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Review Article

Radiological Approach to Forefoot Pain
前腳掌疼痛的放射線學診斷

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ABSTRACT

Forefoot pain is a common clinical complaint in orthopaedic practice. In this article, we discuss the anatomy of the forefoot, clinical and radiological approaches to forefoot pain, and common painful forefoot disorders and their associated radiological features.

中 文 摘 要

前腳掌疼痛是一種很常見的骨科臨床問題。在這篇文章中，我們將研究前掌的結構，臨床和影像學診斷方法，以及常見的前足疼痛疾病和相關的影像學特徵。

Introduction

Forefoot pain is a common clinical complaint in orthopaedic practice. In general, the foot is divided into three anatomical zones: hindfoot, midfoot, and forefoot. These three zones are divided posteriorly by Chopart's joint and anteriorly by Lisfranc's joint. The forefoot is defined as the part of the foot distal to the Lisfranc joint. It includes the metatarsals, phalanges, and surrounding tendons and soft tissue. Pain in this area can be caused by numerous conditions, which could be due to local or distant causes. In this article, a brief discussion on how to tackle this common problem from a radiological approach is conducted.

Anatomy

Understanding the anatomy plays an important role in tackling complaints in the forefoot region. There are a number of important anatomical structures providing stability to this area. One major static support comes from the plantar plate, which is located under the metatarsal heads, and inserts distally to the base of the proximal phalanx. Dynamic stabilisation comes from the muscles, ligaments, and tendons. Both the intrinsic and extrinsic muscles are important in providing dynamic stabilisation. Collateral ligaments, tendons from the flexor digitorum longus and brevis, and the extensor hood and sling. The deep intermetatarsal ligaments provide stability in the transverse plane by holding the metatarsal heads together and maintaining the plantar arch of the forefoot.[1]

Besides the ligament, there are small intermetatarsal bursae at the dorsal aspect of the intermetatarsal ligaments. The neurovascular bundle lies under the ligament. This is the place where Morton neuroma arises.

Clinical approach

History and physical examination provides most important information in differentiating the causes of forefoot pain. A history of trauma can be the easiest information to obtain from the patient. Other useful background information such as the presence of diabetes or obesity, and a history of vascular insufficiency are all useful and can be obtained from careful history taking. Although patients usually complain of pain over a large ill-defined area, careful examination and guiding questions are often helpful to localise the exact location of the pain. Other pertinent features in physical examination can also guide us to the correct diagnosis, for example, obvious deformity, swelling, presence of a mass, local erythema, or ulcers. Regional abnormalities, such as tight triceps or gastrocnemius, can also increase stress in the forefoot and cause pain. A full examination including the whole lower limb is necessary for tackling forefoot problems.

After isolating the site of the pain, we can narrow down the long differential list and proceed to appropriate investigation. The

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differential list for metatarsalgia is long and can be segregated according to different disease categories: trauma, joint disorder, infection, tendon disorder, and soft tissue masses including neoplastic and non-neoplastic causes. Radiological approaches are discussed in detail for differentiation of these disorders.

Radiological evaluation of the forefoot

In daily practice, investigation usually starts with radiography. Usual practice includes the use of anteroposterior (dorsoplantar) and lateral views. Proper evaluation of the foot needs to include the entire foot and ankle. It is always good to take these radiographs with weight bearing if the patient can tolerate it, because this provides important biomechanical information as well as true deformity and subtle malalignment in the usual position of the patient. The smooth cascade of the metatarsal heads should be assessed. Excessive length or plantar flexion of one of the metatarsals can result in local pressure points and metatarsalgia. Other supplementary views that are commonly performed include oblique views for better visualisation of metatarsal bones, and sesamoid views for suspected sesamoid pathology.[2]

The forefoot is a flat structure with limited thickness, therefore, ultrasound is especially useful for diagnosing forefoot problems. It is also useful for evaluation of superficial tendons for any underlying tenosynovitis, tendinosis, and integrity of tendons in cases of trauma. It can detect fluid-distended joints and mass lesions. If the machine has sufficient resolution, subtle abnormalities such as bone erosion, and synovial thickening and inflammation can also be seen.

