A Review Paper

Women's Musculoskeletal Foot Conditions Exacerbated by Shoe Wear: An Imaging Perspective

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Abstract

The predominance of several musculoskeletal foot conditions in women are largely the result of biomechanical alterations caused by ill-fitting shoes. In particular, the altered biomechanics (associated with high-heeled shoes and shoes with a narrowed toe box) has been linked to the genesis of hallux valgus, hammer toe deformity, Haglund syndrome, metatarsal stress fracture, Freiberg infraction, and Morton neuroma.

In reviewing the imaging findings of several of these conditions, we emphasize the role of radiographs, special radiographic views, and the utility of more costly studies, such as magnetic resonance imaging.

The link between shoe wear and foot abnormalities has long been established. In an 1897 issue of the *Journal of Bone and Joint Surgery,* Bradford[1] noted alterations caused by shoes through an analysis of historical art, including art of ancient and medieval civilizations. Contemporary shoe styles for women continue to cause deformity and predispose to injury, perhaps even more so than in the past.

Poorly fitting shoes are a major contributing factor to the difference in incidence of foot disorders between women and men.[2] Traditionally, men's shoes tend to be wider and have lower heels than women's shoes. Both high heels and a narrow toe box have been implicated in the development of such forefoot abnormalities as hallux valgus, bunions, intractable callosities, metatarsalgia, and Freiberg infraction. High-heeled shoes transmit increased pressure and stress toward the forefoot and increase the risk for posttraumatic fracture during falls. [3,4] Sandals and clogs have been named as a contributing factor to the so-called Vineyard fracture, a fifth metatarsal avulsion injury named after vacationers on Martha's Vineyard in Massachusetts[5] (Figure 1). Shoes with heels as short as 1.5 inches have been shown to significantly increase knee torque and may have implications for knee osteoarthritis in women.[6] Special populations, such as ballet dancers and high-performance athletes, should be considered separately, as marked alterations in weight-bearing result in specific injury patterns.

Imaging of the Foot

Radiographs should always be the first imaging study used for evaluation of foot pain and/or deformity. Weight-bearing radiographs are most helpful for assessing arthritic and alignment abnormalities. Non–weight-bearing radiographs are obtained only if an acute injury is suspected. Typical radiographic evaluation includes weight-bearing anteroposterior and lateral views and non–weight-bearing internal oblique views. Specialized

Figure 1. Vineyard fracture—fifth metatarsal avulsion injury named after vacationers on Martha's Vineyard, Massachusetts.

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Figure 2. Crossover sign. Weight-bearing anteroposterior view of foot shows overlap of first and second digits caused by severe hallux valgus.

radiographic projections, such as tangential sesamoid views, may be useful in individual cases.

Radiographs are assessed for ABCS (Alignment, Bone density, Cartilage spaces, and Soft tissues). Magnetic resonance imaging (MRI) is most helpful when radiography results are normal, when symptoms persist or remain unexplained, or when additional information regarding soft tissues or bone marrow is desired. MRIs provide excellent soft-tissue contrast, which allows differentiation of various muscles, tendons, and fluid-filled structures and permits bone marrow edema to be identified. Bone scan and computed tomography (CT) have a lesser role in evaluating these conditions. Ultrasound can be useful when specialty expertise is available. The ACR (American College of Radiology) Appropriateness Criteria are available as guidelines for choosing the best imaging study in a particular clinical situation.[7] The descriptions in the next sections underscore the usual imaging findings in some of the common conditions in women and indicate when advanced imaging studies, such as MRI, are useful.

