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Stress Fractures of the Foot and Ankle

Jason Brockwell, FRCSEdOrth, Yeung Yeung, FRCSEdOrth,* and James F. Griffith, FRCR†*

Abstract: Stress fractures are common athletic injuries of the foot and ankle, described in every bone except the lesser toes, and reviewed here. Early diagnosis usually allows for simpler treatment and quick recovery. Early clinical presentations can be subtle, so a high degree of suspicion and a systematic approach, coupled with an understanding of the diagnostic limitations present in early injury, is required. Such a rigorous approach ultimately pays dividends for these patients, who are usually keen to return quickly to athletic activity. "High-risk" fractures include the medial malleolus, the talus, the navicular bone, the base of the fifth metatarsal, and the hallux sesamoids. We support recommendations of early surgery in high-risk fractures.

Key Words: fracture, stress fracture, fatigue fracture, sport, dance, foot, ankle

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Stress fractures are common athletic injuries of the foot and ankle, described in every bone except the lesser toes, and reviewed here. Early diagnosis usually allows for simpler treatment and quick recovery. Early clinical presentations can be subtle, so a high degree of suspicion and a systematic approach, coupled with an understanding of the diagnostic limitations present in early injury, is required. Such a rigorous approach ultimately pays dividends for these patients, who are usually keen to return quickly to athletic activity. "High-risk" fractures include the medial malleolus, the talus, the navicular bone, the base of the fifth metatarsal, and the hallux sesamoids. We support recommendations of early surgery in high-risk fractures.

WHAT ARE STRESS FRACTURES?

Stress fractures are fractures of bones due to repetitive loading rather than a single traumatic event. A stress fracture differs from an insufficiency fracture. Although a stress fracture occurs in normal bone subjected to abnormal load, an insufficiency fracture occurs in abnormal bone subjected to normal load.

Factors precipitating stress fractures in the foot and region may be intrinsic or extrinsic. Intrinsic factors include a high longitudinal arch, leg-length discrepancy, and excessive forefoot varus, whereas extrinsic factors include an over-vigorous training regimen, incorrect footwear, and equipment.

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HISTORIC CONTEXT

The Prussian military physician Breithaupt[1] described foot pain and swelling in military recruits in 1855—though according to Jansen,[2] Breithaupt attributed this problem to inflammation of the tendon sheaths and ligaments. Debate continued about the pathology of "March foot" despite radiographs demonstrating metatarsal fractures as early as 1897 by Stechow.[3]

Most "march" fractures were seen in military recruits such that military medical personnel were initially most familiar with their recognition and treatment. From the late 1950s, this condition because increasingly recognized by the civilian orthopedic community, whereas from the 1970s it was appreciated that these fractures were particularly common in sportsmen.[4–10]

EPIDEMIOLOGY

As stress fractures have been described in almost every bone in the foot and ankle,[4,11–27] but with increasing availability of magnetic resonance imaging (MRI) many subtle and early lesions are being identified, and understanding of the differential diagnoses is improving.

Stress fractures are very common in military training. In a very sensitive prospective scintigraphy study of 295 Israeli military recruits, a 31% incidence of stress fractures was found. Eighty percent of the fractures were in the tibial or femoral shaft, whereas only 8% occurred in the tarsus and metatarsus. Sixty-nine percent of the femoral stress fractures were asymptomatic, but only 8% of those in the tibia. Fifty-three percent of the recruits in the study with pain after exertion were found to have stress fractures.[28]

In a study of Finnish military conscripts with foot and ankle pain[29] and negative radiographs, 131 conscripts displayed 378 bone stress injuries in 142 ankles and feet when examined by MRI, yielding an incidence of 126/100,000 person-years. Fifty-eight percent of fractures occurred in the tarsal bones and 36% in the metatarsal bones. Multiple bone stress injuries in 1 foot were found in 63% of the cases. The talus and calcaneus were the most commonly affected single bones. Injuries to the other bones of the foot were usually associated with at least one other stress injury. Twelve percent of injuries comprised a high-grade bone stress injury (grade 4-5) with a fracture line on magnetic resonance images and these were usually seen in the talus and calcaneus. The remaining (88%) of injuries were low-grade injury (grade 1-3) as indicated by bone marrow edema on MRI.

In a prospective study of 783 males Israeli recruits aged from 17 to 26 years. The risk of stress fracture was inversely proportional to age on both univariate and multivariate analysis. Each year of increase of age above 17 years reduced the risk of stress fracture by 28%.[30]

HISTORY AND PHYSICAL EXAMINATION

History

A complete and careful history is important if one wishes to avoid being caught out, by for instance, an athlete with an underlying, and undiagnosed, medical condition, for example anorexia nervosa—which can cause confusion on imaging,[31] or who has a problem on top of a known concurrent medical condition, for example diabetes—which probably causes "premature aging" of the bones.[31,32]

Most athletes will complain of localized vague discomfort with activity, which settles on cessation of activity, and often recurs on resumption of normal training.

