal 25–33% of the metatarsal head. This removes the offending osteophytes, improves toe dorsiflexion, and preserves the good articular cartilage on the middle and plantar aspects of the metatarsal head (28). A dorsiflexion osteotomy of the proximal phalanx (Moberg procedure) may be used concurrently with a cheilectomy in selected patients to increase functional toe dorsiflexion (39). The Keller arthroplasty, or resection of the base of the proximal phalanx, should not be used in athletes, because it disrupts the plantar plate and flexor hallucis brevis attachments to the proximal phalanx

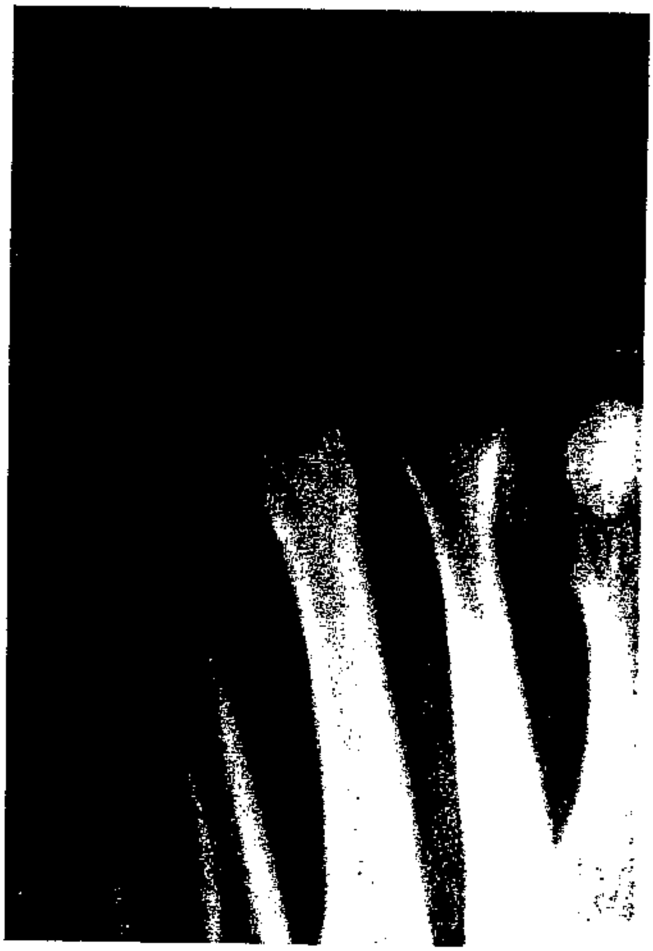

Figure 7—Freiburg's disease of the third metatarsal head. The head is flattened and sclerotic.

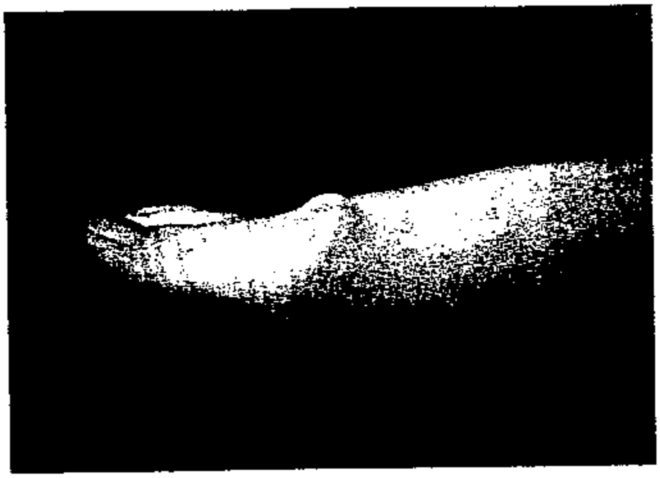

Figure 8—A clinical photo of a patient with hallux rigidus. Large dorsal osteophytes of the metatarsal head are visible. These osteophytes limit toe extension and rub on the top of the shoe, causing local irritation and occasional neuritic symptoms.

and will result in decreased push-off strength. Arthrodesis of the first MTP joint usually results in satisfactory pain relief, but the stiffened joint may be poorly tolerated by athletes. Other recently recommended surgical procedures involve resection of a small portion of the proximal phalanx with interposition of capsule or tendon into the joint to act as an arthroplasty (2,21). Prosthetic replacement of the first MTP joint is not recommended, especially in the athletic population, because of concerns with implant failure, loosening, and silicone synovitis.