Hallux Valgus

Hallux valgus deformity, one of the most common foot conditions in adults, is often associated with hammer toes and other deformities of the lesser toes. The term hallux valgus connotes an angular deformity of the first metatarsophalangeal (MTP) joint with associated lateral deviation of the great toe. This is often in association with metatarsus primus varus, recognized by the coincident medial deviation of the distal first metatarsal in relation to the second metatarsal. The overlying soft-tissue swelling associated with the hallux valgus is termed a bunion, originating from the Latin word for "turnip." Biomechanical alterations caused by shoe wear are thought to be responsible for the female predominance of this condition. Paleontologic studies have suggested that the incidence of hallux valgus increased after the medieval introduction of shoes with narrow toe boxes.[8] Comparisons of shoe-wearing and non–shoe-wearing populations in China demonstrated a dramatic increase in hallux valgus in shoe-wearing populations.[9] Other studies have shown that a majority of women wear shoes narrower than their feet and that the more ill-fitting the shoe, the higher the incidence of foot pain and deformity.[10]

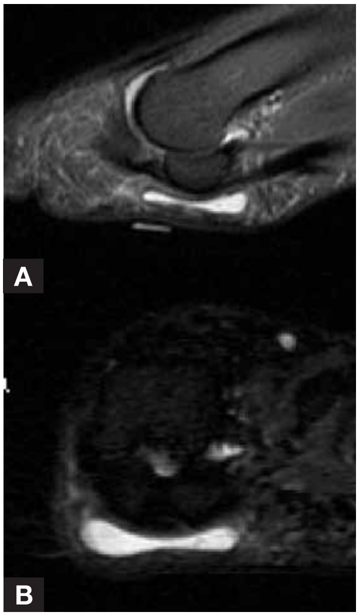

Figure 3. Adventitial bursitis. Sagittal fat-saturated proton density (A) and axial short TI recovery (B) sequences show simple adventitial bursitis on plantar aspect of first toe, aggravated by repetitive stress from tight-fitting shoes.

The most common presentation of hallux valgus is pain along the medial aspect of the first MTP joint. This is often associated with soft-tissue swelling and hypertrophic skin changes. Symptoms are usually exacerbated by shoe wear. In some instances, the deformity is so advanced that there is overlap of the first and second digits, demonstrated radiographically as the "crossover sign" (Figure 2). Clinically, the second toe in such cases is referred to as a crossover toe. Repetitive friction, as might occur with poorly fitting shoes, can lead to development of adventitial bursitis on the medial or plantar aspect of the first MTP joint (Figure 3).

Radiographic assessment of hallux valgus is useful in evaluating angular deformities, articular surfaces, sesamoid subluxation, bone stock, bone length, and the presence of arthritic change (Table I).

Several radiographically assessed angles are commonly used in evaluating hallux valgus: hallux valgus angle,

Table I. Radiographic Checklist in Evaluation of Hallux Valgus

Measure angular deformities in hallux valgus
Assess alignment and articulations of first digit
Assess degree of sesamoid subluxation
Check for presence of bunion
Check for presence of arthritis
Assess quality of bone stock

Figure 4. Hallux valgus. Weight-bearing anteroposterior view of foot: (A) hallux interphalangeus angle, (B) hallux valgus angle, (C) metatarsus primus varus angle, (D) first intermetatarsal angle.

hallux interphalangeus angle, metatarsus primus varus angle, and first intermetatarsal angle (Figure 4). The hallux valgus angle has been demonstrated to be the main predictor of successful surgical correction, with correction rates declining with angles larger than 37°.[11]

The hallux valgus angle is measured by subtending the long axes of the proximal phalanx and the first metatarsal. A normal value is less than 15°. Hallux valgus can be graded mild (16°-25°), moderate (26°-35°), or severe (>35°). The hallux interphalangeus angle, measured between the long axis of the first proximal phalanx and the first distal phalanx, normally measures less than 8°. The metatarsus primus varus angle is the angle between the long axes of the medial cuneiform and the first metatarsal and normally measures less than 25°. The first intermetatarsal angle, formed by the long axes of the first and second metatarsals, is normally less than 10° and is used to determine whether a proximal osteotomy is necessary for foot reconstruction.[12]

The articular configuration of the distal first metatarsal and the alignment of the articular surfaces have implications for the development of hallux valgus. A rounded metatarsal head is most common and most prone to subluxation. In contrast, a flattened or chevron-shaped articular surface is more resistant to developing a hallux valgus deformity. Normal alignment of the articular surfaces of the MTP joint is an important consideration in patients with hallux valgus, as abnormal alignment between the metatarsal and phalangeal

