Metatarsalgia. A practical approach

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Learning objectives

To review the normal anatomy of the metatarsal region with Ultrasound (US) and Magnetic Resonance (MR) images.

To highlight the role of different imaging methods in the radiological work-up of patients with forefoot pain.

To discuss the radiological signs and clinical aspects of the disorders that may lead to metatarsalgia, focused on the lesser metatarsals.
Background

Pain of the forefoot is a common clinical problem that affects a wide range of population. It is caused by many pathologies from different nature, and sometimes their diagnosis may be difficult without the help of imaging.

Metatarsalgia etiology include trauma-related conditions, instability of the metatarsophalangeal (MTP) joint, Freiberg infarction, soft-tissue masses, inflammatory and infectious processes and bone tumors.

We must bear in mind that an important cause of pain of the forefoot are the mechanical disorders that lead to a weight bearing alterations, but these are not discussed in this paper.

Imaging plays an important role in determining a specific diagnosis in order to provide an appropriate treatment.

The aim of this paper is to give a practical approach of metatarsalgia, in order to make an accurate diagnosis by integrating the location, morphology, imaging features, predisposing factors and clinical aspects of different disorders.
ANATOMY

The forefoot is the anterior area of the foot, distal to Lisfranc joint. Forefoot includes the five metatarsal and fourteen phalange bones, and the surrounding soft tissues. A pair of sesamoid bones are located under the head of the first metatarsal bone.

Plantar plate is the main structure for the stability of the MTP joint. It is situated under the metatarsal head, and its distal attachment inserts directly to the bone of the proximal phalanx (plantar surface). Plantar plate thickness is 2-5mm and its width is 8-13mm. Fig. 1 on page 13

To obtain a good diagnostic MR images of the plantar plate, a 2-3mm slices oriented perpendicular to the axis of the plate should be taken, with no gap. Images in T1, T2, GRE and a sequence with fat saturation on the three planes, with a small FOV are recommended. Fig. 2 on page 13  Fig. 3 on page 14

Extrinsic and intrinsic musculature of the foot provide dynamic stabilization.

Other stabilizing structures are, collateral ligaments, the flexor digitorum longus and brevis tendons and the extensor hood and sling.

The deep transverse intermetatarsal ligament avoid the separation of metatarsal heads and helps to maintain the plantar arch, as plantar aponeurosis does.

Intermetatarsal bursae lie between the MTP joints, dorsally to the deep transverse intermetatarsal ligament. Bursae between the second and third, and third and fourth digits extend about 1 cm distal to this ligament, but there is no extension of the bursa in the other web spaces.

Between the deep transverse intermetatarsal ligament and intermetatarsal bursae there is the neurovascular bundle, where Morton’s neuroma arise from.

CAUSES OF METATARSALGIA Fig. 4 on page 15

TRAUMA & MICROTRAUMA

1. Stress fractures Fig. 5 on page 16
A stress fracture is an overuse injury that commonly affects runners, dancers and military recruits. Steroids therapy, metabolic disorders or other systemic factors may be predisposing factors as well.

The diaphysis of the second metatarsal bone is more prone to suffer a stress fracture because of its rigid location. It can also affect the sesamoid bones and at the synchondrosis among the portions of a bipartite sesamoid bone.

It manifests as pain that can be accompanied by swelling and warmth on the affected area.

X ray may be negative initially but follow-up films will demonstrate callus formation. Radiographically occult fractures can be accurately detected with MR imaging. The early stage presents as bone marrow edema, hypointense on T1WI and hyperintense on T2WI. After that, appears a hypointense fracture line surrounded by marrow edema, hypointense on T1WI and hyperintense on fluid-sensitive MR imaging sequences.

2. Sesamoiditis Fig. 6 on page 17

Sesamoiditis is caused by repetitive trauma to the plantar aspect of the forefoot.

MR should be done if suspected. Its features include an increased signal intensity of bone marrow of the sesamoid bone (usually both) on STIR images, and a normal or decreased signal intensity on T1WI. Reactive soft-tissue abnormalities (bursitis, synovitis) are commonly associated.

3. Tendon disorders

Tenosynovitis can be secondary to inflammatory disease, mechanical irritation or infection. It causes forefoot tenderness and pain, and the tendons of the first toe are the most commonly involved.

US reveals tendon sheath widening, often filled with fluid, and loss of the tendons margins and of their normal fibrillar echotexture.

On MR there is a fluid signal distention of the tendon sheath and pathologic enhancement of the sheath after contrast administration.