If bone abnormalities are suspected, computer tomography (CT) provides much needed information on the bone itself. Fractures, erosions, periosteal reaction, and anything related to the bone cortex, are readily seen in CT. CT can detect soft tissue masses, intraosseous lesions, and most importantly, calcification. In cases of trauma, CT can be performed in supine position and do not need special positioning as requested by special radiographic view. It help to alleviate patients' pain in radiographic positioning and provide important information on joint alignment, fracture orientation, and articular surface involvement.

Magnetic resonance imaging (MRI) is the best tool for determining the nature of soft tissue. It depicts the soft tissue structures, including muscles, tendons, ligaments, and especially cartilage, which can be difficult for all the above modalities. It is useful for detection of subtle or stress fractures, which sometimes can be difficult to detect on CT and radiography.[3,4] It can also characterise soft tissue lesions, and allow better delineation of the extent, relationship, and involvement of the surrounding musculotendinous and neurovascular structures. It is increasingly used to evaluate patients with forefoot complaints, because it allows a specific diagnosis based on its exact anatomical location, signal characteristics, and morphological features. With its increasing availability, it could become an even more popular imaging modality for diagnosing forefoot problems.

Common disease entities in forefoot

Trauma

A properly taken radiograph is a good early assessment for trauma patients especially for detection and assessment of fracture. We need a meticulous approach when dealing with trauma cases. It is always good to start with the general alignment of the bones. Check the alignment of all metatarsals, phalanges, and never miss the Lisfranc's joint: the second metatarsal base should always align precisely with the second cuneiform, and any disruption to the smooth contour or stepping should raise the suspicion of a Lisfranc dislocation. Carefully trace all the bony cortices for any cortical discontinuity or stepping. It is embarrassing to miss a Jones fracture (fracture of the base of 5th metatarsal) at the end of the attention span (Figure 1).

Always ensure each metatarsal and phalangeal head has a normal smooth spherical outline. Flattening of any metatarsal or phalangeal head suggests avascular necrosis. When the collapse affects the second and third metatarsal head, it is known as Freiberg's infarction (Figure 2). It commonly affects women wearing high-heel shoes, but the symptoms often lag behind the degenerative changes occurring in radiography. MRI is helpful in early detection by showing low signal intensity in T1-weighted images, and high signal intensity in T2-weighted and short tau inversion recovery (STIR) images.[3,4]

MRI is also useful in cases of micro-trauma, which are difficult to evaluate in plain films. Stress fractures are easily detected by MRI

Figure 1. Jones fracture (fracture at the base of the 5th metatarsal; arrows): (A) dorsoplantar view; (B) oblique view.

Figure 2. Freiberg's infarction with flattened second metatarsal head (secondary to trauma): (A) dorsoplantar view; (B) oblique view.

with marrow oedema in T2 and STIR images; and sometimes even prior to the fracture line, local osteopaenia or sclerosis appear in CT (Figure 3).[3] Occupational history of runners, gymnasts, police officers, or other professional athletes gives a clue prior to selecting the right investigation modality.

The small hallux sesamoids are often missed due to their size. They are intratendinous and located in the flexor hallucis brevis and abductor hallucis tendons. They are subjected to stress due to their anatomical position, and are prone to fractures, stress injuries, inflammation, and avascular necrosis. This can be the cause of persistent unexplained forefoot pain. With good physical examination and high clinical vigilance, appropriate investigations can be chosen to target these small structures. Sesamoid view radiography can visualise these small bones. MRI has good sensitivity in detecting subtle injuries (Figure 4).[2–4]

Joint disorder

Hallux valgus is a common complaint with significant pain and deformity in the forefoot. It is easy to detect at physical examination. This can present with bunion pain and painful callosity at the second metatarsal head and/or along the plantar medial edge of the hallux. First metatarsophalangeal joint pain with synovitis or degeneration can also occur (Figure 5). Radiography of the foot under weight bearing reveals the subtle biomechanical abnormalities, as well as the secondary features such as associated soft tissue swelling and early degeneration. Plain radiographs also provide a good assessment for postoperative condition.

Arthritis is another large disease category of joint disorder that can result in forefoot pain. Arthritis can be divided into four main groups: inflammatory arthritis, degenerative arthritis, crystal arthropathy, and septic arthritis. Differentiation of arthritis can be made clinically according to history, serology, and pattern of involvement. In radiology, the diagnosis is similarly drawn by pattern recognition, that is, looking at the pattern of joint involvement. Looking at a single joint and jumping to a conclusion, missing out the remaining joints, ancillary radiographic features, relevant history and biochemistry, often leads to incorrect diagnosis, and unnecessary treatment and further investigation. The detail of pattern recognition of arthritis is beyond the scope of this article. Some commonly encountered forms of arthritis in the forefoot are discussed instead.