HALLUX VALGUS

Hallux valgus, commonly known as a bunion deformity, is lateral deviation of the hallux with respect to the first metatarsal. Hallux valgus is often associated with medial deviation of the first metatarsal, known as metatarsus primus varus. The cause of hallux valgus is probably a combination of familial predisposition and improper shoewear. With increasing lateral deviation of the hallux, the MTP joint becomes incongruent, the sesamoids subluxate laterally, the hallux pronates, the medial aspect of the first metatarsal head becomes more prominent, and weight bearing shifts from the first metatarsal head to the second metatarsal. Weight transfer to the lesser metatarsals may result in the formation of a painful plantar keratosis under the second metatarsal head. As the great toe moves laterally, it may crowd the second toe leading to a hammertoe or cross-over toe deformity of the second toe. A bunion deformity can be quantitated by measurements of the hallux valgus angle and first-second intermetatarsal angle (Fig. 10, A and B).

The presence of an asymptomatic hallux valgus deformity in the athlete does not warrant treatment. However, some athletes may suffer debilitating pain from even a minor hallux valgus deformity. The athlete will usually present with a red, enlarged, painful area on the medial aspect of the first metatarsal head. Compression may occur between the first and second toes. In severe cases a second toe deformity may occur and a painful keratosis may form under the second metatarsal head. Baxter (3) has coined the terms compensated bunion and decompensated bunion to help direct treatment of the athletic bunion. A compensated bunion is a mild deformity without MTP joint subluxation and without marked lateral sesamoid subluxation. A decompensated bunion is a moderate to severe deformity characterized by hallux valgus angle greater the 25°, intermetatarsal angle greater than 15°, lateral sesamoid subluxation, and great toe pronation.

The treatment of hallux valgus in the athlete should be conservative if possible. A wider athletic shoe should be used to decrease pressure on the irritated medial bunion. Achilles stretching should be used in cases of Achilles contracture. A simple toe spacer between the first and second toes is often helpful. A silicone bunion pad placed over the bunion may be helpful in alleviating direct pressure on the prominence. In cases of pes planus associated with hallux valgus, a medial longitudinal arch support with Morton's extension under the first MTPJ may also alleviate symptoms. Most compensated bunions can be treated successfully with nonoperative treatment.

As the bunion deformity becomes more severe and decompensated, conservative measures usually fail to provide relief. Baxter feels that a simple distal chevron osteotomy (a distal osteotomy of the first metatarsal head with tightening of the medial capsule) is sufficient to relieve symptoms. (3) (Fig. 11, A and B.) He feels that although complete correction of the deformity is not always achieved, the conversion of a decompensated bunion to a compensated bunion is all that is required. More extensive surgical procedures, such as proximal osteotomies, joint fusions, or joint replacements should be avoided, because of the extensive nature of these procedures and because of their prolonged recovery times.

TURF TOE

Turf toe is a dorsiflexion injury to the first metatarsophalangeal joint resulting in pain, swelling, and disability. This injury became more common in football players with the advent of artificial turf. The tendency of artificial turf to become hard and stiff over time may be a factor in the

Figure 9—A lateral radiograph of the first MTP joint of a patient with hallux rigidus. Dorsal osteophytes of the metatarsal head and proximal phalanx are seen.

