Unraveling the plantar plate in MRI: normal and pathologic findings

Desvendando a placa plantar na ressonância magnética: achados normais e patológicos

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ABSTRACT

The plantar plate (PP) is a fibrocartilaginous structure located below the metatarsal head, which plays an important role in the weight bearing transmission and stability of the metatarsophalangeal joints. The injury of PP is the main cause of metatarsalgia. This study shows normal and pathological findings in magnetic resonance imaging (MRI) suggestive of abnormalities of the PP. Abnormalities of the PP in MRI have been described only recently and they are often confused with bursitis or neuroma. The MRI is useful in the diagnosis of the PP injury in the initial stages of the process, helping the early diagnosis and avoiding delays by implementing specific treatment.

Keywords:

Plantar plate/anatomy & histology; Wounds and injuries/physiopathology; Metatarsalgia; Magnetic resonance imaging

RESUMO

A placa plantar é uma estrutura fibrocartilaginosa localizada abaixo da cabeça dos metatarsianos, que tem papel importante na transmissão de carga e na estabilização das articulações metatarsofalângicas, sendo que sua lesão é uma das principais causas de metatarsalgias. Nosso objetivo foi demonstrar os achados normais e patológicos por ressonância magnética sugestivos de alteração da placa plantar. As alterações da placa plantar por ressonância magnética só recentemente têm sido descritas e frequentemente são confundidas com bursites ou neuroma. A ressonância magnética é útil no diagnóstico das lesões da placa plantar nas fases iniciais do processo, auxiliando no diagnóstico precoce e evitando atrasos na instituição do tratamento específico.

Descritores:

Placa plantar/anatomia & histologia; Ferimentos e lesões/fisiopatologia; Metatarsalgia; Imagem por ressonância magnética

INTRODUCTION

The plantar plate (PP) is a fibrocartilaginous structure located beneath the metatarsal head, which plays an important role in load transmission and in stabilization of the metatarsophalangeal joints. Plantar plate injuries are one of the main causes of metatarsalgia.[1,2] However, PP abnormalities in magnetic resonance imaging (MRI) have only recently been described and are often confused with bursitis or neuroma.

This article was aimed at demonstrating the MRI findings suggestive of PP abnormalities. Clinical diagnosis of PP insufficiency is known to be difficult in the initial stages, since the symptoms may mimic other causes of metatarsalgia. Early diagnosis may avoid delays in specific treatment.[3,4]

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ANATOMY AND HISTOLOGY

The PP is a firm, flexible fibrocartilaginous structure that can reach 20mm x 9mm x 2mm (length x width x thickness).[1] It occupies a ventral and central position in the metatarsophalangeal joints. Proximally, it is thinner and loosely attached to the periosteum near the metatarsal neck. Distally, it is thicker and more firmly attached to the base of the proximal phalanx, becoming thinner in its central portion adjacent to the enthesis, where there is often a juxta-insertional groove. These findings are not to be confused with tears.[1]

The PP is suspended by the proper and accessory collateral ligaments, and interconnected laterally by the deep transverse intermetatarsal ligament. The interosseous tendons are located at the junction of the deep transverse ligament with the PP. The flexor tendon of the fingers is located on the lower border of the PP. Also, note that on the lateral borders of the distal insertion of the PP, this plate is closely entwined with the joint capsule, the proper collateral ligaments, and the interosseous tendons, which makes it hard to clearly distinguish between these structures in a routine examination. This anatomical unit, formed by the proximal phalanx, the PP and their insertional connections, is described as phalangeal apparatus, a term adapted by the authors and referred to herein as "plantar plate insertion complex", due to the difficulty in clearly distinguishing between the various structures in this topography in the MRI study.[5]

MECHANISMS OF INJURY OF THE PLANTAR PLATE

The PP is subject to tension and traction forces, mainly during ambulation, and any factor that results in excessive loads will initially lead to degeneration and, if the underlying cause is not corrected, to tearing, which may or may not be associated with injury to the capsule, the lateral collateral ligament and the homolateral interosseous tendon.

