MRI AND DIFFERENTIAL DIAGNOSES OF PAIN AROUND THE MID- AND FOREFOOT

A PICTORIAL OVERVIEW WITH A FOCUS ON ATHLETES

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Pain in the mid- and forefoot in athletes may have a variety of causes, which often cannot be reliably distinguished by means of history and clinical examination. Therefore MRI plays an important role in the differential diagnosis (Figure 1). The most common causes of pain are stress reactions (bony microtrauma only discernible by MRI) and stress fractures, degeneration and tears of the plantar plate and Morton's neuroma. At the metatarsophalangeal joint of the great toe, inflammatory flares of pre-existing joint degeneration are commonly observed, especially in runners and tennis players. Gout is a condition also oberved in younger patients, including athletes. Somewhat less common causes of pain in the mid- and forefoot include arthritides of the metatarsalphalangeal joints (for example in rheumatoid arthritis), intermetatarsal bursitis, subchondral insufficiency fractures and necrosis of the metatarsal heads, as well as fractures or necrosis of the sesamoid bones.

In some cases, patient history and symptoms alone may allow a definite diagnosis without the use of MRI. However, even in these cases MRI may add important information, enabling visualisation of the extent of pathological changes, which directly impacts on therapeutic management and prognosis.

TECHNICAL CONSIDERATIONS

The basis of an MR protocol for optimised assessment of the mid- and forefoot includes fat-suppressed water-sensitive sequences (proton density or intermediate-weighted sequences) in at least two planes and one T1-weighted sequence usually in the sagittal plane or adapted to the pathology of interest. Additional contrast-
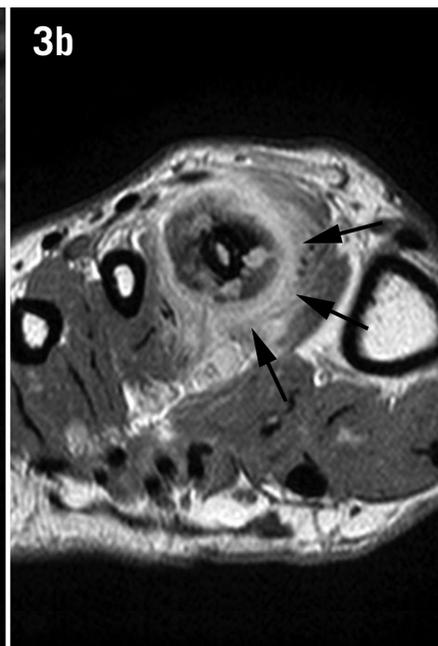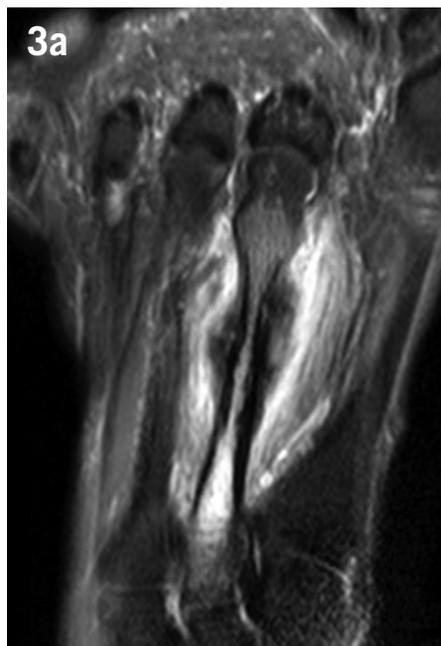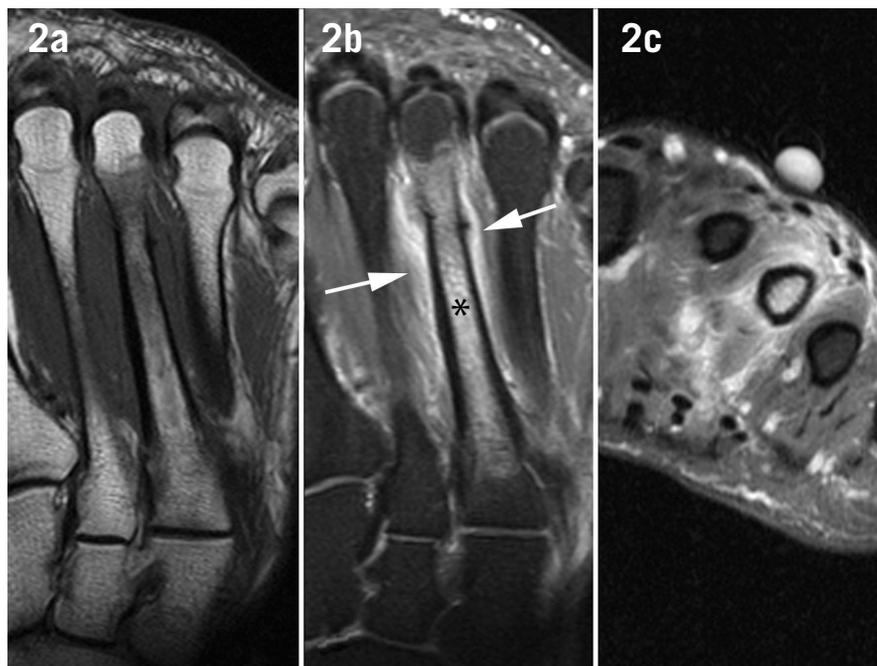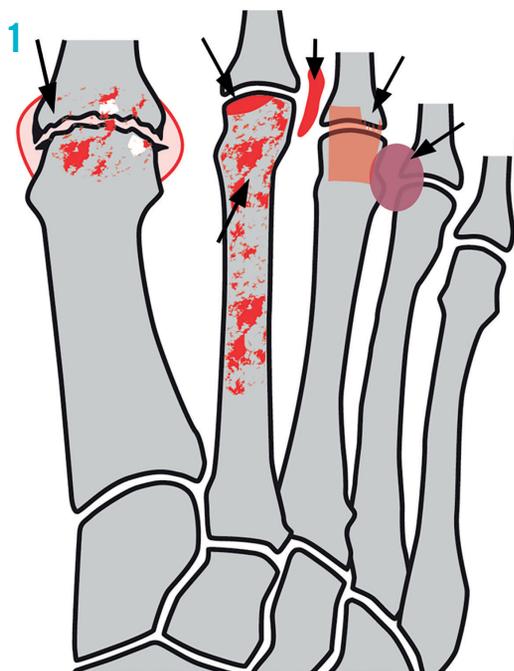
Figure 1: Differential diagnosis of metatarsalgia. Important causes of pain are degenerative joint disease with activation (1), stress reactions (2) with possible collapse and necrosis (3), intermetatarsal bursitis (4), degeneration or tear of the plantar plate (5) and Morton's neuroma (6).