Degenerative arthritis in the forefoot can be primary or secondary. The most commonly affected joint is the first metatarsal phalangeal joint. The main radiographic findings include joint space loss, subchondral sclerosis, osteophyte formation, and subchondral cystic changes. Altered biomechanical stress, as in hallux valgus, can result in early degeneration. Other congenital or acquired abnormalities, trauma, or previous operation, which changes the normal weight distribution, can also result in secondary degeneration (Figure 2).

A number of inflammatory arthropathies can affect the forefoot. Common erosive arthropathies affecting the forefoot include rheumatoid arthritis and psoriatic arthropathy. The metatarsophalangeal joint is the most commonly affected joint in rheumatoid foot (Figure 6). Acute presentation is usually in the form of proximal joint tenderness, as in the metatarsophalangeal joint. There is soft tissue swelling and bursitis, which may be detected on plain radiographs, but is nonspecific to particular arthropathies. In chronic form, erosions and joint space narrowing can be observed in

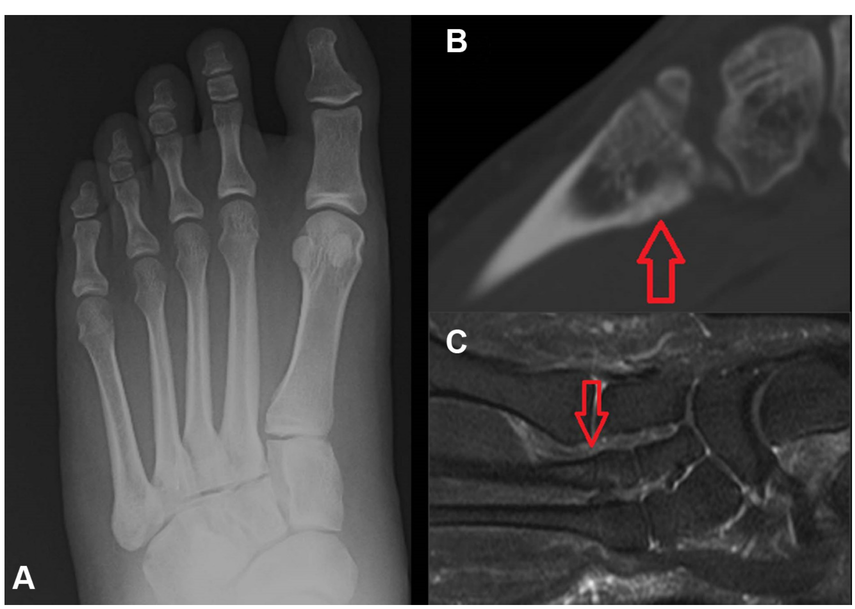

Figure 3. (A) Stress fracture with normal looking radiograph. (B) Stress fracture appearing as hairline fracture at the base of the second metatarsal (arrow). (C) Stress fracture shown as bone marrow oedema at the base of the second metatarsal (arrow).

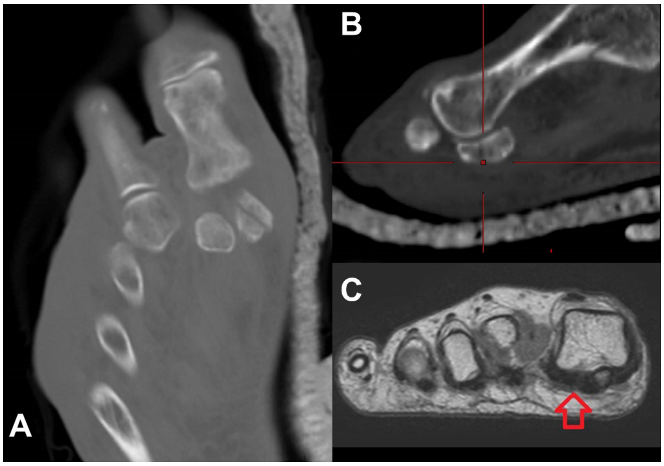

Figure 4. Computed tomography shows fracture of sesamoid bone: (A) transverse view; (B) sagittal view. (C) Avascular necrosis of lateral sesamoid: small and dark looking lateral sesamoid compared to the medial one on magnetic resonance imaging photon density sequence.

radiographs, which are also common findings in other inflammatory arthropathies. The main clue is the presence of periarticular osteopaenia. Coexisting deformities such as hallux valgus or clawing of toes are sequelae of synovitis and ligament incompetence.