A physical activity history is important. We elucidate any changes in duration or intensity of training, change in equipment or technique, or interruption in training because of illness or other factors. A common scenario is the development of symptoms after returning to the same level of training after a few weeks training free interval. Another common scenario is the patient who has sustained or is recovering from an injury in 1 lower limb, and continues training only to develop symptoms of a stress fracture in the contralateral leg due to increased weight bearing on this side. Some fractures, however, for example in the femoral shaft, may be entirely asymptomatic until picked up coincidentally[28] or on completion of the fracture.[33]

A general history including systems enquiry and past-medical history and medications is vital. Stress fractures have been described after surgery to the foot, presumably altering foot biomechanics.[14,34–36]

We enquire specifically about factors related to bone health: diet, smoking, drugs, (including alternative medicines, some of which—illegally—contain synthetic steroids) and, for women, menstruation. In a study of runners with multiple stress fractures, 40% of the females reported menstrual irregularities.[37]

We include a family history to pick up unusual but relevant conditions such as Charcot-Marie-Tooth—the story given may simply be of "foot problems" in other family members.

PHYSICAL EXAMINATION

Biomechanical factors associated with multiple stress fractures are high longitudinal arch of the foot, leg-length inequality, and excessive forefoot varus.[37]

General

One cannot examine the foot and ankle in isolation. It is necessary to pay attention to the whole patient but particularly gait and both lower limbs. Systems examination is guided by history, and unless the history is suggestive, systems examination is not performed.

Gait, Footwear, Braces, and Orthotics

We note the gait in shoes with any orthotics or braces. We inspect the footwear for its appropriateness, age, and pattern of wear. We check the condition and fit of any orthotics and/or braces. We assess the stability (see below) of the foot and ankle in and out of any brace and note the gait in bare feet. We check the ability to walk both on tiptoes and on the heels, and to squat keeping the heels on the ground—with limited ankle dorsiflexion the heels will rise. In patients with a varus heel, we recommend performing a Coleman block test to identify a fixed plantarflexed first ray as a contributing cause.[38]

Appearance

We inspect the legs, ankles, and feet for shape, deformity, swelling, bruising, callosities, and the condition of the skin and nails, noting carefully any side-to-side differences. We look for wasting of the peroneal compartment consistent with Charcot-Marie-Tooth. Inspection from above will give a broad impression of whether foot shape is normal, cavovarus, or planovalgus. Inspection from behind will demonstrate whether the Achilles tendon is in line with the tibia or in valgus or varus. One may see "too many toes" in planovalgus feet: in these patients, insufficiency of the tendon of the tibialis posterior should be ruled out.

With the patient seated or standing and a little weight through the leg, we find talar neutral by grasping the anterior process of the talus between thumb and index and forefingers and moving the subtalar joint from eversion to inversion and back until one can "feel" the talus is neutral—in pronated feet this will often lift the first metatarsal head off the floor, whereas cavus feet are often demonstrated to be high-arched but pronated. With the patient lying prone or kneeling on a chair and with the foot hanging free, find talar neutral while viewing from behind to assess forefoot angle relative to the hindfoot.

Pain and Tenderness

We palpate for tenderness of defined anatomic structures. Accurate isolation of tenderness is the key physical finding for diagnosis. One may perform provocative tests for joints, "piano-key" the metatarsals, grind the sesamoids in different metatarso-phalangeal joint positions in an attempt to define the structures which are painful.

Swelling

Swelling is usual over injured structures. Diffuse swelling of the dorsum of the foot is the most common though nonspecific finding. An ankle joint effusion will be visible as diffuse swelling across the anterior joint line and confirmed by fluctuance. Pressure is transmitted from the posterior joint to the anterior joint if the posterior joint is compressed by squeezing Kager's fat pad between fingers placed anterior to and on either side of the Achilles tendon. It is difficult to identify effusions in any of the foot joints.

Range of Motion

Note the range of motion of each ankle joint with the knees flexed and extended. Also note the range of motion of the subtalar and midfoot and metatarso-phalangeal joints—stiff feet are more prone to stress fracture. Examine the stability of the 1st tarso-metatarsal joint—though there may be no association between hypermobility and lesser metatarsal stress fracture.[39]

Tendon Function

Each tendon crossing the ankle joint is tested by resisting its action and feeling for tightening of the tendon or contraction of its muscle. It is not easy to distinguish a single peroneal tendon rupture, which is probably why they are rarely reported,[40] but other tendon ruptures are usually clinically apparent. In particular one should note eversion strength. There may be peroneal subluxation or dislocation, which may be painless.

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Ankle Ligaments

The anterior draw and inversion tests are used to assess the lateral ankle ligaments. It is difficult to distinguish between subtalar and lateral ankle instability.[41] The distal tibiofibular syndesmosis is assessed by pain provoking tests: external rotation of the talus in the mortise; the "squeeze test"—squeezing the tibia and fibula together; and attempted weightbearing in plantarflexion—which is limited by pain and weakness in a syndesmotic injury.[42]

Neurologic and Vascular

The possibility of problems secondary to a neurologic deficit, especially in the cavovarus foot, should be remembered, and one must check for adequate blood supply.

Imaging and Grading

Even when a diagnosis of stress fracture is clinically apparent, radiographs are usually performed to exclude other bone pathology and/or the coexistence of skeletal anomalies (such as tarsal coalition) that may have led to increasing loading.