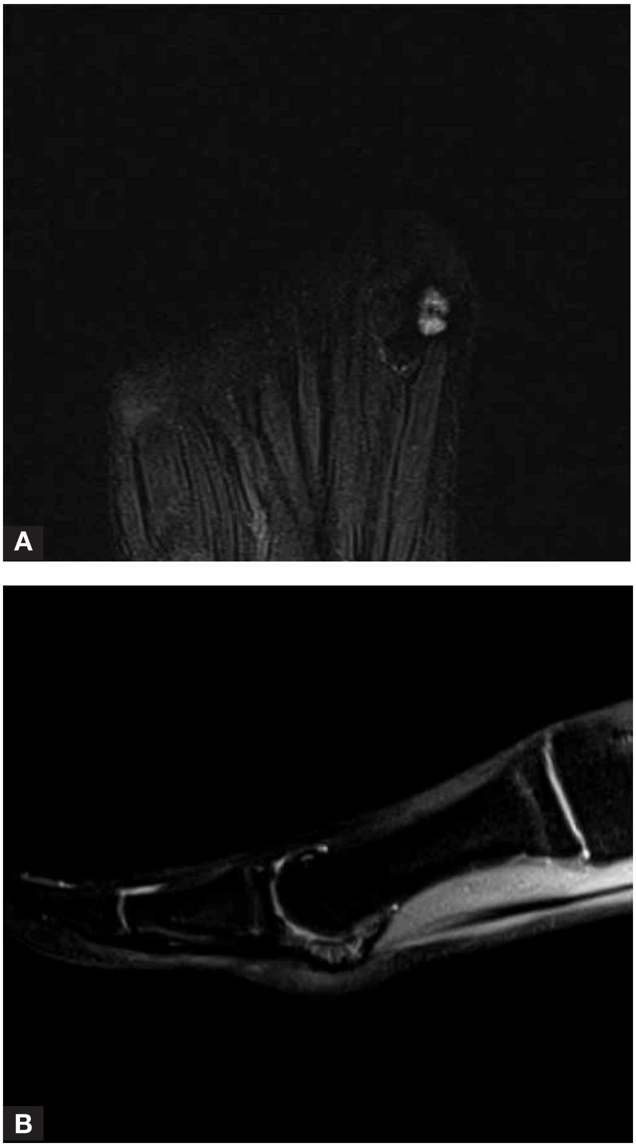

Figure 5. Sesamoid stress fracture. Axial short TI recovery sequence (A) and sagittal T_2-weighted fat-saturated image (B) show abnormal diffuse increased signal within sesamoid bones of patient who wears high heels.

Table II. Utility of Magnetic Resonance Imaging and Computed Tomography in Hallux Valgus

Not used in routine clinical evaluation
Atypical pain and tenderness
Magnetic resonance imaging can be used to evaluate support structures and soft tissues of forefoot as well as first metatarsal tendon shift in patients with hallux valgus
Computed tomography can be used to define anatomy in atypical cases and to evaluate bone stock

Figure 6. Calcaneal stress fracture. Sagittal T_2-weighted fat-saturated (A) and T_1-weighted (B) images show calcaneal bone marrow edema with associated stress fracture.

surfaces may contribute to progression of valgus deformity as a consequence of recurrent subluxations.

Currently, advanced imaging (eg, CT, MRI) does not have a role in the routine diagnostic workup of hallux valgus but may be useful when the clinical picture is unclear (Table II). Advanced imaging is especially useful when patients with hallux valgus present with pain and tenderness that are atypical, away from the medial aspect of the joint. For instance, a patient with hallux valgus deformity with atypical plantar pain and tenderness may have an angular deformity in the setting of painful sesamoid pathology.

Several treatment options are available for correction of hallux valgus deformities. Management is determined by radiographic findings, clinical assessment, and surgeon preference. The ultimate goal is to realign the foot—to correct the alignment of the hallux, the first metatarsal, and the sesamoids. It is also important to maintain the flexibility and plantigrade orientation of the foot. Last, educating patients with respect to properly fitting shoes is of utmost importance and should be assessed both before and after surgery.