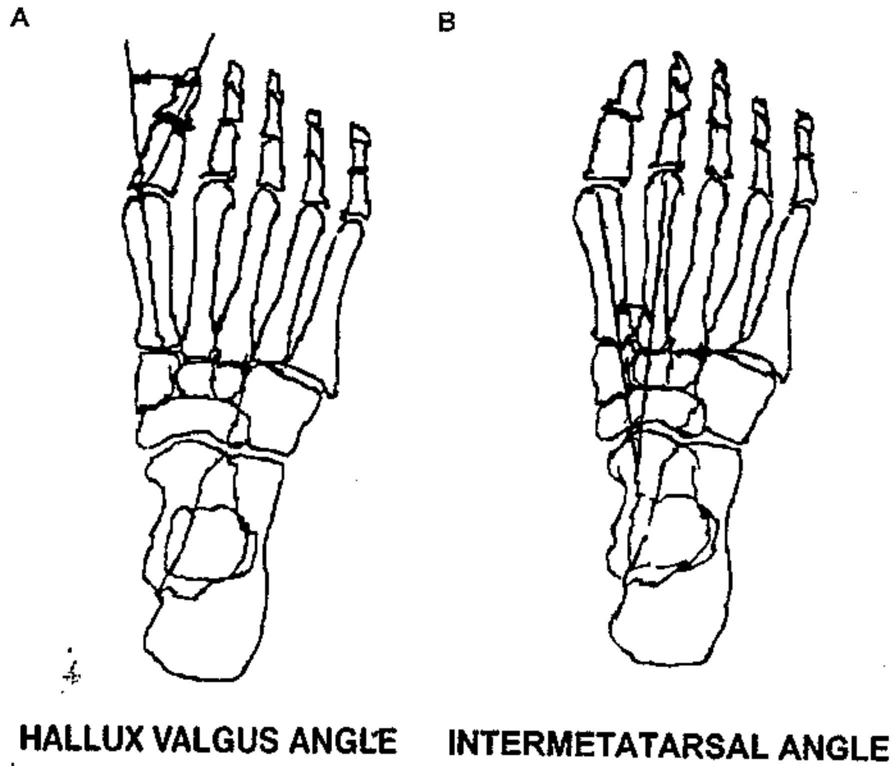

Figure 10—A, The hallux valgus angle is formed by lines drawn down the longitudinal axes of the proximal phalanx and first metatarsal. The normal hallux valgus angle is less than or equal to 15°. B, The intermetatarsal angle is formed by lines drawn down the longitudinal axes of the first and second metatarsals. The normal intermetatarsal angle is less than or equal to 9°.

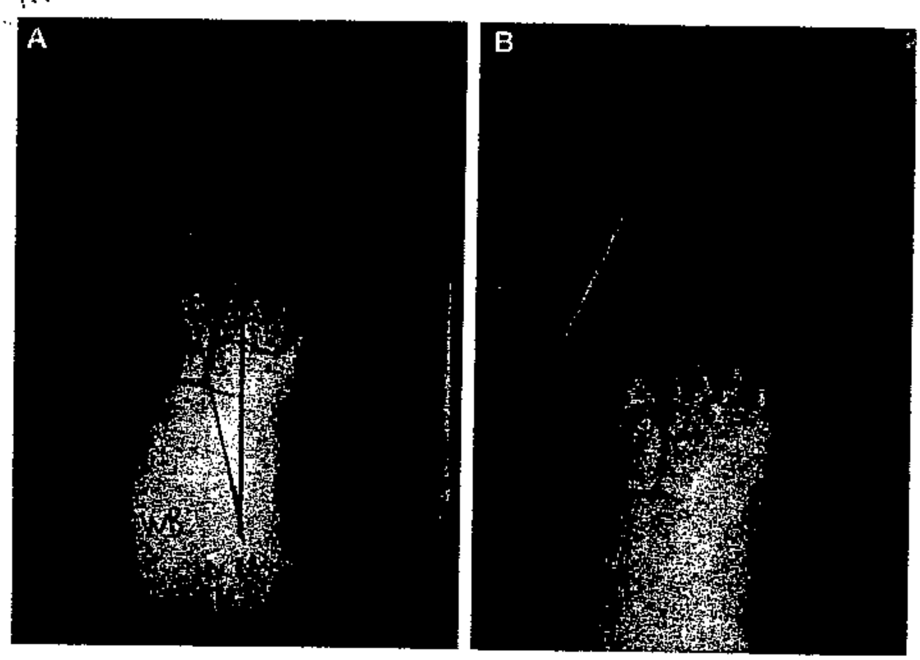

Figure 11—A, A patient with a symptomatic decompensated bunion. The hallux valgus angle is 28°, the first MTP joint is incongruent and the sesamoids are subluxated laterally. B, The same patient after distal chevron bunionectomy. The pin is left in place for 4 wk.

increasing incidence of this injury (5). Perhaps more important is the increasing flexibility of athletic shoe soles, which allows increased toe dorsiflexion during play. Football players are at greatest risk for this injury as they are tackled while landing from a jump or if another player lands on the back of their heel forcing the first MTP joint into hyperdorsiflexion (46).