In the ankle and foot region, the sensitivity of radiographs in detecting stress fractures is dependent on the site of fracture. Radiographs are usually positive at the time of presentation if the stress fracture is located in the metatarsals. For stress fractures located in the midfoot or hindfoot, the reverse is true, with radiographs rarely showing a detectable abnormality. Fractures of the metatarsal shafts induce a large amount of periosteal new bone formation and resultant focal cortical thickening and prominent juxtacortical soft tissue edema. This new bone formation enables these particular stress fractures to be detectable radiographically at presentation. In contrast periosteal new bone formation, cortical thickening and juxtacortical soft tissue edema are not common features of stress fractures elsewhere in the foot and ankle region and as a result these injures are typically radiography occult. In the midfoot and hindfoot, the injury is primarily one of trabecular micro-fracture propagation, which is initially associated with increasing medullary edema and later a clear fracture line. Because injury to trabecular bone is not readily seen on radiographs, stress fractures in the midfoot and hindfoot region are best visualized on MRI examination. Scintigraphy can also be performed to detect stress fractures though may not be quite as sensitive as MRI in this respect, and also does not provide the same structural detail as MRI examination. For suspected stress fractures of the sesamoid bones, computed tomography (CT) is often a useful supplement to radiographic examination.

Grading systems for stress fractures have been described both for magnetic resonance and scintigraphy though these are not uniformly applicable to the foot and ankle region.[43,44]

The magnetic resonance grading system described by Fredericson et al[43] can be applied to stress fractures of the forefoot bones though not those of the midfoot or hindfoot. In this system, grade 0 indicates a normal examination. Grade 1 indicates mild-to-moderate periosteal edema on T2-weighted images only, with no focal bone marrow abnormality. Grade 2 represents more severe periosteal edema and bone marrow edema on T2-weighted images only. Grade 3 indicates moderate-to-severe edema of both the periosteum and marrow on both Tl-weighted and T2-weighted images. Grade 4 represents a low-signal fracture line on all sequences, with changes of severe marrow edema on both T1-weighted and T2-weighted images. Grade 4 may also show severe periosteal and moderate muscle edema. For stress fractures of the midfoot or hindfoot, the most usually abnormality is increasing degrees of marrow edema most readily detectable on fat-suppressed T2-weighted sequences followed by the emergence of a discrete fracture line. If marrow edema is present without a visible fracture line, this is often referred to as a "stress injury" or "stress reaction" rather than a "stress fracture."

Similarly, the scintigraphic grading system described by Zwas et al[44] can be applied to stress fractures of the forefoot bones though not those of the midfoot or hindfoot. In this system, fractures are graded as 1-4 depending on the level and extent of tracer activity. Grade 1 refers to mild localized cortical activity; Grade 2 to more extensive and more intense cortical activity; grade 3 indicates tracer activity both in the medullary canal and the cortex, whereas grade 4 refers to tracer activity extending across the bone width.[44]

Outcome

The majority of foot and ankle stress fractures recover well with relative rest. High-risk fractures which may have a less favorable outcome include the medial malleolus, the talus, the navicular bone, the base of the fifth metatarsal, and the hallux sesamoids. Stress fractures of the medial malleolus, navicular, and base of the fifth metatarsal may require surgery. However, the particular indications for surgery are not supported by level 1 evidence, and the longer-term significance of talar injuries is not yet understood.

SPECIAL INVESTIGATIONS

Footprint

If available, a pressure mat, which displays the pressure of the footprints and center of gravity, can aid understanding. The shape and peak pressures of the footprint and location of the centre of gravity provide information about the foot. A 1 or 2-m-long pressure mat allows for a more natural walk (or run) as it is very difficult to place a footstep cleanly on a small pressure mat (Fig. 1).

FIGURE 1. Force platform demonstrates pressures under feet, in addition to center of gravity and ground reaction force. Use of a long platform allows a natural gait.

FIGURE 2. Video motion analysis—note change in heel alignment with different footwear.

Video Running Assessment

A video analyzed running assessment adds information. Simple video analysis software (eg, Dartfish, Swinger or Silicon Coach) allows the tester to stop motion and analyze angles—for instance heel varus or valgus (Fig. 2).

Electromyography and Reaction Times

Electromyography and other tests to measure muscle reaction times are presently used as research tools and are unlikely to come into routine clinical practice in the near future, though it is likely that muscle fatigue predisposes to stress fracture in runners.[45] Thirty experienced runners participated in a maximally exhaustive run above the anaerobic threshold. Surface electromyographic activity of calf muscles was monitored, and plantar pressures measured using an in-shoe monitoring system. Toward the end of a fatiguing run increased maximal force, peak pressure, and impulse were apparent under the second and third metatarsal heads and the medial midfoot. This increased forefoot loading helps explain the high prevalence of metatarsal stress fractures associated with running and fatigue.[45]

SPECIFIC DIAGNOSES

Toes

Stress fractures of the toes are relatively rare.

Hallux

A single case of stress fracture of the distal phalanx of the hallux has been reported in a ballet dancer, presumably associated with the stress of the pointe position (Fig. 3). This healed with appropriate rest.[17]

A handful of cases of stress fractures of the medial aspect of the base of the proximal phalanx of the hallux have been reported.[26,27,46–48] There is a strong association with hallux valgus.[47] The patients complain of localized pain and tenderness. All healed with appropriate early rest, but a chronic case required internal fixation and bone grafting.[46]

Second Toe

A single case of stress fracture of the proximal phalanx of the second toe has been reported in an adolescent female athlete.[49]

Lesser Toes

No cases of 3rd to 5th toe stress fractures have been reported.