Figure 2: Stress reaction without fracture line of the third metatarsal with only moderate signal alteration in T1 (a) but intense high signal in the bone marrow (asterisk in b) and the surrounding soft tissues (arrows in b) in fluid-sensitive intermediate-weighted fat-suppressed sequences (b,c).

Figure 3: Chronic stress reaction. Intense callus formation and pronounced oedema-like signal alterations are seen in the bone marrow and soft tissues (a, proton-density-weighted fat-suppressed image). The oedematous tissue shows marked contrast enhancement (b, axial T1-weighted fat-suppressed image, arrows).

enhanced sequences may be applied to further characterise the nature and extent of inflammatory or neoplastic entities.

FINDINGS

Stress reactions and stress fractures

History and symptoms are usually sufficient to raise the suspicion of pathologies related to biomechanical overload. These may be visualised using MRI but are not necessarily seen on conventional radiographs. The role of MRI is to distinguish whether the condition is consistent with a stress reaction (depicted as diffuse bone marrow oedema) or whether a fracture has already occurred (Figure 2). In case of worsening or an inadequate healing response, MRI may be helpful to rule out the development of a fracture in areas of stress reactions or to exclude non-union in cases of existing stress fractures (Figure 3). Both unfavorable outcomes may also be confirmed or excluded by a state-of-the-art multi-detector CT.

A stress fracture that is the result of overload on a normal, healthy bone is also called a 'fatigue fracture'. The diagnosis of a stress fracture becomes much more challenging when the patient cannot recall an obvious reason for the overload and only detailed investigation may reveal the mechanism. Typical reasons for pathological loading are new footwear, insoles or altered course of movement due to pain in other joints. Also stress fractures at atypical sites my cause diagnostic problems (Figure 4).