The mechanism of injury is most commonly dorsiflexion, although hyperplantarflexion injuries have also been reported. The plantar plate is the ligamentous attachment of the sesamoids and flexor hallucis brevis to the base of the proximal phalanx. With forced dorsiflexion of the hallux beyond its normal soft tissue restraints, tearing of the plantar plate and collateral ligaments can occur. With severe injuries, fracture of the sesamoids can occur and dorsal dislocation of the first MTP joint is possible. The dorsal articular surface of the first metatarsal head is compressed by the base of the proximal phalanx, which may result in articular injury.

Clinically, athletes with turf toe presents with a red, swollen, stiff first MTP joint. They may have a history of a single dorsiflexion injury or multiple injuries to the great toe. The joint may be tender both plantarly and dorsally. Players may have a limp and be unable to run or jump because of pain.

Clanton and Ford (9) have classified the severity of turf toe injuries from grades 1 to 3. A grade 1 sprain is a minor stretch injury to the soft tissue restraints with little pain, swelling, or disability. A grade 2 sprain is a partial tear of the capsuloligamentous structures with moderate pain, swelling, ecchymosis, and disability. A grade 3 sprain is a complete tear of the plantar plate with severe swelling, pain, ecchymosis, and inability to bear weight normally. Radiographs of the foot should be obtained to rule out fracture of the sesamoids or metatarsal head articular surface and to check joint congruity.

Initial treatment of turf toe is rest, ice, a compressive dressing, and elevation (RICE). A nonsteroidal antiinflammatory medication is recommended. A compressive dressing and cryotherapy is recommended the first 48 h after injury. The toe should be taped to limit dorsiflexion with multiple loops of tape placed over the dorsal aspect of the hallucal proximal phalanx and criss-crossed under the ball of the foot plantarly (46). Physical therapy for passive range of motion and progressive resistance exercises are begun as soon as symptoms allow (24,46). Patients with grade 1 sprains are allowed to return to sports as soon as symptoms allow, usually immediately. Patients with grade 2 sprains will require 3–14 d rest from athletic training. Grade 3 sprains will require crutches for a few days and up to 6 wk rest from sports participation. A return to sports training too early after injury could result in prolonged disability. A study of 20 patients with turf toe injury has documented a 50% incidence of persistent symptoms at 5 yr (9) Shoe modifications incorporating a stiffer sole or an orthotic with a rigid forefoot section will help to limit hallux dorsiflexion and prevent hyperextension reinjury (46).