Sesamoids

Sesamoid stress fractures are a challenge! The medial sesamoid bone is the most commonly fractured. The first

FIGURE 3. Radiograph of ballet dancer en pointe. Note cortical hypertrophy of 2nd and 3rd metatarsal shafts.

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FIGURE 4. Radiograph of painful bilateral bipartite medial sesamoids in a ballet dancer.

problem is of diagnosis—it is difficult to distinguish a stress fracture from an inflamed bipartite sesamoid clinically or radiologically. Radiographs of the contralateral foot may help by showing if the symptomatic bipartite sesamoid has a wider gap and less distinct or irregular edges at the opposing osseous margins, which would be consistent with a fracture. Only 25% of bipartite sesamoid bones are bilateral[10] (Fig. 4). In the recent report of medial sesamoid stress fractures confirmed at surgery, whereas radiographs revealed fragmentation of the medial sesamoid, MRI did not always confirm the diagnosis, whereas bone scan and CT were more useful in this respect.[12] Treatment of medial sesamoid stress fractures can range from cessation of sports activity and use of a cam walker, a shoe with a Morton bar, a u-shaped felt pad, cast immobilization, or operative repair and bone-grafting of a nonunion to excision of the sesamoid if fragmentation is present.[10,12,50] In the most recent report, after failure of conservative treatment, surgical excision of the proximal fragment was successful in all 3 patients.[12] In athletes, a pragmatic approach may be a steroid injection and a short period of rest, proceeding to excision of the proximal fragment if nonoperative treatment fails.

Metatarsal Bones

Among the metatarsals, the second is most commonly injured, followed by the third, base of fifth, then probably fourth and first.

First Metatarsal Bone

In a pre-MRI era series of 827 stress fractures in soldiers, 15 were found in the first metatarsal, representing 11% of all stress fractures in the metatarsals. All were in the proximal end of the bone.[51] The radiographic feature is internal callus, as the fracture is in cancellous bone.

Lucas described 1st metatarsal stress fractures healing with relative rest in a comfortable padded shoes such as a sports shoe. He cautioned against casting.[18]

A dorsally located, proximal epiphyseal stress fracture (Salter-Harris III) with intra-articular extension of the first metatarsal has been described in a 14-year-old boy. Successful fracture healing was achieved with a rocker sole shoe modification and activity limitation.[52]

Second Metatarsal—Distal

Distal second metatarsal stress fractures are probably the most common stress fractures in the foot and ankle

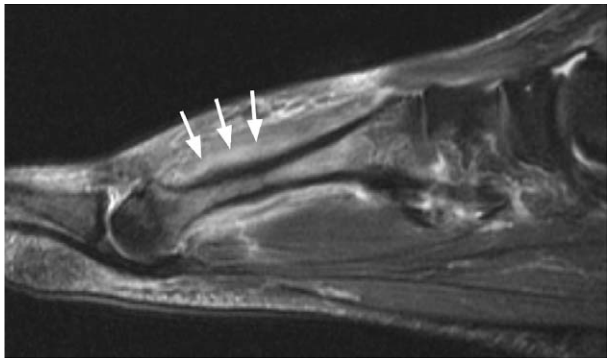

FIGURE 5. Thirty-seven year-old female golfer with the forefoot pain. T2-weighted sagittal MRI showing an isolated stress fracture of the 2nd metatarsal shaft with the marrow edema, cortical thickening due to reparative new bone formation (arrows) and a moderate degree of juxtacortical edema. This fracture was apparent on radiographs. MRI was requested to rule out concominent injury in view of unremitting symptoms. MRI indicates magnetic resonance imaging.

(Fig. 5). They occur in runners and other sportsmen, and in ballet dancers (though the classic ballet stress injury is of the base of the second metatarsal—see below). In runners, the likely cause is the high bending stress on the second metatarsal.[53]

There are numerous reports of healing with relative rest.[10] In straight forward cases with no underlying medical or biomechanical issues, full weight bearing, if needed in a cam walker as long as comfort allows, gives rapid and reliable recovery.

In 1944 military surgeons described keeping soldiers in normal basic training by placing a steel bar one-half of an inch wide, one-eighth of an inch thick and 6 inches long in the boot. This treatment was successful in 96% of 307 patients.[54]

In more complicated cases or where there is clinical or MRI evidence of involvement of other metatarsal bones a period of nonweight bearing is indicated. Children with physeal injuries must rest to prevent damage to the physis. Young ballet dancers commencing pointe are at risk of distal second metatarsal physeal injury (Fig. 6).

Second Metatarsal—Base

Second metatarsal base stress fractures are common in female ballet dancers because of the pointe position (Fig. 7) and also because many have poor bone health with poor nutrition, low-body weight and amenorrhea. The usual location is at the proximal metaphyseal-diaphyseal junction. In a series of 64 fractures reported by O'Malley,[55] treatment consisted of a short leg walking cast for 6 patients, and a wooden shoe and symptomatic treatment for the remainder. At follow-up, 14% of patients still had occasional pain or stiffness in the midfoot with dancing. The patients returned to performance at an average of 6.2 weeks after diagnosis. No patients required bone grafting for persistent symptoms. There were 8 repeat fractures (at the same site) occurring on average 4.3 years after initial fracture, all of which healed with conservative care.

Good results with simple early treatment were reported by Harrington et al[56] in a group of 8 ballet dancers.

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FIGURE 6. STIR (short T1 inversion recovery) coronal magnetic resonance imaging of distal physeal injury in 11-year-old ballet dancer showing edema in the epiphysis and metaphysis.