Sesamoid Pathology

Wearing high heels increases the biomechanical forces on the sesamoids. The medial and lateral sesamoid bones lie plantar to the MTP joint and increase the efficiency of the flexor hallucis brevis muscle. With elevation of the heel comes increased loading on these bones. Metatarsal-sesamoid forces are double when walking in high heels than when walking barefoot.[13] Painful sesamoid conditions that can develop include sesamoiditis, stress reaction, osteonecrosis, fracture, arthrosis, and a symptomatic bipartite sesamoid (Figure 5).

Hammer Toe

Hammer toe is a deformity that affects the lesser (second through fifth) toes and is characterized by hyperflexion at the proximal interphalangeal joint with or without extension of the MTP joint. This configuration resembles a hammer. The condition is in large part the consequence of increased mechanical pressure from narrow, pointed shoes.[2] Further constriction of the toe box may occur with high-heeled shoes, as the foot is forced to slide forward into a constricted space. Hammer toes are often associated with corns and calluses caused by the continuous rubbing of tight-fitting shoes against the skin.

Although the diagnosis is clinical, radiographs may be helpful in assessing the severity of involvement and guiding surgical management. Standing lateral radiographs best demonstrate deformities of the lesser toes; however, bony overlap may necessitate multiple projections. CT may be used adjunctively for detailing bony anatomy before surgery in atypical cases.

Stress Fractures

Stress fractures are among the most common sports-related injuries in both men and women. The dramatic increase in women's participation in sports over the past decades has resulted in an increase in sports-related injuries, including stress fractures. Both female sex and improper

Table III. Utility of Magnetic Resonance Imaging in Stress Fractures

Negative radiographs
Confirm diagnosis and exclude other causes of forefoot pain
Evaluate fracture and extent of edema
Conduct follow-up examination to evaluate healing
Persistent pain despite treatment and rest