In contrast to fatigue fractures, the term 'insufficiency fracture' is used for fractures caused by physiological loading of a mechanically insufficient bone. It often affects elderly patients with generalised osteoporosis or patients with inactivity osteopenia after a prolonged period of rest, or unloading, as may be encountered in a post-surgical setting in athletes. However, insufficiency fractures may also occur with unknown etiology and may therefore be called 'idiopathic' (Figure 5). In most cases,
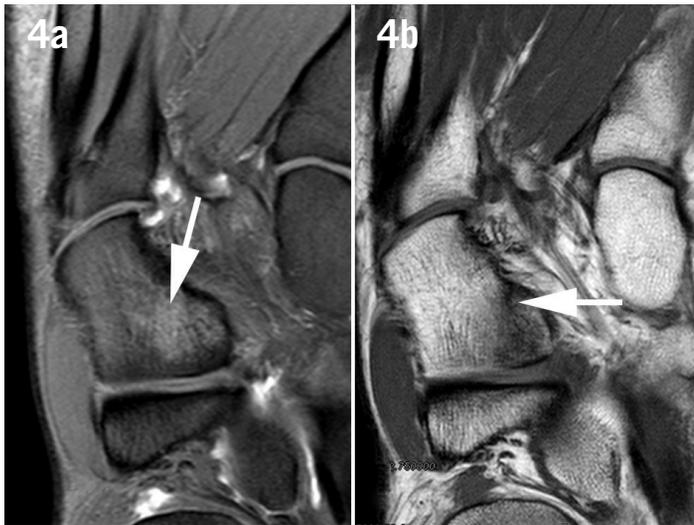
Figure 4: Less common site of a stress fracture in the cuboid bone. Proton-density-weighted fat-suppressed image (a) shows only minor hyperintense signal alterations (arrow). However, a fracture line is visible in T1 (b).
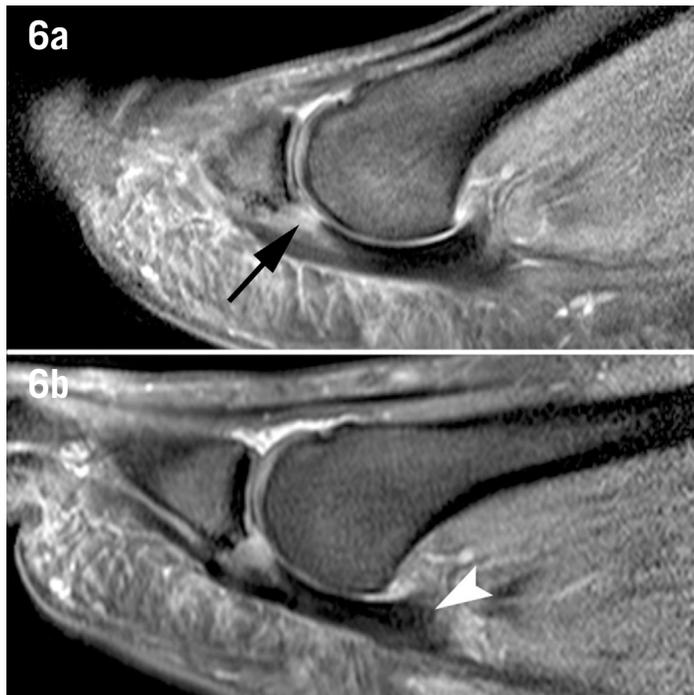
Figure 5: Stress reaction of unknown origin in multiple metatarsal bones (arrows) and surrounding soft tissues. History did not reveal unusual load. These findings are likely due to idiopathic insufficiency fractures of the trabecular bone.

Figure 6: Typical site for a tear of the plantar plate at its distal insertion (a, arrow). Six months later (b) there is still no sign of healing. In contrast, the plantar plate shows increasing dislocation towards the midfoot (arrowhead).

they are located in the trabecular bone or in the subchondral bone adjacent to joint surfaces. Early diagnosis is paramount to reduce loading and avoid the the risk of cortical fracture, collapse and possible necrosis[1].

Degeneration and tear of the plantar plate

On the plantar side, the joint capsules of the metatarsophalangeal and interphalangeal joints have strong fibrocartilaginous reinforcements that are called the 'plantar plates'. Adjacent plantar plates are interconnected by the deep transverse metatarsal ligaments, which merge with the plantar plates on their medial and lateral borders.

On their plantar aspect, the flexor tendon sheath fuses with the plantar plate. Degeneration or tear of the plantar plate will cause dorsal joint instability.

Tears commonly occur at the distal insertion of the plantar plate of the metatarsophalangeal joints (Figure 6), less commonly at the level of the metatarsal heads. The lesions may be focal, affect large parts of or the entire plantar plate with or without involvement of the collateral ligaments[2]. Of the lesser toes, the second is the most common site for plantar plate injury, somewhat less frequently the third toe is involved. Plantar plate tears are very uncommon in the fourth and fifth toe.

Tears of the plantar plate often cause intense soft tissue reaction, which should not be misinterpreted as Morton's neuroma (Figure 7)[3]. They may also induce formation of a neo-bursa (Figure 8).