The main factor that leads to overloading of the small metatarsophalangeal joints and, consequently, of the respective plantar plates, is the mechanical failure of the first ray. When this failure occurs, the load will be transmitted in a greater degree to the adjacent metatarsal, i.e., to the second metatarsal. This explains why the PP of this joint is the most frequently injured; moreover, the second ray is less mobile and more susceptible to stress than the others, since its base lies within the furcula formed by the cuneiforms. The principal causes of insufficiency of the first ray are hallux valgus, short or hypermobile first metatarsal, lengthening of the second ray, and complications of trauma or surgery. Shoes with a narrow anterior base and a high heel can also contribute to uneven load distribution, increasing this load on the central rays.[6]

As mentioned above, plate injury is characterized by poor load distribution and excessive stress. Therefore, the injury will initially occur at the site bearing the greatest weight, i.e., at the distal enthesis. This fact, associated with physiological axial torsion of the metatarsals, which determines a supine angular orientation of the heads from the second to the fifth rays, means that the load is greater on its lateral border where tears are most frequent[7] (Figure 1).

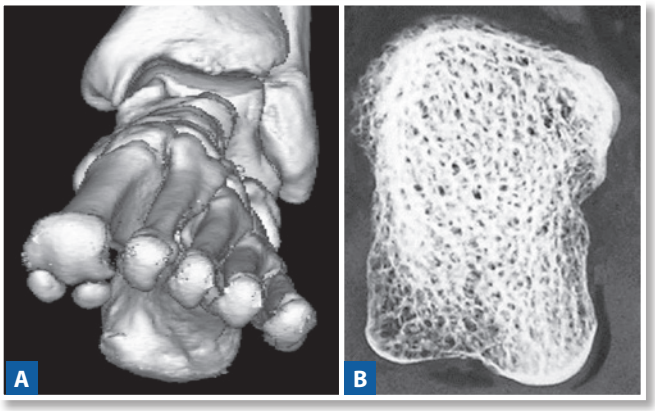

Figure 1 | (A) Physiological torsion of metatarsals. Three-dimensional tomographic reconstruction (B) Note the thickness of the trabeculae and subchondral cortex in the lateral segment of the second metatarsal head, indicating more load in this topography. Cross-sectional image of a second metatarsal head sample kindly provided by Dr. Donald L. Resnick.

There is initial alteration of the PP and of the adjacent capsule, with no tearing and possibly no signs of instability upon physical examination. However, this is usually painful, as there is an ancillary inflammatory process in the adjacent soft tissues. As the hyperextension forces persist, the insertion of the PP and of the capsule may become thin and insufficient, or even rupture, leading to instability of the metatarsophalangeal joint.[1] In this phase of instability, the inflammatory process in the adjacent soft tissues is usually more severe. Signs of overloading of the underlying plantar cushion are frequent and may be associated with joint effusion and flexor tenosynovitis. Dorsiflexion of the proximal phalanx and flexion of the distal phalanx ("claw toe") may also be evident, a finding which is better characterized upon physical examination. In cases where there is tearing or insufficiency of the lateral collateral ligament and/or of the associated interosseous tendon, there is dorsal displacement of the proximal phalanx in addition

to medial deviation of the toe, a condition known as crossover second toe.[8]

Although PP injuries occur more frequently in the second metatarsophalangeal joint, they may also occur in the third ray and very infrequently, in the fourth ray.

NORMAL AND PATHOLOGICAL FINDINGS OF THE PLANTAR PLATE IN THE MRI STUDY

In the MRI study, sagittal, coronal (short axis) and axial (long axis) images are recorded in the T1 and T2-weighted fat-saturated sequences, whenever possible with high spatial resolution coils, to provide greater anatomical detail. The intravenous administration of paramagnetic contrast agents is useful as it increases the sensitivity of the test to detect PP abnormalities but it is not essential.[9]

T2-weighted fat-saturated images are the most useful in evaluation of the PP, which is best characterized in the sagittal and coronal axes. In the sagittal plane, the PP usually appears as a rectangular low signal intensity structure on the plantar surface of the metatarsophalangeal joint, with a loose proximal insertion near the metatarsal neck and a firm distal insertion at the base of the proximal phalanx. In the coronal images of the forefoot, the plate appears as an inverted "C" shaped structure, located beneath the metatarsal head. It is less thick in its central portion at the distal insertion, in which there is a groove that accommodates the flexor tendon, and should not be confused with a tear. Depending on the mechanism of injury, there is usually initial involvement of the lateral segment of the PP and not of its central portion.