Extension of the base of 2nd metatarsal fracture into the Lisfranc joint in 4 ballet dancers was reported by Micheli et al.[20] With early recognition and diagnosis, in 3 of the 4 patients the fracture healed with immobilization and modified training. One patient required surgical resection because of persistent nonunion of the necrotic fracture fragment. In the series of 64 fractures reported by O'Malley,[55] 3 fractures extended into the tarsometatarsal joint, and all healed without surgery. Muscolo et al[57] reported a single stress fracture nonunion at the base of the second metatarsal in a ballet dancer.

The risk of extension into the Lisfranc joint, possibly requiring surgery, must be discussed with a dancer who wishes to continue to dance with a base of second metatarsal stress fracture, with the intention of allowing it to heal at the end of a season.

Second metatarsal base stress fractures also occur in nondancers. Compared with patients with distal fractures, patients with base fractures have longer duration of symptoms, do less training, have shorter first metatarsal length, Achilles contracture, reduced bone density, and have experienced prior unilateral or bilateral stress fracture).[58]

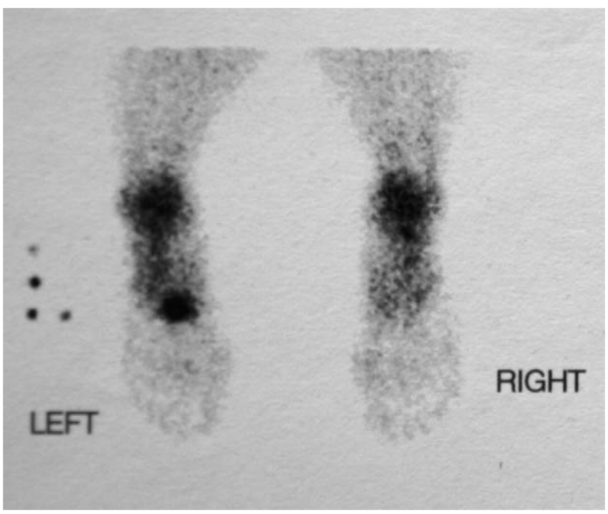

FIGURE 7. Bone scan of base left 2nd metatarsal stress fracture in ballet dancer. Radiograph was negative.

Third Metatarsal Bone

Distal third metatatarsal stress fractures behave like second metatarsal fractures.

A stress fracture of the base of the third metatarsal is described after an endoscopic plantar fasciotomy.[36] It healed with relative rest.

Fourth Metatarsal—Distal

Distal fourth metatatarsal stress fractures behave like second metatarsal fractures.

Fourth Metatarsal—Base

Saxena et al[59] reported a series of 5 proximally located fourth metatarsal stress fractures, which generally healed in a period of 8 to 16 weeks. Those patients who remained symptomatic for longer than 16 weeks did not go through the recommended period of immobilization. Forefoot adduction was apparent in 3 out of the 5 patients. The anatomy of the proximal fourth metatarsal may play a role in the delayed healing of these injuries. The fourth metatarsal has been described as the most resistant to dorsiflexion,[60] usually being the last to rise when all of the metatarsals are moved dorsally. As the fifth ray is relatively hypermobile, it is theorized that forces may be translated to the fourth metatarsal.

Fifth Metatarsal—Base

In 1896 at New Brighton, England, Robert Jones himself suffered the fracture that bears his name.[61] He incurred the injury while dancing around a tentpole at a military garden party. In his original article, published 6 years later, he clearly described the fracture at the proximal part of the diaphysis of the fifth metatarsal, and he stressed the role of the constraining ligaments between the fourth and fifth metatarsals and the cuboid.[62] This was confirmed by Kavanaugh et al[63] in his anatomic dissections.

In 1978, Kavanaugh et al[63] described 22 patients with 23 Jones fractures. Thirteen of the 23 fractures were in young athletes, often occurring during training and causing significant disability. The clinical picture in 9 of the 22 patients suggested that the injury was a stress fracture. Delayed union occurred in 12 (67%) of 18 patients treated conservatively. Thirteen of 22 patients underwent surgery. Four patients were operated on within 2 weeks of injury. The fractures were clinically united in 6 weeks and radiologically united at 3 months after the operation, in the first description of intramedullary fixation of this fracture. In athletes with acute fractures and nonathletes with delayed union, intramedullary screw fixation of the fracture was advised. As then, numerous authors have concurred.[64–66]

Metatarsal Heads

The MRI appearances of stress fractures of the metatarsal heads can overlap with subchondral fractures in adults in a presumed bone marrow edema—avascular necrosis (AVN) spectrum similar to Freiberg's infraction in adolescents.[67] In subchondral fractures of the metatarsal heads, shaft fractures were present in 21% (3/14) and were the most common coexisting abnormality.[67] The location and radiographic appearance of metatarsal head

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subchondral fractures are similar to those seen in Freiberg's infraction. Although Freiberg's infraction affects adolescents (12 to 18 y) and metatarsal head subchondral fractures are seen in adults, both entities likely share a common pathogenesis that may include mechanical stress, subchondral fracture, vascular injury, and subsequent osteonecrosis.[67]