The interpretation of imaging findings at the metatarsophalangeal joint of the great toe with its distinct anatomy may be challenging. In this location the sesamoids, the intersesamoid and the sesamoid-phalangeal ligaments reinforce the plantar joint capsule. The fibrocartilaginous plantar
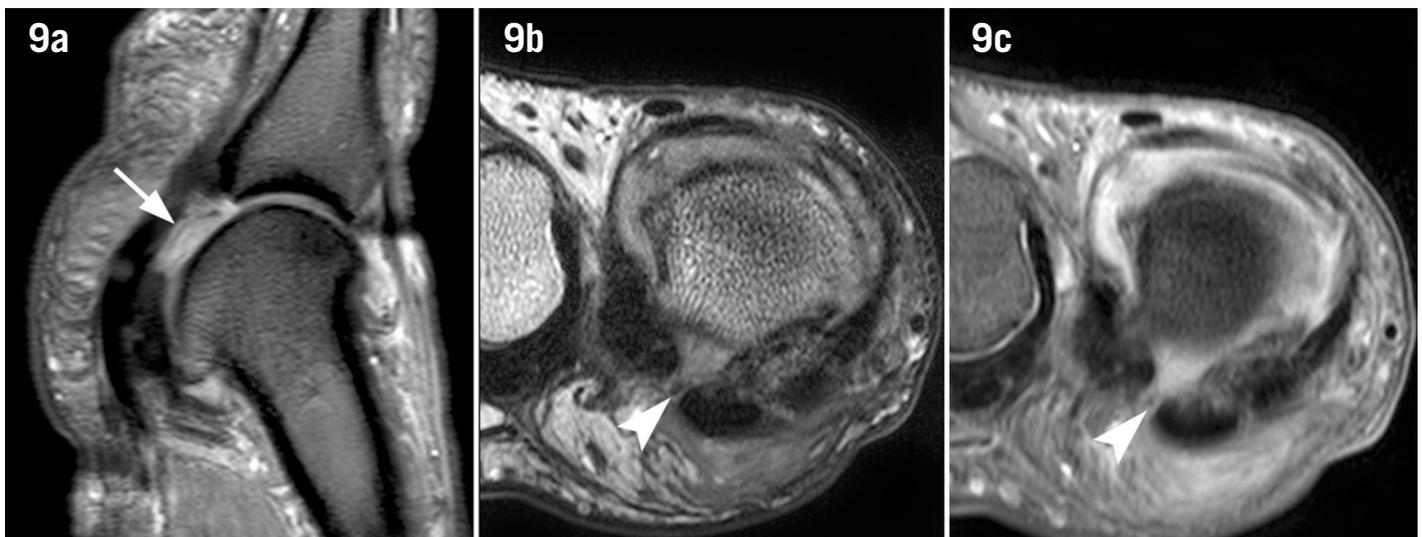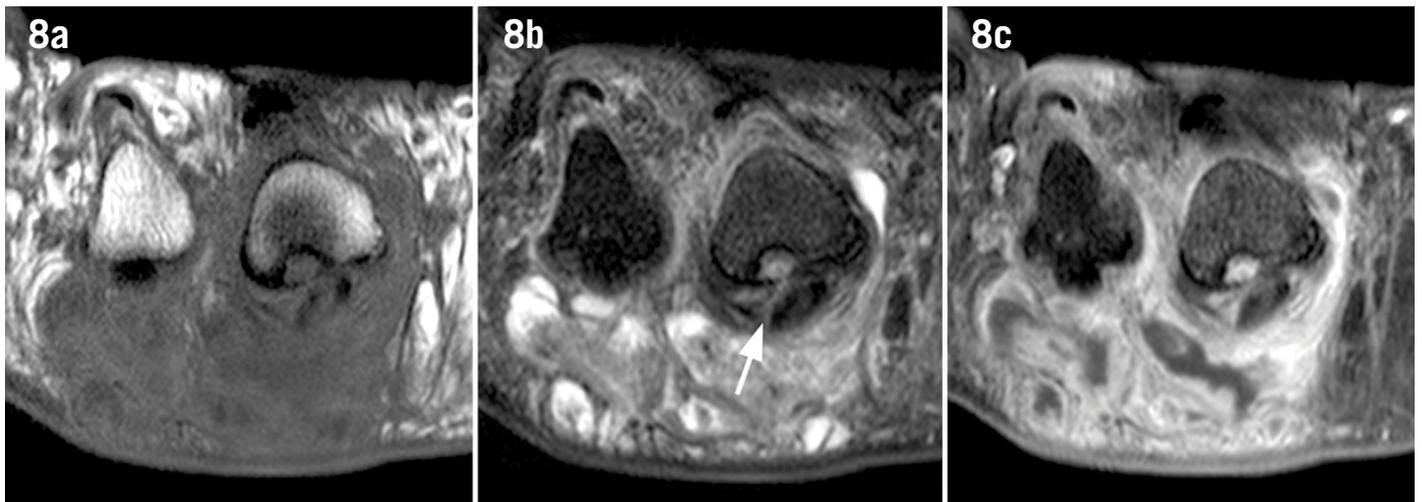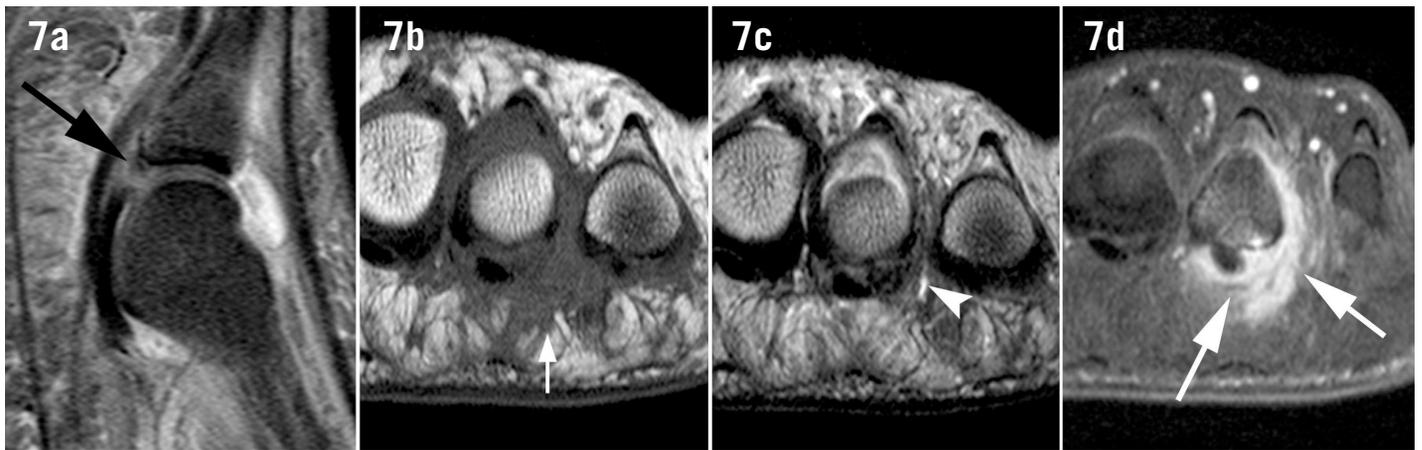
Figure 7: Tear of the plantar plate at the typical location (a) sagittal proton-density-weighted fat-suppressed image (arrow). T1-weighted sequence (b) shows a soft tissue mass, resembling a Morton's neuroma at a first glance. More detailed evaluation reveals the nerve and vessel bundle, which is not running through the mass, being displaced to the plantar side (arrow). In addition, the small fluid collection in the center of the mass (c, T2-weighted sequence, arrowhead) is not typical for a Morton's neuroma. Contrast administration (d, T1-weighted fat-suppressed image) shows intense enhancement (arrows) and the association to the plantar plate tear.