Psoriatic arthropathy is a proliferative arthropathy and enthesopathy (Figure 7). In the forefoot, it also targets the metatarsophalangeal joints, where bony erosions and proliferations occur. When attacking the interphalangeal joint, pencil-in-cup appearance of the phalanges may be seen, as in the hands. Due to the enthesopathy, there may be fuzzy bone margins at the attachment of the fascia (e.g., plantar fascia), tendons, and ligaments.[4,5]

Another common arthropathy that targets the forefoot is gout. It is an acute crystal arthropathy, with the first metatarsophalangeal joint most commonly affected (Figure 8). In the acute phase, radiographs show dense soft tissue swelling around the joint. The erosions are classically of a punched-out/mouse bite appearance or over-hanging margins.[1,2] The presence of calcified tophus signifies a relative chronic course of the disease.

Neuropathic arthropathy has a rapid and alarming course in the forefoot as in other joints. There is rapid erosion and destruction of forefoot joints. The radiographic features can be striking, with subtle swelling and erosions initially, rapidly progressing to deformity, joint destruction, and derangement with bony fragments, debris or loose-body formation.[6] Its picture overlaps largely with that of infective arthritis. The joint can be so deformed that it cannot be recognised, giving the term "arthritis mutilans" (Figure 9). A history of diabetes neuropathy or leprosy would confirm the diagnosis. Calcification is also a radiographic clue: tram-track vascular calcification can be seen in diabetic vasculopathy, while soft tissue/nerve calcification is also present in cases of leprosy.

Figure 5. Hallux valgus with first metatarsophalangeal joint degeneration.

Infection

It is not difficult to detect infection in clinical examination. Infection or septic arthritis of the metatarsophalangeal joints is common in patients with neuropathy, especially in diabetes. Local tenderness, erythema, and ulcers often herald the more sinister bone and joint infection. Imaging has the role of confirming the diagnosis, and evaluating the extent of the infection. Radiographs often show soft tissue swelling. Bone erosion is difficult to detect early, but occurs in a rapid manner (Figure 10). CT helps to detect the presence of bone erosion, periosteal reaction, intraosseous sequestrum, and sometimes sinus tracts and associated collections. MRI with intravenous gadolinium contrast is sensitive for inflammation, but it is often difficult to differentiate from acute neuropathic disease, which requires other secondary signs such as abscesses, sinus tracts, or ulcers to give a definite diagnosis, but these secondary signs can be readily detected at the physical examination.[2,3,6]

Tendon disorders

There are many tendons originating from the leg and terminating in the forefoot. Any congenital or acquired problem of the tendon also appears at the level of the forefoot and causes pain. Upstream tendon dysfunction also alters the biomechanics of the foot, resulting in forefoot pain. For example, tarsal tunnel problems, or tight Achilles tendon can alter stress at the level of the forefoot.

For assessing tendon disorders, cross-sectional imaging is the most useful tool. In the past, CT has been used to detect swollen or discontinued tendons, or sometimes gross fluid within the tendon sheath, as in tenosynovitis. Nowadays, ultrasound and MRI are far superior for detection of tendon problems compared to CT. MRI is sensitive to fluid signals or inflammation within tendons. It can also show fine details of the tendon, its course, and its surrounding. It can give a good general picture of the pathology and its aetiology. The superficial nature of the tendons at the forefoot makes ultrasound a suitable and fast examination tool. High-resolution ultrasound has the advantage of magnifying the tendon and examining it closely. The ability to examine the tendons dynamically is a major advantage for this modality.