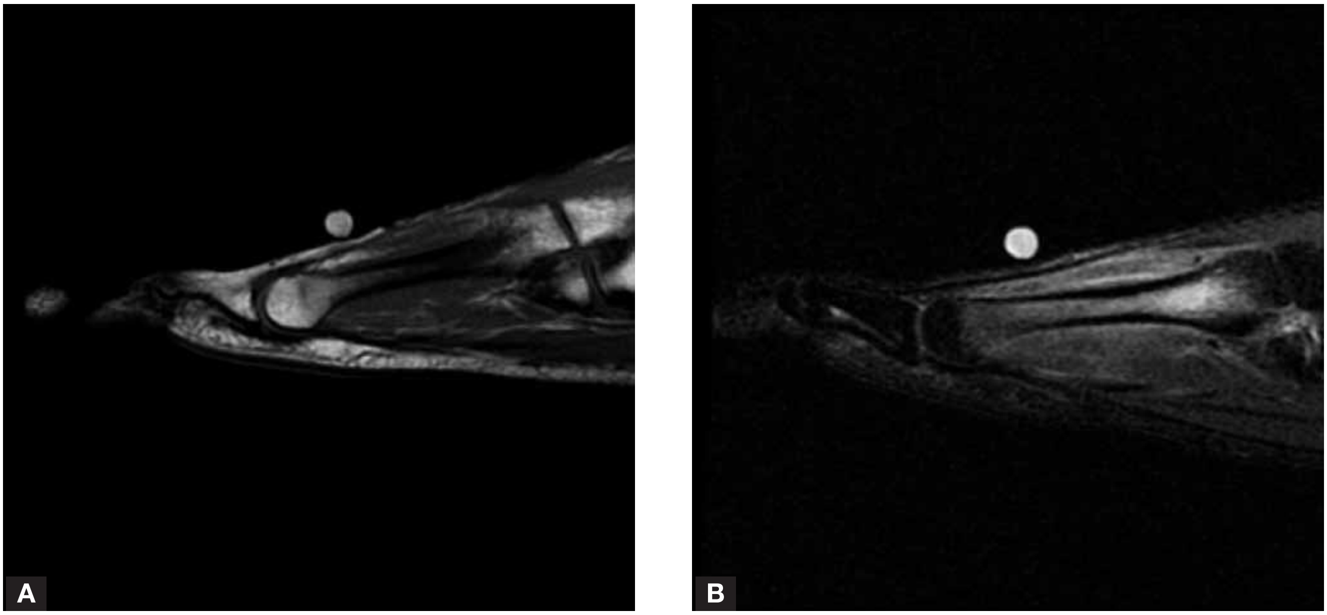

Figure 7. Metatarsal stress reaction. Sagittal T_1-weighted (A) and sagittal short TI recovery (B) forefoot sequences show bone marrow and soft-tissue edema secondary to stress reaction of the metatarsal shaft. Radiographs (not shown) were negative.

footwear are risk factors for development of stress fractures. Compared with men, women have an increased likelihood of developing stress fractures. Sex differences have also been found in the anatomical distribution of stress fractures. A study of female soldiers in basic training found that the most common lower extremity sites for stress fractures were the calcaneus (39%), the metatarsals (31%), and the lower leg (21%), whereas the calcaneus accounted for 66% of lower extremity stress fractures in these soldiers' male counterparts[14] (Figure 6).

Women with the "female athlete triad," the combination of osteoporosis, eating disorders, and amenorrhea, are at particular risk for stress fractures. Stress fractures can be divided into insufficiency and fatigue fractures. Insufficiency fractures are the result of normal stress applied to abnormal bone, whereas fatigue fractures occur as a result of repeated stress that exceeds normal bone's ability to recover. Several mechanisms may be involved in development of these fractures; however, an induced hypoestrogenic state (thought to impair normal bone repair mechanisms) and osteoporosis place these women at especially high risk.[15]

Shoe wear is another important consideration in prevention of stress fractures. Results from a study of military recruits suggested that shock-absorbing material may help prevent stress fractures from developing. Soft, lightweight shoes with anatomically fitting insoles have also been suggested in the prevention of stress fractures.[16] Lack of structured training and abrupt increases in activity levels increase the likelihood of developing stress fractures.

Imaging is integral in the diagnostic workup for stress fractures. The imaging workup typically begins with radiography, which for the foot, consists of frontal, lateral, and internal oblique views. Radiographs may appear negative in subtle or early stress fractures. Careful examination of the cortex is necessary to detect early lucency, which may progress to cortical thickening, periosteal reaction, and sclerosis as reparative remodeling occurs. Callus formation at the fracture site may take up to 2 to 3 weeks to appear radiographically.

Wilson and Katz[17] classified stress fractures according to radiographic appearance. Type I stress fractures demonstrate a fracture line without callus formation or periosteal reaction. Type II fractures include those with focal sclerosis and formation of endosteal callus. Periosteal reaction and external callus formation at the stress fracture site are classified as type III. Mixed combinations of types I through III are classified as type IV. In the setting of a negative radiograph but persistent clinical suspicion, 2- to 3-week follow-up radiographs may be useful in confirming a fracture by demonstrating early signs of healing. More sensitive imaging may be performed at time of presentation with either bone scintigraphy or MRI. Bone scans, however, may yield positive results in several other conditions, including infection, inflammation, and tumors. MRI is both sensitive and specific for diagnosing stress fractures and can detect stress reaction, the precursor to stress fracture. Stress reaction is identified as early bone marrow edema, without a discrete fracture

Table IV. Utility of Magnetic Resonance Imaging in Morton Neuroma

Confirm diagnosis and exclude other causes of forefoot pain
Evaluate extent of disease
Conduct preoperative planning
Evaluate associated bursitis

Figure 8. Osteonecrosis of third metatarsal head (Freiberg infraction). Magnetic resonance imaging (MRI) in axial plane shows (A) decreased signal with third metatarsal head on T_1-weighted sequences and (B) increased signal on short TI recovery sequences. MRI is more sensitive in diagnosing early osteonecrosis, in which findings may be radiographically occult. (C) Anteroposterior view of foot shows increased sclerosis and flattening of third metatarsal head. These are late findings.

line (Figure 7). When present, a dark fracture line on T_1-weighted images confirms the diagnosis of a stress fracture. Table III describes several uses of advanced imaging (MRI) with respect to stress fractures.