Figure 8: Formation of an extended neo-bursa in the soft tissues in the setting of a plantar plate tear at the second toe (arrow in b). (a) T1-weighted image. (b) T2-weigthed fat-suppressed image. (c) T1-weighted fat-suppressed image after intravenous contrast administration.

Figure 9: Sagittal proton-density-weighted fat-suppressed image. (a) demonstrates a tear of the plantar plate at the great toe (commonly called 'turf toe', arrow). Short axis T2 (b) and proton-density-weighted fat-suppressed images. (c) shows a defect between the distal poles of the sesamoids representing a tear of the inter-sesamoid ligament (arrowheads).
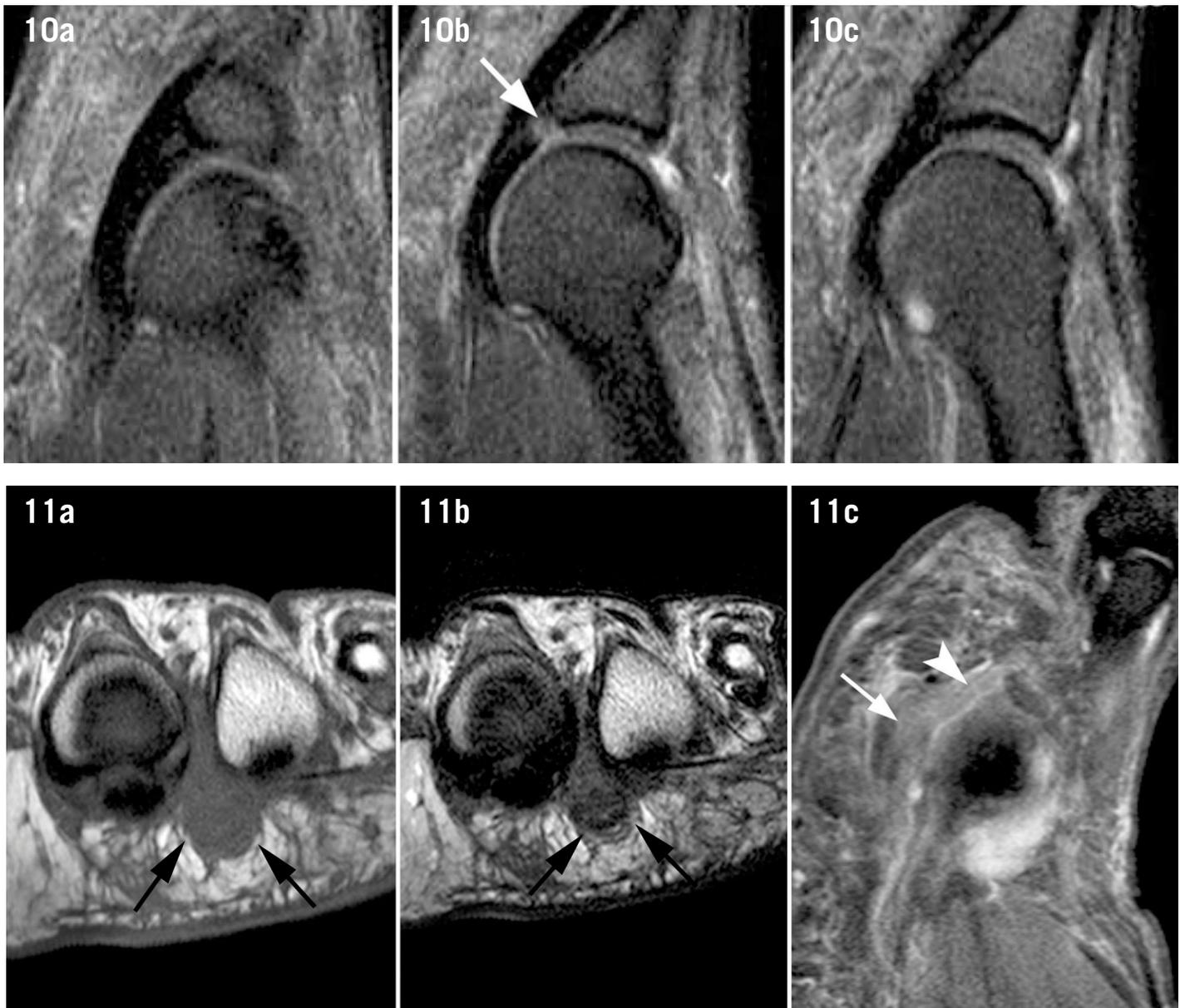
Figure 10: Sagittal proton-density-weighted fat-suppressed image in the medial and lateral aspects of the plantar plate (a, c) show an unremarkable signal void of the distal insertion. The small fluid collection in the midline of the toe (b, arrow) represents a physiologic recess.