Tendon problems can arise from the tendon and the tendon sheath. Tendinosis refers to the angiofibroblastic hyperplasia, degeneration, and necrosis of the tendon. It can be caused by degeneration, local injury, or inflammation. In MRI, tendons affected by tendinosis show increased T1 and T2 signal intensity, but the most important feature is thickening of the tendon itself. High-resolution ultrasound can detect the thickened tendon, loss of tendon margin and its fibrillar echo texture, and increased vascularity.[4]

Tenosynovitis, is inflammation of the sheath housing the tendon (Figure 11). Its similarity to synovial cavity makes it prone to synovial inflammatory disorder, infection, or mechanical irritation. The main finding in tenosynovitis includes fluid accumulation around the tendon, and enhancement of the sheath due to inflammation. In severe cases, the tendon sheath is stenotic, resulting in friction and repeated trauma to the tendon. Tendon

Figure 6. Rheumatoid arthritis of both feet. Note the small erosions in the right third metatarsal head, and the diffuse periarticular osteopaenia: (A) dorsoplantar view; (B) oblique view.

rupture or degeneration may arise. When such situations do happen, it may be possible to detect mass-like lesions along the course of the tendon in the forefoot, or loss of particular motion/ power provided by the affected tendon.

Masses

There are many masses that can arise from all tissue types in the forefoot: from soft tissue to bone, from benign to malignant. The main role of imaging is to locate (or more precisely, confirm) where the mass arises, and to characterise the mass. Each of the aforementioned investigation modalities has its own strength in mass characterisation.

In the case of soft tissue masses, it is important to know if the lesion is cystic (Figure 12) or solid (Figure 13). Ultrasound is the best tool for assessing this particular characteristic. Ganglions, as in the hands and wrists, are the most common cystic mass lesions of the foot and ankle. Their typical location is at the dorsal aspect of the metatarsophalangeal joint. They can cause pain due to local mass effects. The aetiology of this lesion is thought to be from repetitive trauma, leading to mucoid cystic degeneration. It is usually a well-defined cystic lesion. In ultrasound, the typical appearance is an anechoic structure with posterior acoustic enhancement. In MRI, unless it is complicated with previous rupture or infection, the T1 signal is dependent on protein content. The lesion has homogeneous high T2 STIR signals approaching those of water.[3,4]

Besides ganglions, bursitis is another common cystic lesion of the forefoot, especially the intermetatarsal bursae. They can become inflamed and fluid distended, resulting in a cystic lesion similar to ganglions. The main feature to differentiate these two is the location. Bursitis usually arises at pressure points, while ganglions can arise anywhere.[3,4]

Figure 7. Psoriatic arthropathy: (A) dorsoplantar view; (B) oblique view. Pencil-in-cup appearance of phalanges. Bone whiskering at the corners. Acro-osteolysis at tuft.

Figure 8. Gouty arthritis: (A) dorsoplantar view; (B) oblique view. Dense soft tissue swelling (lumps and bumps) at the interphalangeal and metatarsophalangeal joints of the big toe. Erosion with hang-over edges at the first metatarsal head.

Figure 9. Arthritis mutilans: (A) dorsoplantar view; (B) oblique view. Totally deformed feet with licked candy stick appearance of phalanges.

Figure 10. Osteomyelitis of the distal phalange of the big toe: (A) dorsoplantar view; (B) oblique view. Note the gross soft tissue swelling and massive bone erosion.

Going deeper from the dorsal to plantar aspect, we have the interdigital space, where Morton neuroma arises (Figure 14). The term is misleading because this is not a genuine neoplasm. It is a mass arising from perineural fibrosis and nerve degeneration.[3,4] It typically arises between the metatarsal head, usually at the second and third interspaces. Patients usually complain of feeling a mass or pain in the interspace. Prior to the era of cross-sectional imaging, radiographic suspicion was raised when there was widening of the interspace in weight bearing anterio-posterior views of the foot (Sullivan's sign). Morton neuroma appears in MRI as a lesion with iso- to hyperintense T1 signals, as in muscle, and with relatively iso- to hypointense T2 signals when compared to fat. The lesions demonstrate intense enhancement after intravenous gadolinium administration, which is better depicted in fat-saturated sequences.