Metatarsal Head Osteonecrosis (Freiberg Infraction)

Freiberg infraction most often involves the second metatarsal head, with the third and fourth metatarsals less commonly affected. One etiologic theory is that the osteonecrosis is secondary to the repetitive stress and microfractures that occur at the junction of the metaphysis and the growth plate. The stress of increased weight-bearing from high-heeled shoes makes this process more common among young women.[18,19] Patients most commonly present with atraumatic forefoot pain and swelling, often localized to the metatarsal head. They also may demonstrate decreased range of motion at the corresponding MTP joint. However, some patients may be asymptomatic or may report only vague exertional forefoot pain. Freiberg infraction characteristically occurs unilaterally; however, bilateral involvement is possible.[20] Radiographs, MRI, or both can be used to document changes consistent with Freiberg infraction. Conventional radiographs may be normal initially, but over time can demonstrate sclerosis of the metatarsal head and widening of the joint space (Figure 8A). Complete collapse of the metatarsal head, flattening, and fragmentation are late findings. Oblique radiographs may be helpful in appreciating subtle changes.

MRI allows accurate diagnosis before radiographic changes occur. Early MRI findings demonstrate nonspecific bone marrow edema within the affected metatarsal heads, characterized by low signal intensity on T_1-weighted images and corresponding high signal intensity on T_2-weighted sequences (Figures 8B, 8C). In addition, advanced MRI techniques may allow assessment of bone viability by analyzing postcontrast enhancement characteristics. As the condition progresses, there may be flattening of the metatarsal head and development of low signal intensity changes on T_2-weighted sequences as sclerosis ensues.[21]

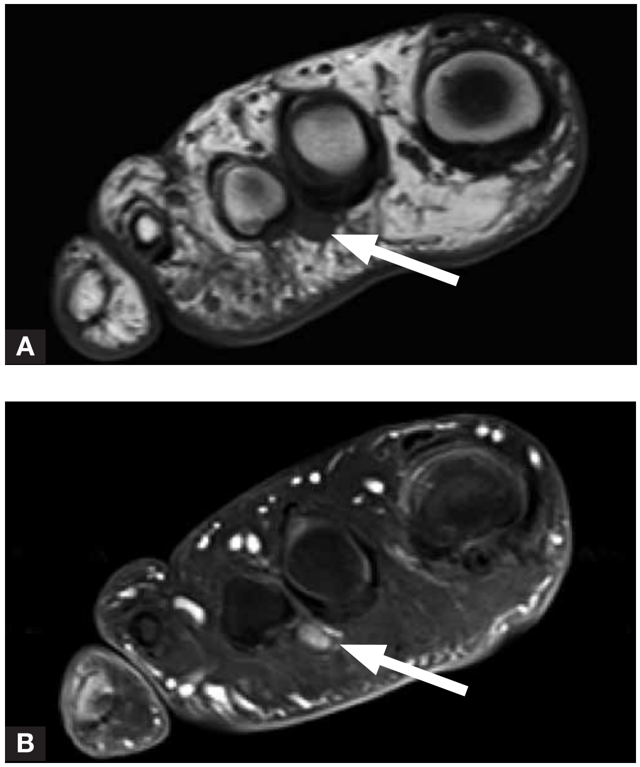

Figure 9. Morton neuroma. (A) T_1-weighted image through forefoot shows dumbbell-shaped mass extending from intermetatarsal space between second and third digits towards the plantar aspect of foot. (B) Postcontrast T_1-weighted fat-saturated image at same level shows diffuse enhancement of the mass.