Figure 11: Morton's neuroma in the second intermetatarsal space with a typical teardrop shape (a, T1-weighted image, arrows). T2-weighted image (b) shows characteristic low signal caused by the high connective tissue content (arrows). The sagittal proton-density-weighted fat-suppressed image (c) depicts the exiting nerve (arrow) visible at the distal pole of the mass (arrow).

plate distal to the sesamoids is only very thin. Injuries of these plantar capsular structures are also termed 'turf toe' (Figure 9).

In the midline of each toe a small joint recess is present at the distal insertion of the plantar plate (Figure 10), which should not be mistaken for a tear[4,5]. Tear of the plantar plate always involves at least the medial or lateral component.

Morton's neuroma

The term Morton's 'neuroma' is outdated and misleading, as these findings are not caused by nerve or nerve sheath tumors but represent perineural fibrosis. As the interdigital nerve and vessle bundle enters and exits the lesion, the mass resembles a tumor originating from the nerve itself. This paper will nonetheless use the same terminology as it is still commonly used by clinicians and facilitates communication, however, being fully aware of the misnomer.

The typical teardrop shape (Figure 11) and the location in the intermetatarsal space at the level of the metatarsal heads are characteristic Morton's neuroma findings. Due to the high content of connective or fibrous tissue they exhibit remarkably low signal in T2-weighted sequences. T1-weighted sequences show non-specific intermediate signal intensity of soft tissue. The amount of enhancement after intraveneous contrast administration is very variable and does not enable diagnostic conclusions.

With lateral compression of the foot, Morton's neuroma dislocate in a plantar direction. This phenomenon represents the so-called Mulder sign on clinical examination[6]. MRI may also profit from this effect to facilitate the depiction of Morton's neuroma: an examination with the patient

in a prone position, with the foot in plantar flexion and with additional lateral compression through fixation of a flexible coil will commonly delineate the mass and its shape in a characteristic fashion (Figure 12).

Morton's neuromas are almost always located in the second or third intermetatarsal space. Note that their size may be stable over years (Figure 13) and that small masses (less than 5 mm) are frequently encountered in asymptomatic individuals.

Examination after previous resection of a Morton's neuroma is particularly challenging, as post-surgical fibrotic changes are common and may look like recurrence of a Morton's neuroma. A reliable distinction of asymptomatic and symptomatic post-operative findings with imaging is not always possible[7].

Intermetatarsal bursitis

Small bursae are present between the metatarsal heads. Usually they are not depicted on MRI and only if they contain small amounts of fluid will they be distinguishable. However, as such these do not represent a pathological finding. Bursae filled with a larger amount of fluid, that exhibit definite peripheral enhancement after contrast administration, are signs of bursitis. Isolated intermetatarsal bursitis without additional pathology of the metatarsophalangeal joints is rare and should always raise the suspicion of an underlying rheumatoid disease (Figure 14). However, bursitis is a frequent concomitant finding in the setting of plantar plate degeneration or tear, as well as in cases of Morton's neuroma[8].