Bone tumours rarely cause pain in the forefoot, unless complicated by local mass effects, pathological fracture, or locoregional infiltration in cases of aggressive lesions. The tumour pattern in the forefoot is surprisingly similar to that in the small bones of the hand. The most

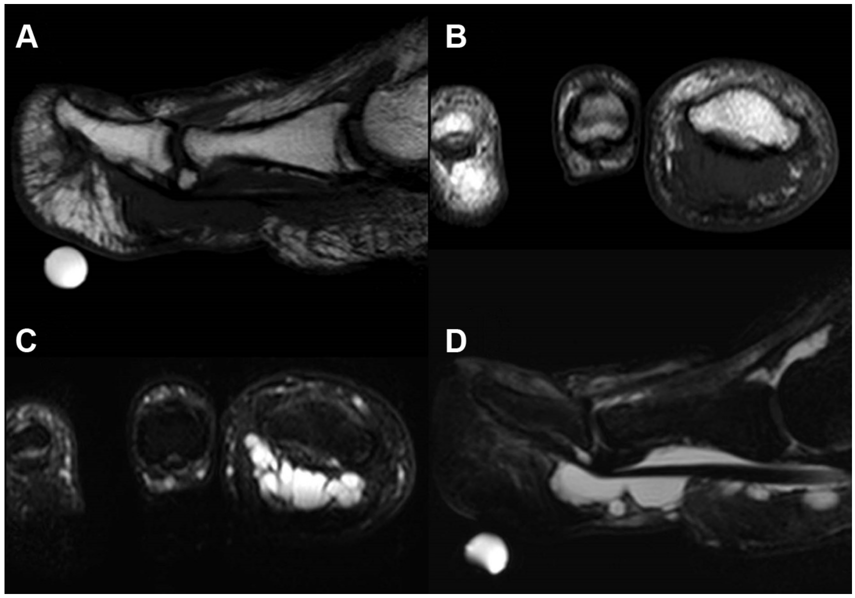

Figure 11. Tenosynovitis of the flexor hallucis longus tendon. Multiple small cystic pouches along the tendon at the plantar side of the big toe. (A) T1 sagittal view; (B) T1 coronal view; (C) T2 coronal view; (D) T2 sagittal view.

common benign tumour is giant cell tumour, followed by chondromyxoid fibroma, and osteochondroma, whereas in the malignant group, chondrosarcoma, osteosarcoma and Ewing's sarcoma are the most common in descending order. Metastatic lesions are even rarer, with lungs, kidneys, and colon the highest in order.[4] Radiographic characterisation is still the universal path to differentiate whether these bone tumours are aggressive or not (Figure 15), while more advanced imaging modalities are helpful for characterising the nature of the lesion, determining the extent and any neurovascular structure involvement, and for locoregional staging.

Conclusion

There is no perfect investigation method in musculoskeletal imaging: every radiological investigation has its own strength and weakness in diagnosing different forefoot disorders. The surgeon should conduct a detailed and careful clinical assessment to choose wisely from the arsenal of radiological examinations to aid the diagnosis.

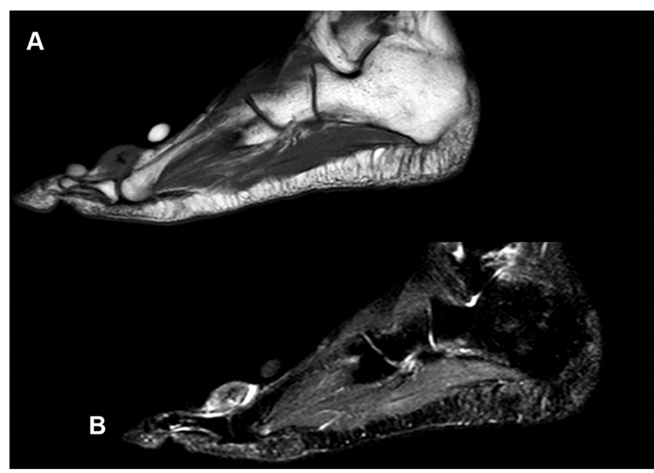

Figure 13. Small lesion at dorsal aspect of foot, indicated by the oil pellet marker. The lesion had an (A) intermediate-intensity T1 signal and (B) heterogeneous high-intensity T2 signal, and was not purely cystic. The pathology of this lesion was vascular leiomyoma.