Tenosynovitis may lead to tendon degeneration and rupture. Rupture is seen as a discontinuity of the tendon fibers and edema. Partial ruptures appear hyperintense on T1, DP and occasionally T2 WI.

INSTABILITY
1. Plantar plaque degeneration/rupture

Plantar plate lesions occur with the hyperextension of the toes by acute or repetitive microtrauma. The hallux valgus deformity, a long secondary ray and the use of high-heeled shoes are predisposing factors because they lead to an altered weight-bearing.

Women and athletes are commonly affected.

Patients complain that the affected toe "feels as though it is trying to go out of position", and present with pain distal and plantar to the metatarsal head. On physical examination, a submetatarsal callus and subluxation of the MTP joint may be seen. Plantar lesions use to occur in the second MTP joint.

X-ray will help to assess about the biomechanics of the feet, and if arthropathy, fracture or other alterations are present.

Sonographically, plantar plate ruptures appear as hypo-anechoic defects, that typically involve its phalangeal attachment, so the plate looses its normal homogeneous hyperechoic appearance. Plantar plate irregular thickening and heterogeneity are US features of degeneration. Fig. 7 on page 18

MRI demonstrate a discontinuity and associated increased signal intensity at the plantar plate attachment onto the proximal phalangeal base on T2 WI. With degeneration or rupture, the plaque becomes thicker. The high signal intensity zone at the distal insertion of the plantar plate becomes longer. Fig. 8 on page 19, Fig. 9 on page 20

Some associated findings are osteophytes, synovitis of the adjacent joint and tendon, subluxation of the flexor tendon (if full-thickness tear) and hyperextension of the proximal phalanx.

2. Osteoarthritis

Osteoarthritis of the forefoot is common in the first MTP joint and in the hallucal sesamoid articulation. It is produced by repetitive loading injury, often over an altered biomechanics of the foot (Hallux valgus the most common).

It clinically presents with painful limitation of motion.

It is diagnosed by X-ray, although seen often in an MR study performed for another reasons.

Joint space narrowing, osteophytes, subcondral cysts and sclerosis are characteristic features of osteoarthritis.
FREIBERG INFARCTION

Freiberg infarction is the term used for osteonecrosis of the head of the metatarsal bones (MB), which affects especially the second one. It is characterized by collapse of the subcondral bone, osteonecrosis and cartilaginous fissures.

Its etiology remains unclear, but it is thought to be multifactorial, probably by a combination of a traumatic insult and vascular compromise in a patient with predisposing factors. Those may be the use of high-heeled shoes, repetitive stress, steroids...

It is more frequent in women and young adults whose main complaint will be pain and limitation, although symptoms may not appear until osteoarthritis has established.

The best imaging modality to diagnose acute Freiberg infarction is MR, while delayed phase can be diagnosed by X-ray.

Early MRI findings include low-signal intensity on T1-WI of the metatarsal head and high-signal intensity on T2-WI and STIR images, which are nonspecific findings. On late phase of the process, the metatarsal head appears flattened and collapsed, with low-signal intensity on both T1 and T2-WI that reveals sclerosis. A fracture line can also be seen. Fig. 10 on page 21, Fig. 11 on page 22

This phase can also be diagnosed on X-ray, that demonstrates the metatarsal head collapsed with sclerosis and reduced articular space. Osteoarthritis features will add in the final stage.

SOFT TISSUE MASSES

1. Bursitis Fig. 12 on page 23

Intermetatarsal bursitis may be caused by trauma, infection, and inflammatory processes. However, instability and excessive weight-bearing stress (high-heeled shoes) are contributors.

Bursitis present as a well-defined fluid collection, located at pressure points, hypointense on T1WI and hyperintense on fluid-sensitive MRI sequences. They show peripheral enhancement after contrast administration.

It must bear in mind that bursae with a transverse diameter less that 3mm may be physiologic.

Bursitis often coexist with Morton’s neuroma and other disorders that diminish the intermetatarsal space.
2. Morton´s neuroma Fig. 13 on page 24

Once believed to be true neoplasms, currently are considered benign lesions secondary to chronic nerve entrapment that lead to perineural fibrosis and neural degeneration. Its usual location is in the third intermetatarsal web space.

Patients complain of intermetatarsal pain, often electrical or throbbing, that radiates to toes, although they may be asymptomatic as well.

High-heeled shoes are predisposing factor, as well as any disorder that narrows the intermetatarsal space (biomechanical or anatomic). Thus, women are more frequently affected.

On US, a reduced intermetatarsal space is seen, which is occupied by an hypoechoic mass, that is usually well circumscribed.