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REFERENCES

1. Apley, A. G. Open sesamoid: a re-appraisal of the medial sesamoid of the hallux. *Proc. R. Soc. Med.* 59:120–121, 1966.
2. Barca, F. Tendon arthroplasty for the first metatarsophalangeal joint in hallux rigidus: preliminary communication. *Foot Ankle Int.* 18:222–228, 1997.
3. Baxter, D. E. Treatment of the bunion deformity in athletes. *Orthop. Clin. North Am.* 25:33–39, 1994.
4. Baxter, D. E., and C. Zingas. The foot in running. *J. Am. Acad. Orthop. Surg.* 3:136–145, 1995.
5. Bowers, K. D., Jr., and R. B. Martin Impact absorption: new and old Astroturf at West Virginia University. *Med. Sci. Sports* 6:217–221, 1974.
6. Breithaupt, M. D. On the pathology of the human foot. *Med. Zeitung* 24:169, 1855.
7. Brudvig, T. J., T. D. Gudger, and L. Obermeyer. Stress fractures in 295 trainees: a one-year study of incidence as related to age, sex, and race. *Mil. Med.* 148:666–667, 1983.
8. Cavanagh, P. R. The biomechanics of lower extremity action in distance running. *Foot Ankle* 7:212, 1987.
9. Clanton, T. O., and J. J. Ford. Turf toe injury. *Clin. Sports Med.* 13:731–741, 1984.
10. Coughlin, M. J. Sesamoid pain: causes and surgical treatment. *Instr. Course Lect.* 39:23–35, 1990.
11. Coughlin, M. J. Crossover second toe deformity. *Foot Ankle* 8:29–39, 1987.
12. Delee, J. C., J. P. Evans, and J. Julian. Stress fractures of the fifth metatarsal. *Am. J. Sports Med.* 5:349–353, 1983.
13. Dobas, D. C., and M. D. Silvers. The frequency of partite sesamoids of the metatarsophalangeal joint. *J. Am. Podiatry Assoc.* 67:880–882, 1977.
14. Duthrie, R., and G. Houghton. Constitutional aspects of the osteochondroses. *Clin. Orthop. Rel. Res.* 158:19–27, 1981.
15. Eisele, S. A., and G. J. Sammarco. Fatigue fractures of the foot and ankle in the athlete. *Instr. Course Lect.* 42:175–183, 1993.
16. Fortin, P. T., and M. S. Myerson. Second metatarsophalangeal joint instability. *Foot Ankle Int.* 16:306–313, 1995.
17. Gardner, L. I., J. E. Dziados, B. H. Jones, et al. Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. *Am. J. Public Health* 78:1563, 1988.
18. Gauthier, G., and R. Elbaz. A subchondral bone fracture: a new surgical treatment. *Clin. Orthop.* 142:93–95, 1979.
19. Graham, C. E., and D. M. Graham. Morton's neuroma: a microscopic evaluation. *Foot Ankle* 5:150, 1984.
20. Greenfield, J., J. Rea, Jr., and F. W. Ilfeld. Morton's interdigital neuroma: indications for treatment by local injection versus surgery. *Clin. Orthop.* 185:142–144, 1984.
21. Hamilton, W. G., M. J. O'Malley, and F. M. Thompson. Capsular interposition arthroplasty for severe hallux rigidus. *Foot Ankle Int.* 18:68–70, 1997.
22. Hoskinson, J. Freiburg's disease: a review of long-term results. *Proc. R. Soc. Med.* 67:106–107, 1974.
23. Jahss, M. H. The sesamoids of the hallux. *Clin. Orthop.* 157:88–97, 1981.
24. Katcherian, D. A. Pathology of the first ray. In: *Orthopaedic Knowledge Update, Foot and Ankle.* M. S. Mizel, R. A. Miller, and M. W. Scioli (Eds.) Rosemont, IL: American Academy of Orthopaedic Surgeons, 1998, pp.157–159.
25. Katcherian, D. A. Treatment of Freiburg's disease. *Orthop. Clin. North Am.* 25:69–81, 1994.
26. Lawrence, S. J., and M. J. Botte. Jones' fractures and related fractures of the proximal fifth metatarsal. *Foot Ankle* 14:358–365, 1993.
27. Mann, R. A. Hallux rigidus. *Instr. Course Lect.* 39:15–21, 1990.
28. Mann, R. A. Hallux rigidus: treatment by cheilectomy. *J. Bone Joint Surg.* 70A:400–406, 1988.
29. Mann, R. A. Biomechanics of running. *In: AAOS Symposium on the Foot and Leg in Running Sports.* St. Louis: CV Mosby Co. 1982: pp. 30–44.
30. Mann, R. A., and M. J. Coughlin. Keratotic disorders of the skin. In: *Surgery of the Foot and Ankle.* R. A. Mann and M. J. Coughlin (Eds.). St. Louis: Mosby-Yearbook, 1993, pp.533–441.
31. Mann, R. A., and M. S. Mizel. Monarticular nontraumatic synovitis of the metatarsophalangeal joint: a new diagnosis? *Foot Ankle* 6:18–21, 1985.
32. Mann, R. A., and J. D. Reynolds. Interdigital neuroma: a critical clinical analysis. *Foot Ankle* 3:238–243, 1983.
33. Marshall, L. A. Clinical evaluation of amenorrhea. In: *Medical and Orthopedic Issues of Active and Athletic Women,* R. Agostini and S. Titus (Eds.). Philadelphia: Hanley and Belfus, 1994, pp. 152–163.
34. Matheson, C. O., D. B. Clement, D. C. McKenzie, J. E. Taunton, D. R. Lloyd-Smith, and J. G. MacIntyre. Stress fractures in athletes: a study of 320 cases. *Am. J. Sports Med.* 15:46–58, 1987.
35. McBryde, A. M., Jr. Stress fractures in athletes. *J. Sports Med.* 3:212–217, 1975.
36. McBryde, A. M., Jr., and R. B. Anderson. Sesamoid problems in the athlete. *Clin. Sports Med.* 7:51–60, 1988.