Table V. Utility of Magnetic Resonance Imaging in Haglund Syndrome

Confirm diagnosis and exclude other or coexistent causes of hindfoot pain
Evaluate retrocalcaneal and retro-Achilles bursitis
Evaluate calcaneal marrow signal
Assess Achilles tendon
Conduct preoperative planning

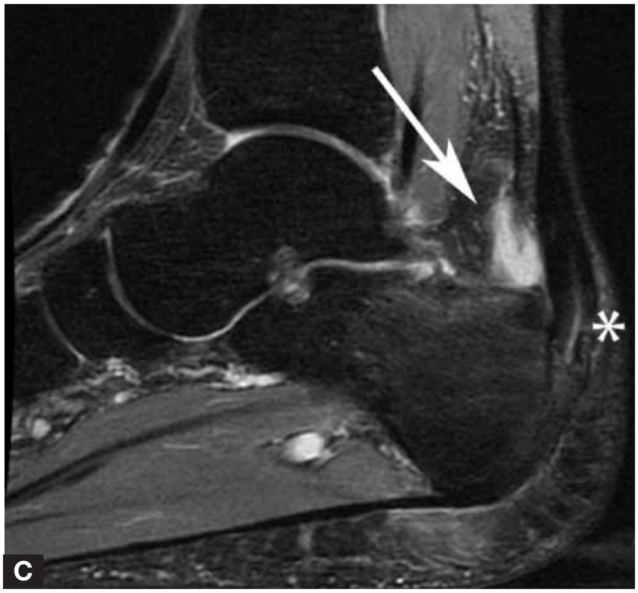

Figure 10. (A) Parallel pitch lines in normal hindfoot. Line is drawn along plantar surface of calcaneus. Next, perpendicular line is drawn to posterior subtalar joint. Another line is then constructed from posterior edge of subtalar joint, parallel to plantar surface line. Normal bursal projection that does not extend superior to this parallel line is normal, as shown above. Bursal prominence that extends superiorly above this line indicates Haglund deformity. (B) T_1-weighted sequence shows unusually prominent bursal projection (asterisk) in patient with Haglund deformity. (C) Sagittal short TI recovery sequence through the hindfoot shows retrocalcaneal bursitis (arrow) and insertional interstitial tear of the Achilles tendon (anterior to asterisk) demonstrated by abnormal intrasubstance signal.

Morton Neuroma

Morton (interdigital) neuroma is a fibrosing process classically occurring in the third intermetatarsal webspace between the third and fourth digits or the second intermetatarsal webspace between the second and third digits. The lesion is thought to arise from compression and irritation of the plantar digital nerve, resulting in perineural and neural thickening, with or without an adjacent bursitis. Mechanical irritation is amplified by increased force redistributed to the metatarsal heads from pointed and high-heeled shoes. A constricted toe box is another contributor. This may account for the high female-to-male ratio of Morton neuroma, which has been reported to be as high as 18 to 1.[22] Clinically, the lesion may present as pain and tenderness in the intermetatarsal webspace. Paresthesia and numbness may be seen in the distribution of the affected plantar interdigital nerve. Symptoms are exacerbated with continued activity or increased plantar pressure, notably with use of high-heeled shoes or shoes with tight toe boxes.

Although the diagnosis of Morton neuroma is usually made on the basis of clinical examination and history, both ultrasound and MRI have had a role in confirming the diagnosis and evaluating the extent of disease. Table IV lists several uses for advanced imaging (MRI) in clinically suspected Morton neuroma. Although ultrasound is less expensive and more portable than MRI, it is operator-dependent and less accurate in detecting smaller lesions.[23] MRI provides exquisite detail of forefoot anatomy, aids in treatment planning, and may help to exclude other potential sources of forefoot pain. Optimal imaging of the forefoot is performed in multiple planes with a small field of view to detail the musculotendinous and neurovascular anatomy. Conspicuity of the neuroma may be improved by imaging the patient in the prone position.[24] Still, there is no requirement for ultrasound or MRI in patients with suspected Morton neuroma, as clinical assessment maintains a high sensitivity and specificity in detecting these lesions.[23]

The classic MRI feature is a dumbbell-shaped mass in the intermetatarsal space below the intermetatarsal ligament (Figure 9A). The mass is typically low in signal on T_1-weighted images and low to intermediate in signal on T_2-weighted images. This lesion demonstrates variable enhancement on postcontrast imaging.