Sesamoids

Pathology of the sesamoid bones may cause serious forefoot pain in athletes. Differentiation of fractures from bipartite sesamoids is easiest with radiography. In the case of bipartite sesamoids the two parts are rounded and the two bony surfaces do not match in congruent fashion as is the case with fracture fragments. If MRI shows normal fat signal in both parts, a bipartite sesamoid may also be assumed. Low signal in T1-weighted images in one or both parts may indicate a stress reaction (Figure 15), necrosis in the setting of a bipartite sesamoid or non-union after a sesamoid fracture.
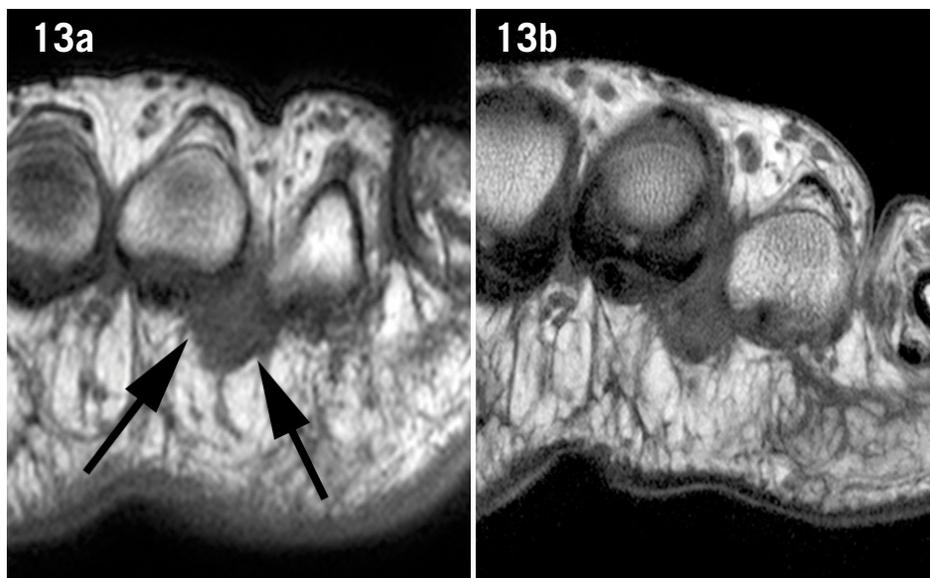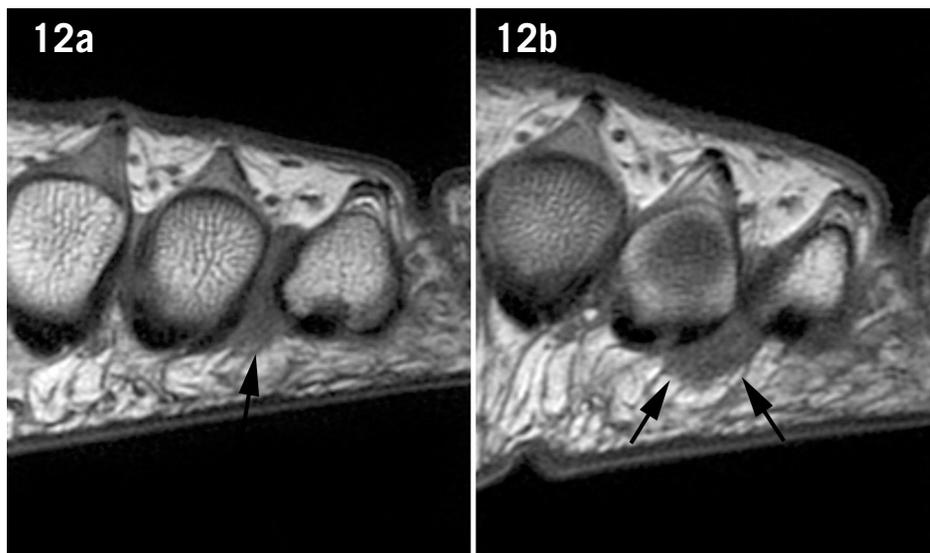
Figure 12: T1-weighted image of Morton's neuroma with the patient lying in the supine position and the foot being in neutral position (a, arrow). The mass is located between the metatarsal heads and its shape is not well depicted. With the patient in prone position (b), with additional plantar flexion of the foot and lateral compression; the mass is displaced with much better visibility of the characteristic shape (arrows).

Figure 13: Axial T1-weighted image of typical Morton's neuroma in the third intermetatarsal space (a, arrows). Six years later (b), absolutely identical findings are observed.

Inflammatory signal changes with and around the sesamoids that are often of unknown origin and are associated with pain, are considered to represent sesamoiditis[9,10].

Gout

As a rule of thumb, presentation of arthritis in a single joint in males raises the suspicion of gout, particularly if the first metatarsophalangeal joint is affected (Figure 16). Although MRI may only depict a non-specific inflammation and serum urate measurements are normal, the diagnosis should not be ruled out as serum levels of urate fluctuate, so may not be diagnostic.

Specific findings on MRI are commonly observed only in cases of chronic gout, with deposits of signal void crystals and formation of tophi. The latter often cause characteristic bony erosions distant from the joint surface, which are commonly recognised on radiography.

Degenerative osteoarthritis

Degeneration of the first metatarsophalangeal joint is extremely common and may also be observed in younger, active patients. However, even in the presence of MRI-depicted inflammatory activation, it is often asymptomatic. Metatarsalgia is not necessarily explained by these degenerative findings of the first metatarsophalangeal joint, and additional pathology – which could be much more relevant – may easily be overlooked. The distinction of asymptomatic and symptomatic conditions is not possible with MRI.

On the other hand, degeneration of the tarsal and the tarsometatarsal joints is often a cause of symptoms. MRI exhibits the classical findings of joint degeneration (narrowing of joint space, osteophyte formation, cyst formation, subchondral bone marrow lesions (Figure 17)) and regularly, signs of concomitant inflammation (joint effusion, synovitis, distension of the joint capsule).