37. Milgrom, C., M. Giladi, H. Kashton, et al. A prospective study of the effect of a shock-absorbing orthotic device on the incidence of stress fractures in military recruits. *Foot Ankle* 6:101–104. 1985.
38. Monteleone, G. P. Stress fractures in the athlete. *Orthop. Clin. North Am.* 26:423, 1995.
39. Moberg, E. A simple operation for hallux rigidus. *Clin. Orthop.* 142:55–56, 1979.
40. Morton D. J. *The Human Foot: Its Evolution, Physiology, and Functional Disorders.* New York: Columbia Press, 1935, pp. 179–186.
41. Mulder, J. D. The causative mechanism in Morton's metatarsalgia. *J. Bone Joint Surg.* 33B:94–95, 1951.
42. Myburgh, K. H., L. K. Bachrach, B. Lewis, et al. Low bone mineral density at axial and appendicular sites in amenorrheic athletes. *Med. Sci. Sports Exerc.* 25:1197–1202, 1993.
43. Pester, S., and P. C Smith. Stress fractures in the lower extremities of soldiers in basic training. *Orthop. Rev.* 21:297–303, 1992.
44. Protzman, P. R. Physiologic performance of women compared to men at the U.S. Military Academy. *Am. J. Sports Med.* 7:191–196, 1979.
45. Richardson, E. G. Injuries to the hallucal sesamoids in the athlete. *Foot Ankle* 7:229–244, 1987.
46. Sammarco, G. J. *Turf toe. Instr. Course Lect.* 42:207–212, 1993.
47. Sammarco, G. J., and R. T. Hockenbury. Biomechanics of the foot and ankle. In: *Basic Biomechanics of the Musculoskeletal System.* V. H. Frankel and M. Nordin (Eds.). Baltimore: Williams and Wilkins, in press.
48. Schwellnus, M. P., G. Jordaan, and T. D Noakes. Prevention of common overuse injuries by the use of shock absorbing insoles: a prospective study. *Am. J. Sports Med.* 18:636–641, 1990.
49. Schon, L. C. Nerve entrapment, neuropathy, and nerve dysfunction in athletes. *Orthop. Clin. North Am.* 25:47–59, 1994.
50. Scranton, P. Pathologic and anatomic variations of the sesamoids. *Foot Ankle* 1:321–326, 1981.
51. Scranton, P. E., and R. Rutkowski. Anatomic variations in the first ray. Part B. Disorders of the sesamoids. *Clin. Orthop.* 151: 256–264, 1980.
52. Sharkey, N. A., L. Ferris, T. S. Smith, and D. K Matthews. Strain and loading of the second metatarsal during heel lift. *J. Bone Joint Surg.* 77A:1050–1057, 1995.
53. Simkin, A., I. Leichter, M. Giladi, M. Stein, and C. Milgrom. Combined effect of foot structure and an orthotic device on stress fractures. *Foot Ankle* 10:25–29, 1989.
54. Smillie, I. Freiburg's infraction (Koehler's second disease). *J. Bone Joint Surg.* 39B:580, 1955.
55. Szabo, R. M. Carpal tunnel syndrome—general. In: *Operative Nerve Repair and Reconstruction*, R. H. Gelberman (Ed.). Philadelphia: J. B. Lippincott, 1991, pp. 882–883.
56. Thompson, F. M., and W. G. Hamilton. Problems with the second metatarsophalangeal joint. *Orthopedics* 10:83–89, 1987.
57. Torg, J. S., F. C. Balduini, R. R. Zelko, H. Pavlov, T. C. Peff, and M. Das. Fractures of the fifth metatarsal distal to the tuberosity. *J. Bone Joint Surg.* 66A:209–214, 1984.
58. Trepman, E., and S. J. Yeo. Nonoperative treatment of metatarsophalngeal synovitis. *Foot Ankle Int.* 16:771–777, 1995.
59. Van Hal, M. E., J. S. Keeve, T. A. Lange, and W. G. Clancy. Stress fractures of the sesamoids. *Am. J. Sports Med.* 10:122–128, 1982.
60. Weinfeld, S. B., and M. S. Myerson. Interdigital neuroma. *J. Am. Acad. Orthop. Surg.* 4:328–335, 1996.
61. Whittle, A. P. Fractures of the foot in athletes. *Op. Tech. Sports Med.* 2:43–57, 1994.
62. Wu, K. K. Morton's interdigital neuroma: a clinical review of its etiology, treatment, and results. *J. Foot Ankle Surg.* 35:112–119, 1996.