Multiple Metatarsal Bones

Sequential stress fractures of the metatarsals can occur; particularly when these fractures are displaced.[10] Shifting of the fracture relieves the pressure on the bone that had the stress concentration before the fracture. Transfer lesions then occur and progressive fractures develop, eventually involving all of the metatarsals. Severe deformity can occur during this process (particularly the development of hammer toes), producing abnormal weight-bearing patterns. In patients with multiple stress fractures, one must repeat or review the search for an underlying cause, which can be structural, metabolic, neurological, or hormonal. However, a striking underlying cause beyond slightly abnormal biomechanics is not always found: Sequential fatigue fractures of the fourth, second, and third metatarsals in the same foot were reported in a military aviator in the absence of abnormal stresses or underlying bone disease. The likely etiologic factor was altered foot biomechanics, as identified by pedobarographic assessment.[68]

Cuneiform Bones

In a pre-MRI era series of 827 stress fractures in soldiers, 3 fractures were found in the cuneiforms.[51] A handful of cases have been reported.[13,19,51] A potential diagnostic challenge is the very unusual bipartite medial cuneiform.[69]

Navicular Bone

Navicular stress fractures were first reported in greyhounds in 1958,[70] but the first report in humans was in 1970.[71] The navicular stress fracture is a high-risk stress fracture because it often does not heal with relative rest.[64]

Diagnosis

The history is usually of vague foot pain. Tenderness at the "N-spot" on the dorsal navicular is a common, though not universal, finding,[72] though pain on hopping on tip-toes is recently reported.[73] Radiographs are often negative, as the fracture is in the center of the navicular in the saggital plane, which is oblique to the plane of the x-ray beam on standard radiographic projections of the foot.[72] Torg et al[72] proposed inverting the foot in an attempt to place the x-ray beam perpendicular to the widest axis of the navicular. In the pre-MRI era, diagnosis was a challenge (Fig. 8). Bipartite navicular bones are uncommon, but may cause confusion.[74] CT scan is usually sufficient to distinguish this entity. Accessory navicular bones are very common findings, though can usually be distinguished from stress fractures quite easily.

Classification of Navicular Fractures

One classification system of navicular stress fractures was proposed by Saxena et al[73] based on return to activity time and fracture pattern on computerized tomography. CT fracture patterns were classified as: isolated dorsal cortical break (type I), fracture propagation into the navicular body (type II), and fracture propagation to the other cortex (type III) with modifiers "A" (associated AVN of a portion of the navicular); "C" (cystic changes of the fracture), and "S" (sclerosis of the fracture margins). Sclerosis of the fracture margins was the most common change seen in patients with persistent symptoms.

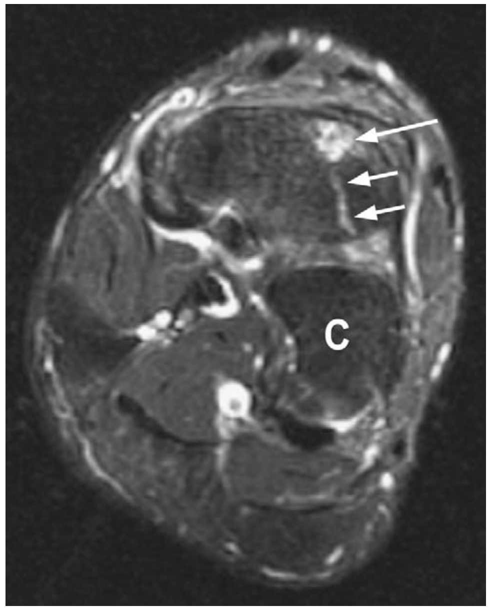

FIGURE 8. Coronal T2-weighted fat-suppressed magnetic resonance image in 29-year-old marathon runner. There is a stress injury close to the dorsal cortex of the navicular bone (long arrow) with a vertical fracture-extending inferior toward the plantar cortex (short arrows). Note the lack of surrounding marrow edema. Radiograph was negative. C = cuboid.

Management of Navicular Fractures

In a retrospective review of 21 navicular stress fractures published in 1982,[72] all 10 fractures initially treated in nonweight bearing casts healed without complications. Seven of 9 patients whose fractures were treated by either limitation of activity but continued weight-bearing or immobilization in a weight-bearing cast were unable to resume vigorous activity after treatment because of pain associated with delayed union, nonunion, or fracture recurrence. Many authors concurred that treatment should begin with nonweight-bearing immobilization in undisplaced fractures.[75–77]

Despite management recommendations being widely published, Burne et al[78] noted that they were often disregarded, with consequently poorer outcomes. Only 2 of 11 patients (18%) with navicular stress fractures received the literature-recommended management of at least 6 weeks nonweight-bearing cast immobilization. Of these 11 patients, only 6 (55%) returned to sports at their previous level.

Saxena's group[79] went on to apply their classification system and management recommendations to a prospective group of patients, using the original group as a historic control. Nineteen athletic patients seen between the year 1999 and 2003 were studied. Nonoperative management was recommended for patients with type I injuries and open reduction and internal fixation for type II and III injuries. Return to activity for type I was 3.8 months, type II was 3.7 months, and type III was 4.2 months. Fifteen of 16 competitive athletes returned to full competition, including all who had open reduction and internal fixation. They concluded that, using their management protocol, navicular stress fractures take about 4 months to heal and surgery should be recommended for more severe (type II and III) injuries.[79]

Longer-term outcome studies are awaited.