The diagnosis is commonly established based on clinical findings and radiography. Tendinopathy of the distal tibialis anterior tendon (Figure 18), is a common differential diagnosis.
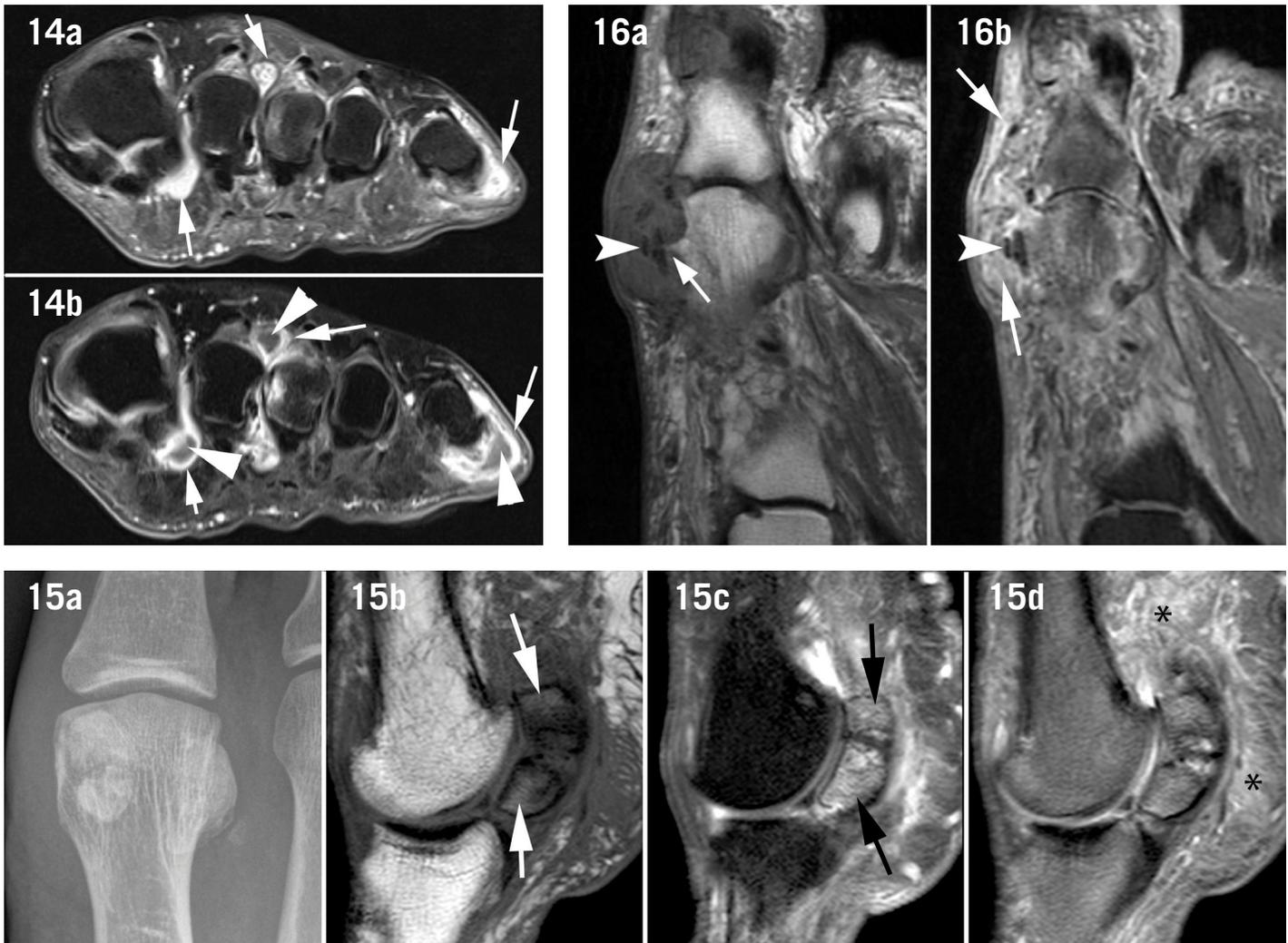
Figure 14: Intermetatarsal bursitis in rheumatoid arthritis. Proton-density-weighted fat-suppressed image shows fluid-equivalent signal (a, arrows). Only T1-weighted fat-suppressed image after contrast administration (b) depicts true amount of synovial imflammation (arrows) with fluid depicted as hypointensity (arrowheads).

Figure 15: Bipartite sesamoid (radiographic image in a) with intense chronic stress reaction. The relatively well-maintained fat signal on the T1-weighted image (b, arrows) and the intense contrast enhancement on the T1-weighted fat-suppressed image after intravenous contrast administration (c, arrows) are findings not favoring necrosis. The cystic changes and adjacent sclerosis demonstrate the chronicity of the lesion. Proton-density-weighted fat-suppressed image shows diffuse oedema in the adjacent soft tissues (d, astrisks).

Figure 16: Axial T1-weighted image shows charactersitic manifestation of gout at the great toe with spur-like bone proliferation (arrow in a) and a large surrounding tophus. Urate deposits are seen within the mass as areas of signal void (arrowhead in a and b). Image b represents a T1-weighted fat-suppressed image after contrast administration, which shows diffuse soft tissue enhancement (arrows).

SUMMARY

In summary, pathologies of the mid- and forefoot are relatively common and may cause considerable pain. The described entities are particularly relevant in patients who are active and subject their foot to considerable loading, such as athletes. Clinical manifestation and history commonly point towards the diagnosis, but MRI is a helpful adjunct tool in ruling out differential diagnoses and characterising the extent of the lesion.

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Figure 17: Tarsometatarsal joint degeneration at the first toe. T1-weighted sagittal image (a) shows narrowing of the joint space (arrows), small osteophyte formation and subchondral sclerosis (arrowheads). The proton-density-weighted fat-suppressed image (b) shows ill-defined subchondral bone marrow lesions, a characteristic sign of osteoarthritis (arrows).

Figure 18: Tendinopathy of the distal tibialis anterior tendon (arrows) may cause clinical symptoms similar to the degeneration shown in Figure 16. Proton-density-weighted fat-suppressed images in the coronal (a) and sagittal (b) plane are shown.

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