Enhancement is best appreciated on T_1-weighted fat-suppressed sequences (Figure 9B).

MRI evaluation is used to ascertain the size and degree of dorsal and plantar extension and the presence or absence of intermetatarsal bursitis. The lesion should be distinguished from an isolated bursitis, which would demonstrate diffuse increased signal on T_2-weighted sequences with enhancement confined only to the periphery (as with other fluid collections). It is not uncommon, however, for a Morton neuroma to be associated with an adjacent bursitis.[25]

Haglund Syndrome

Posterior heel pain combined with a visible and palpable "pump-bump" was first described by Haglund[26] in 1927 and attributed to low-backed, rigid shoes. Haglund syndrome is the constellation of Achilles tendinitis, retrocalcaneal bursitis, and retro-Achilles bursitis. Haglund deformity is a bony prominence (bursal projection) along the posterior superior lateral ridge of the calcaneus, separate from the Achilles tendon insertion site, which is more posterior and inferior (Figure 10A). A higher incidence of Haglund syndrome is seen in people with Haglund deformity because of the increased repetitive mechanical stress, which compresses the retrocalcaneal bursa against the Achilles tendon between the shoe and the calcaneus.

Clinically, patients may present with recurrent pain and swelling at the posterior heel, secondary to a retrocalcaneal and/or superficial bursitis surrounding the Achilles tendon. The term pump-bump was applied to the painful soft-tissue prominence caused by a retro-Achilles bursitis that develops on the posterior ankle, exacerbated with use of heeled pumps. Interestingly, the condition is common in adolescent women; it is thought to occur during their transition to high heels.[27]

Radiographs are often helpful in confirming the diagnosis of Haglund syndrome and excluding other sources of heel pain. The lateral radiograph is most helpful, as it can demonstrate soft-tissue thickening in the region of the distal Achilles tendon and a distended retrocalcaneal bursa, as well as a convexity of the soft tissues at the Achilles insertion posteriorly (the pump-bump). The lateral view also determines the presence of a prominent calcaneal bursal projection (Haglund deformity).

Pavlov and colleagues[28] described a radiographic method for assessing Haglund deformity. In this method, parallel pitch lines are used as an objective measure of the calcaneal bursal projection (Figure 10A). A line is drawn from the anterior tubercle to the medial tuberosity along the plantar surface of the calcaneus, as seen on the lateral projection. A perpendicular line is constructed through the posterior edge of the talus. A second parallel line is then drawn from this point at the posterior edge of the subtalar joint. A bursal projection that violates this line is considered abnormal and confirms Haglund deformity.

MRI demonstrates both bone-deformity and soft-tissue changes and can detect structural changes within the Achilles tendon (Figures 10B, 10C). Table V outlines the utility of MRI in the imaging evaluation of Haglund syndrome. Fluid-sensitive sagittal sequences are best for demonstrating the classic findings in Haglund syndrome, which may include enlargement of the distal Achilles tendon (>9 mm in diameter), Achilles tendon insertional tears, fluid in the retrocalcaneal and retro-Achilles bursae, and/or bone marrow edema in the posterior calcaneus at the Achilles insertion. MRI evaluation before Haglund deformity resection allows anticipation of a weakened Achilles tendon and planning for possible reinforcement.[29]

Conclusion

In summary, standing radiographs of the foot are useful in detecting and quantifying alignment abnormalities of the foot and toes. Conditions such as stress fractures and osteonecrosis may be difficult to detect on radiographs, and early diagnosis is facilitated by MRI, which can detect marrow edema, or by bone scintigraphy, which can detect early healing. Soft-tissue lesions (such as bursitis) may be detected on radiographs, but deeper abnormalities (such as Morton neuroma) are poorly defined on radiographs. In these conditions, MRI or ultrasound is of most value.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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