MR images demonstrate a rounded or teardrop shaped soft tissue mass that projects inferiorly into the plantar subcutaneous fat, iso-intense on T1WI. Signal intensity on T2WI is usually low, but it depends on how fibrotic it is; the more fibrotic, darker appears.

Gadolinium is not needed, but if administered, Morton´s neuroma usually enhances, although its enhancement depends on how fibrotic or cellular it is. The differential diagnosis include the truth interdigital neuroma, intermetatarsal bursitis and the synovial cyst (they all appear hyperintense on T2WI).

3. Ganglion cysts

Ganglia are the most common soft tissue masses of the foot. They are synovial cysts, probably secondary to repetitive trauma which leads to mucoid cystic degeneration.

They are typically located dorsal to metatarsalphalangic joints and tendons.

On US they appear as rounded or polilobulated anechoic masses, well circumscribed, arising from tendons or joints. On MRI ganglia show homogeneous high signal intensity on T2WI and STIR images. Their signal intensity on T1WI depends on their protein content, and range from low to intermediate. Contrast is not needed for their diagnosis, but if administered, peripheral rim enhancement may appear.

4. Giant cell tumor

Giant cell tumor of the tendon sheath is a localized and extra-articular form of pigmented villonodular synovitis.

Usually a painless mass, when it hurts is because of its mass effect.
US shows solid, homogeneous masses, with vascularity; nonspecific findings.

On MR it appears as a lobulated mass in close relation with the tendons or joints, with intermediate-low signal intensity on both T1W, GRE and T2W images as a result of hemosiderin content. After contrast is administered, a strong homogeneous enhancement appears.

5. Plantar fibromatosis Fig. 14 on page 25

Plantar fibromatosis is a benign and localized fibrous proliferation of the plantar aponeurosis, usually in the superficial and medial aspect.

Men are most commonly affected, and it is bilateral in 20-50% of cases. It has been associated with alcoholism, Diabetes Mellitus and smoking cigarettes among others.

Clinically, it manifests as subcutaneous nodules, that may be painful if located in a weight-bearing area.

Usually ultrasound is enough for the diagnosis. It appears as a fusiform hypoechoic or heterogeneous mass in the middle or distal plantar fascia.

MR images display an infiltrative and nodular mass that grows along the aponeurosis, with low to intermediate signal intensity on T1WI and low signal on T2WI. Contrast enhancement is variable.

6. Adventitial bursitis/ callus Fig. 15 on page 26

Adventitial bursae are acquired bursae secondary to excessive friction between soft tissue and underlying bone protuberances. Repetitive stress and biomechanic alterations contribute to their development. The fat pad may be warm, with point tenderness and a palpable mass.

Adventitial bursitis may be contiguous with the skin or with flexor tendon sheath, or continuous from one to the other.

There is a wide spectrum of US findings; from a focal well-defined anechoic area to broad ill-defined geographic areas or heterogenous collections. Doppler signal can demonstrate hyperemia.

On MR, well-defined bursitis follow the signal of fluid on all pulse sequences.

Ill-defined signal alterations in the fat pad are common and less likely to be symptomatic than well-defined bursae, especially if they are located under the first and fifth MTP joints.
With time, adventicial bursitis become more fibrotic and their signal intensity drops on T2 and STIR images. These are the features of calluses, that may enhance following the administration of contrast.

7. Foreign body granuloma

It is a nonspecific mass, usually heterogeneous, so the history of previous trauma or the visualization of the foreign body will be the key for the diagnosis.

Ultrasonographically it manifests as a ring-like reactive lesions surrounding the foreign body (not always seen).

MRI show lesions with low signal intensity on T1WI and high signal intensity on T2WI, surrounded by inflammatory tissue. Areas of low signal intensity may be seen on T2 within the mass, corresponding to fibrosis. Contrast administration enhances the periphery.

Sometimes it is possible to visualize the foreign body, hypointense in all pulse sequences.

One should consider that a granuloma may become infected.

8. Soft tissue neoplasms Fig. 16 on page 27

The most common benign soft tissue masses of the foot are nerve sheath tumors (schwannoma and neurofibroma) and lipomas. Lipomas follow the same signal intensity of fat in all pulse sequences.

US of nerve sheath tumors reveals a well defined hypoechoic mass with variable posterior acoustic enhancement and Doppler helps to distinguish them from cystic lesions.

The features of nerve sheath tumors on MRI are nonspecific. Schwannomas use to appear as a well defined lesion, with intermediate signal intensity on T1WI and increased signal intensity on T2WI.