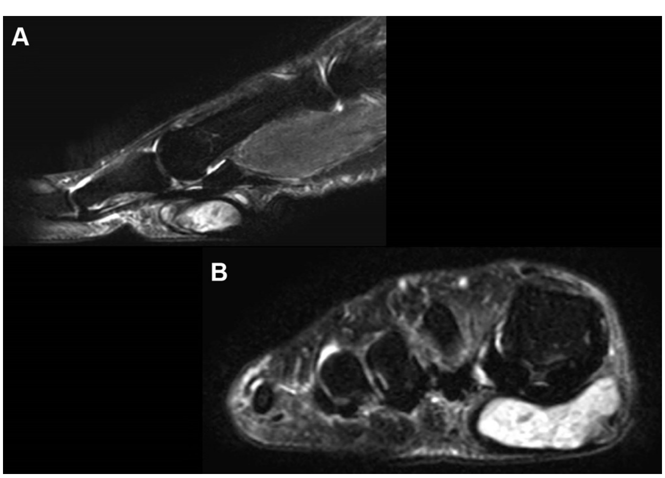

Figure 12. Cystic lesion at the plantar surface is well depicted as a high signal intensity lesion on T2 fat-saturated sequence magnetic resonance imaging: (A) sagittal view; (B) coronal view.

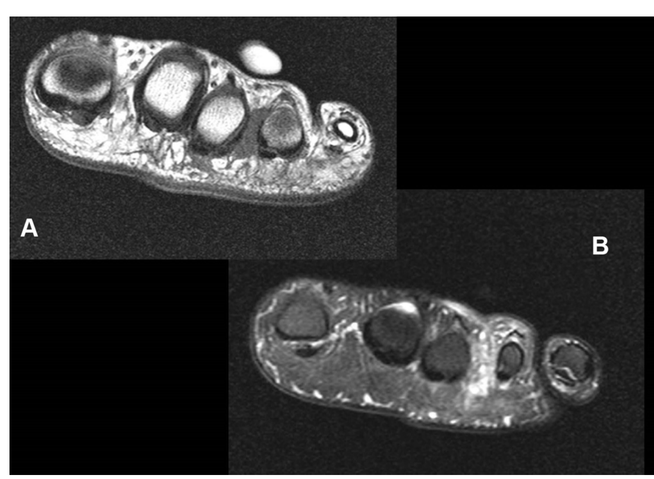

Figure 14. Morton neuroma arising from the third interspace, as (A) intermediate-intensity T1 and (B) high-intensity T2 signal lesions.

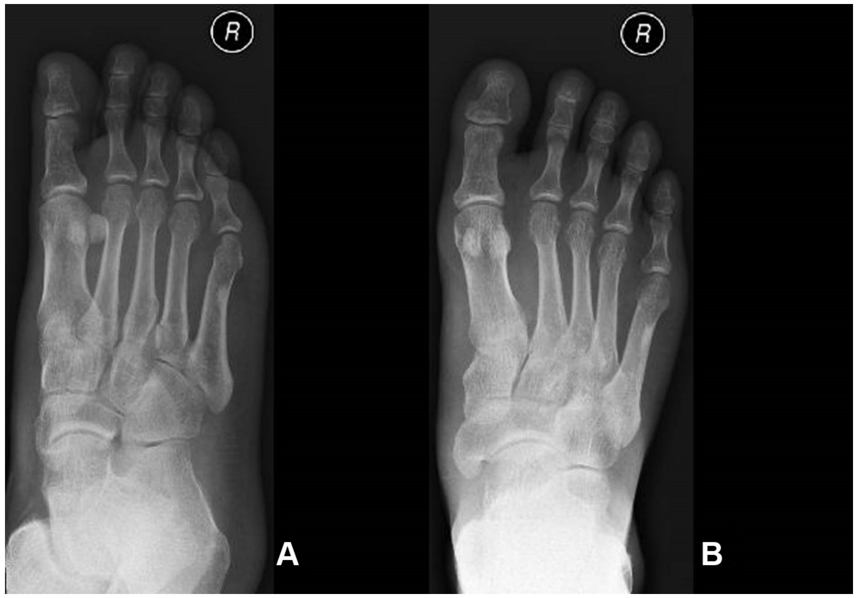

Figure 15. A well-marginated, cortical-based sclerotic lesion at the diaphyseal region of the right fifth metatarsal; likely a nonaggressive bone lesion. (A) Oblique view; (B) dorsoplantar view.

Conflicts of interest

All authors declare no conflicts of interest.

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