Navicular Stress Avulsion Fracture

Orava reported 9 cases of stress-related avulsion fracture of the tarsal navicular in athletes. This uncommon over-use injury is thought to occur after repetitive cyclic compressive loading with impingement of the tarsal navicular. The small dorsal triangular fracture fragment is best seen on weight-bearing lateral view radiographs, whereas isotope scan and/or CT helps confirm the diagnosis. Operative management is recommended in highly symptomatic cases or elite athletes because of shorter recovery time.[24]

Cuboid

Stress fractures of the tarsal cuboid are rarely reported, but with increasing use of MRI they are likely to be recognized more frequently. Stress and insufficiency fractures have been described, including in children.[22,80–82] Two cases in collegiate athletes mimicked peroneal tendinopathy on presentation. Management consisted of immobilization and activity modification, with complete resolution of symptoms in both cases.[11]

Talus

Talar stress fracture was first described in 1965.[83] They are hard to identify on x-ray, but stress reactions are common on MRI. MRI was performed on 12 ankles of 11 "asymptomatic" professional ballet dancers. Bone marrow edema was seen only in the talus, in 9 of the 12 ankles, and was associated with pain in all cases. On fluid-sensitive sequences, bone marrow edema was ill defined and centered in the talar neck or body, although in 3 cases it extended to the talar dome.[15]

Sormalaa et al[84] assessed the incidence, anatomic distribution, and nature of fatigue bone stress injuries of the talus in military recruits with MRI. There were 51 cases, giving an incidence of 4.4 (3.2-5.5)/10,000 person-years. Bilateral injuries were seen in 5. Of the 56 bone stress injuries, 40 occurred in the head, 15 in the body, and 5 in the posterior part of the talus. In 4 cases, both the head and the body were affected. The talus was the only bone affected in 12 cases. In 44 cases, a stress injury was also present in other tarsal bones. A grade 1-3 injury was found in 46 and a grade 4 injury with a fracture line in 10. Injuries of the upper part of the body were associated with calcaneal stress injuries in 78%, and injuries of the head of the talus were associated with stress injuries in the navicular in 60%. These injuries are rare but not unseen in military recruits.

True stress fractures of the talus are relatively unusual with only small case series in the literature.[51,85,86]

Talar stress fractures may not have benign long-term outcomes.

There is a single report of bilateral AVN of the talus in an individual who was presumed to have suffered stress fractures during military training.[87]

In a follow-up study of patients who had had MRI grade 4 talar stress fractures treated by nonweight-bearing mobilization,[88] at a mean of 4 years, 60% of tali were symptomatic, 50% showed MRI changes at the site of the original fracture, and 20% showed x-ray changes. In a study of 4 fractures treated by various methods all patients had symptoms in the medium-term.[85]

Stress fractures of the lateral process of the talus are extremely rare.[85] Patients present with lateral ankle or sinus tarsi pain that is exacerbated by activity. Excessive subtalar pronation and plantar flexion may predispose athletes to injury as the lateral process of the calcaneus impinges on the concave posterolateral corner of the talus. Alternatively, a supinated foot may concentrate forces on the lateral process of the talus. Plain films often fail to reveal the stress fracture. Computed tomographic scans are helpful in identifying the lesion at the posterolateral border of the talus. The stress fracture often extends into the subtalar joint, which explains the symptoms in the region of the sinus tarsi. Outcomes after early return to activity are poor. Therefore, a 6-week trial of nonweight-bearing cast immobilization is recommended, followed by rehabilitation and use of an orthosis to correct any excess pronation.

Calcaneum

Calcaneal stress fractures were first described in military recruits, in German in 1937[89] and in English in 1944.[90] The larger studies have been performed in military recruits rather than athletes, but the nature of the injury is likely to be similar. A large recent study[91] in Finnish military recruits using MRI showed that of 34 injuries, 19 occurred in the posterior part of the calcaneus, 6 occurred in the middle part of the calcaneus, and 9 occurred in the anterior part of the calcaneus, with 79% occurring in the upper region and 21% occurring in the lower region. The calcaneus alone was affected in 12 cases (Fig. 9). In 22 cases, stress injury was also present in one or several other tarsal bones (Fig. 10). A distinct association emerged

FIGURE 9. Saggital magnetic resonance imaging of 30-year-old recreational runner with stress fracture of calcaneus. This is a clear fracture line extending across the posterior aspect of the calcaneus with surrounding edema. Radiograph was negative.

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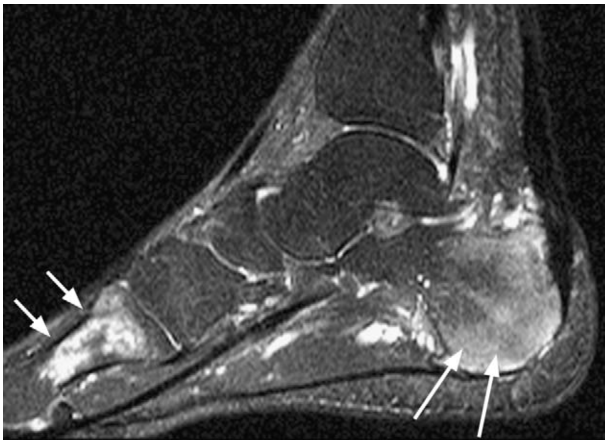

FIGURE 10. Sagittal T2-weighted fat-suppressed magnetic resonance image of 25-year-old athlete showing concomitant stress injuries in the first metatarsal bone (short arrows) and calcaneus (long arrows). These stress injuries comprise marrow edema alone without a visible fracture line. Note the high medial longitudinal arch, which may have contributed to the stress injuries in this patient. Radiograph was negative.

between injuries of the different parts of the calcaneus and stress injuries in the surrounding bones. In only 15% of the patients was the stress injury visible on plain radiographs. All healed with relative rest.