Neurofibroma is a fusiform lesion that can not be separated from the nerve, so its resection requires sacrificing the nerve. Combination of target sign and central enhancement suggests neurofibroma.

Among malignant tumors, we will find more commonly synovial sarcoma in patients under 45 years old, and malignant fibrous histiocytoma or synovial sarcoma in those over 45 years old.

Synovial sarcoma appears as a lobulated heterogeneous mass with fluid levels.

Metastases are very rare.
INFLAMMATORY PROCESSES

The most common inflammatory diseases that affect feet are rheumatoid arthritis, psoriasis and gout.

Rheumatoid arthritis affects middle-aged women, and manifests as pain, stiffness and swelling of the joints. MTP joints are typically affected, and bilateralism is a common feature.

X-ray characteristic features are narrowing of joint space, periarticular osteopenia, juxtaarticular bony erosions, subluxation and gross deformity and periarticular soft tissue swelling.

Although unnecessary most of the times, MRI is useful to determine the extent of the disease and to evaluate the pannus, in order to choose the best therapy. MR features of the disease include erosions, cartilage thinning, subchondral cysts and marrow edema, joint effusion, intra-articular rice bodies, tenosynovitis and bursitis.

Inflammatory pannus is well seen on MRI, showing low-intermediate signal intensity on T1WI and variable signal intensity on T2, appearing hyperintense when the disease is active (synovitis), and hypointense with chronicity (hemosiderin deposits). It avidly enhances after contrast administration when active.

Psoriasis. This autoimmune disease use to appear for the first time as cutaneous lesions in young patients. Psoriatic arthropathy presents in a small percentage of psoriatic patients. Interphalangeal and MTP joints may be involved, usually simetric and bilaterally. The MRI features of psoriatic arthropathy include synovitis, tendonitis, dactylitis, bone edema, bone erosions and soft tissue edema.

Gout is the result of the deposition of sodium urate crystals.

Patients have high levels of uric acid on blood. They present with monoartritis of acute onset, and may repeat the episode during their lives.

It is important to integrate imaging findings, laboratory tests and clinical history and examination in order to avoid misdiagnosis.

It typically affects the first MTP joint. Acute phase imaging findings are nonspecific, and include joint effusion and synovial thickening which can be identified on US or MR. Tophy are the characteristic manifestation of the chronic phase, which appear as peri or intra-articular soft tissue masses that may erode bone. They show low signal intensity on T1WI and variable intensity on T2WI, although hypointense most of cases.
INFECTION

Osteomyelitis usually occur in diabetic patients, as a result of transcutaneous spread of infected cutaneous ulcers, which use to develop under the first and fifth metatarsal heads.

MR will be the most sensitive and specific imaging technique. Bone marrow appears hypointense on T1WI and hyperintense on T2WI and STIR images, and enhances after contrast administration. Cellulitis, sinus tract, a disrupted cortical or abscess may be useful to distinguish infection from neuropathic disease.

Septic arthritis is also most commonly seen in diabetic patients. It results from the spread of an infection in an adjacent soft tissue or bone.

MRI findings are nonspecific, and include joint fluid and synovial thickening which enhances with contrast administration, as well as changes in bone marrow of osteomyelitis.

BONE TUMORS Fig. 17 on page 28

Bone tumors of the feet are uncommon and because of this, its epidemiology is not well known. Benign are much more common than malignant, and the metatarsal bones are the most affected bones.

The most common benign bone tumors are giant cell tumor, osteochondroma and enchondroma, while among malignant, are chondrosarcoma, osteosarcoma and Ewing sarcoma. Metastases are rare, and usually secondary to lung, kidney and colon cancer.

When they develop, they cause pain and swelling even though small, due to the small size of the bones and the little space they have to grow without compress surrounding structures.

X-ray should always be performed when a bone tumor is suspected or detected, it assess about the aggressiveness of the lesion. MRI will be useful for tumor detection and staging.
Images for this section:

- 13-15MHz probe
- Patient in prone position
- Plantar approach
- Pressure manually applied from the opposing surface to separate the metatarsals and dynamically evaluate the compressibility of tissues

Plantar plate is the main structure for the stability of MTP joint.

Longitudinal sonogram shows the plantar plate (arrowheads) between the flexor tendon (orange arrow) and the metatarsal head (MB). It is slightly hypechoic and homogeneous grainy. Note its attachment to the phalanx (small arrowhead). In axial the plantar plate lies between the tendon and the metatarsal head. The hypoechoic line under the plate corresponds to hyaline cartilage.

Fig. 1: Fig 1.

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**Fig. 2:** Fig 2.