A stress fracture of the anterior process of the calcaneus was reported in a Marathon runner who was then noted to have a calcaneonavicular coalition. He recovered with relative rest and returned to running.[92]

Medial Malleolus

The medial malleolus is a relatively uncommon site for stress fractures, but they occur with running and jumping. Repetitive impingement of the talus on the medial malleolus during ankle dorsiflexion and tibial rotation may result in a medial malleolar stress fracture (Fig. 11), possibly exacerbated by anterior osteophytes. The fracture line is vertical or oblique and originates from the junction of the tibial plafond and the medial malleolus.[23,25,93–97]

For individuals with negative radiographs and a positive MRI or bone scan, management is based on the level of athletic activity and the presence of any anterior osteophytes. Most patients could be treated with cast immobilization or ankle bracing and avoidance of impact activities. Athletes wishing to return to competition might be treated with internal fixation[25,94,95] and arthroscopic treatment of any impingement. Both surgical and nonsurgical treatment usually result in a full return to activity; however, resolution of symptoms may take 4 to 5 months with nonoperative management.[95] Internal fixation is recommended for patients with a complete fracture line on radiographs.[93] Due to the high shear forces at the fracture site, nonunion may develop,[95] in which case internal fixation is required.

Lateral Malleolus/Distal Fibula

Devas described 50 fibula stress fractures in athletes seen in the mid 1950s. All fractures were in the distal third of the bone and healed with relative rest.[9] He noted that cast immobilization slowed recovery. Later authors have confirmed his observations.[21]

Anorexia Nervosa

Loss of marrow fat in patients with severe anorexia nervosa results in serous replacement of marrow tissue. Reduced bone mineral density and reduced bone strength are additional features of anorexia leading to an increased fracture risk. Patients with anorexia nervosa often have abnormal bone resulting in osteopaenia and serous bone marrow change. There is an increased risk of fracture and may be the first presentation of the disease. Serous bone marrow change of anorexia nervosa can mask marrow edema, one of the key MRI features of stress fracture, as both result in marrow T1-hypointensity and T2-hyperintensity, which may mask underlying fracture. Scintigraphy is helpful in this clinical setting.[31] Radiologists and clinicians need to be alert to the problems of low-body weight—common in activities such as ballet and gymnastics—and should be aware of the difficulties in diagnosing stress fractures in the presence of serous replacement of bone marrow.

CONCLUSIONS

Stress fractures are common athletic injuries of the foot and ankle, described in every bone except the lesser toes. Early diagnosis usually allows for simpler treatment

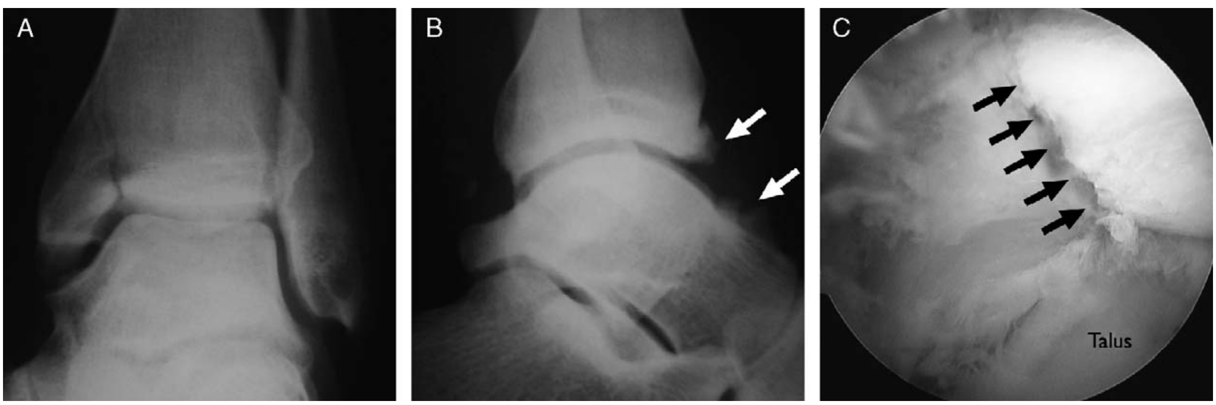

FIGURE 11. A, Anteroposterior radiograph of a stress fracture of the medial malleolus in a 30-year-old soccer player. B, Lateral view shows anterior osteophytes (white arrows). C, At arthroscopy, after removal of the anterior osteophytes, the fracture line is clearly visible (black arrows). It was internally fixed at the same operation.

and quick recovery. Early clinical presentations can be subtle, so a high degree of suspicion and the systematic approach we have described, coupled with an understanding of the diagnostic limitations present in early injury, is required. Such a rigorous approach ultimately pays dividends for these patients, who are usually keen to return quickly to athletic activity. High-risk fractures include the medial malleolus, the talus, the navicular bone, the base of the fifth metatarsal, and the hallux sesamoids. We support recommendations of early surgery in high-risk fractures.

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