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Intermetatarsal bursae lie between the MTP joints, dorsally to the deep transverse intermetatarsal ligament. Between the deep transverse intermetatarsal ligament and intermetatarsal bursae there is the neurovascular bundle.

**Fig. 3:** Fig 3.

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Fig. 4: Fig 4.

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Patient with an old stress fracture on the 2nd metatarsal bone that presents with pain on the 3rd. T1WI demonstrates the callus (*) on the 2nd MB. The 3rd MB presents a low signal intensity line on STIR image surrounded by affected adjacent bone marrow, hypointense on T1WI and hyperintense on fluid-sensitive MR imaging sequences. Notice the soft tissue edema on STIR image.

Fig. 5: Fig. 5

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Bipartite lateral sesamoid bone (arrows) with low signal intensity on T1WI and high signal intensity on STIR. The absence of hypointensity on T2WI rules out osteonecrosis and suggests sesamoiditis.

Sesamoiditis commonly associates reactive soft-tissue abnormalities.

Fig. 6: Fig. 6

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On axial: complete plantar plaque rupture (arrow) with flexor tendon luxation associated.

On longitudinal: Hypoechoic area because of the absences of distal plaque on its attachment to phalanx, which is luxated dorsally. Note the echostructure of normal plaque (†).

Associated findings: osteophytes, synovitis of the adjacent joint and tendon, subluxation of the flexor tendon (if full-thickness tear) and hyperextension of the proximal phalanx.

**Fig. 7:** Fig. 7

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Fig. 8: Plantar plaque disruption with proximal phalanx luxated dorsally.

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MR demonstrates mildly increased signal intensity at the lateral aspect of the plantar plate on T2 WI which is heterogeneous on T1WI, corresponding to a degeneration of the plantar plaque.

US features of degeneration of the plantar plaque, that appears heterogeneous and hypoechoic (arrow)

**Fig. 9:** Fig. 9

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Fig. 10: Freiberg of the 2nd MB. Appreciate high signal intensity on STIR and hypointensity of bone marrow on T1WI due to edema. On sagital image, mild flattened MB head (orange arrow).

Same patient. RX shows a subcondral sclerotic line (orange arrows). Articular space still preserved.

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Fig. 11: Different patient. Late phase. Metatarsal head collapsed with low-signal intensity on both T1 and T2-WI that reveals sclerosis and reduced articular space. Note the rupture of the plantar plate (arrow). Synovitis and joint effusion associated (+). Osteoarthritis features will add in the final stage.

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Fig. 12: Fig. 12

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Morton’s neuroma in the 3rd intermetatarsal space. Teardrop shaped soft tissue mass that projects inferiorly into the plantar subcutaneous fat, iso-intense on T1WI and hypointense on T2WI. Intermetatarsal bursitis (orange arrow) associated, a common finding.

US (different patient). Hypoechoic mass occupies the intermetatarsal space. The image on the right, demonstrates a normal intermetatarsal web space is shown.
Plantar Fibromatosis (orange arrows). US reveals a fusiform iso-hypoechoic mass, arising from the normal plantar fascia (★) MR (different patient). Iso-intense nodular mass that continues with plantar fascia on T1WI. The mild hyperintensity within the lesion on T2WI reveals high cellularity (fibroblast), so the lesion is forming.

**Fig. 14:** Fig. 14

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Adventitial bursitis. Ill-defined heterogeneous geographic area located between the metatarsal bone and the skin (pressure point), with hyperemia shown by Doppler on the right image. Note the hyperkeratoses of the skin (▼).
Schwannoma (histologically proven) adjacent to MTP joint of the 4th toe. US reveals it is a solid lesion, mildly heterogeneous. Doppler demonstrates high vascularization. MRI shows a well defined lesion, with intermediate signal intensity on T1WI and increased signal intensity on T2WI with foci of intermediate signal intensity. The adjacent bone is not affected, nor eroded.

**Fig. 16:** Fig. 16

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Encondroma of the 3rd MB. Lytic medullary bone lesion with well-defined sclerotic margins and endosteal scalloping that insuffates diaphysis. It appears hypointense on T1 and highly hyperintense on T2 with septa. T1 WI after contrast administration shows enhancement of the septa and at the periphery of the lesion. No ossification of chondroid matrix is seen, as usually in hands and feet.

**Fig. 17**: Fig. 17

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Conclusion

Metatarsalgia is a common clinical problem produced by many disorders that radiologist should be familiar with.

The combination of clinical data and imaging findings can provide specific diagnosis that will be important in the management of the patient.
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