The proper collateral ligaments and the interosseous tendons are best evaluated in the coronal and axial images, and their insertions are closely entwined with the external borders of the PP. It is not possible to clearly distinguish between these structures (PP, interosseous tendon, collateral ligaments and joint capsule) using the method at their insertion sites; therefore we prefer the term "plantar plate insertion complex" (Figure 2).

In pathological cases, there is initially signal alteration and slight blurring of the borders in the lateral portion of the PP insertion complex, associated with edema of the adjacent adipose planes, which frequently obliterates the plantar portion of the second intermetatarsal space, without obvious tears.[10,11] The obliteration/edema of the intermetatarsal space is asymmetric and has indistinct limits, unlike Morton's neuroma, which is central and has more clearly defined limits. In addition, pericapsular edema/obliteration is sometimes the main finding, and is enhanced following administration of intravenous paramagnetic contrast, due to the inflammatory abnormality caused by overload. These findings are apparently consistent with the zero-degree arthroscopic findings of the anatomical classification of PP injuries described by Nery et al., and there may be no signs of instability upon physical examination[2] (Figure 3).

If appropriate treatment is not provided, the condition progresses to tearing of the PP, with the appearance of signs

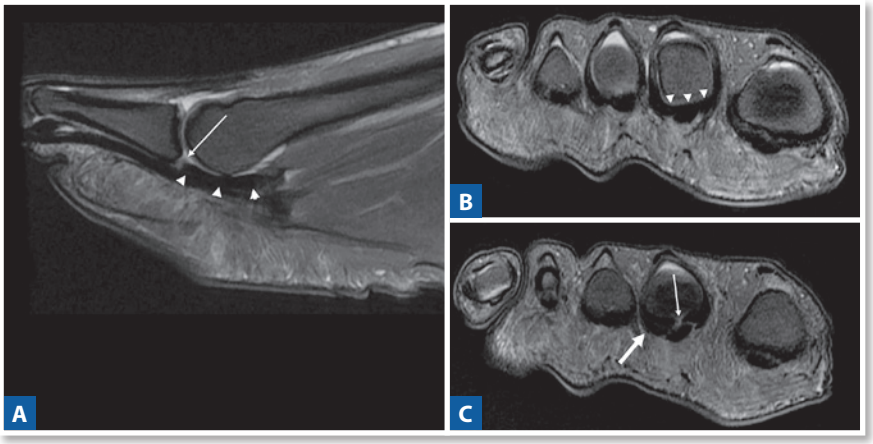

Figure 2 | Anatomy of the plantar plate. MRI images. (A) Sagittal image, T2-weighted fat-saturated sequence. (B, C) Coronal images, T2-weighted fat-saturated sequences with. Plantar plate (arrowhead). Central groove in the sagittal and axial images, which should not be confused with tearing (thin arrow). Lateral insertional plantar complex, where the injury frequently starts, name of the term phalangeal apparatus adapted by the authors (thick arrow).

of instability ("claw toe") and an increase in inflammatory abnormalities, possibly in combination with joint effusion, adventitious bursitis, osteitis and tenosynovitis. Rupture of the PP is identified by an area of high signal intensity which is generally transversal, and in the lateral aspect of its distal insertion, in the T2-weighted fat-saturated sequence, or following administration of intravenous paramagnetic contrast agent. At this stage, the presence of local scar/inflammatory tissue often hinders a better assessment of the extent of the rupture. MRI might underestimate the extent of the PP rupture, which can be evidenced in studies that correlate the arthroscopic findings of PP injuries and MRI aspects. In cases where there is associated tearing and/or insufficiency of the lateral collateral ligament and/or of the homolateral interosseous tendon, there may be crossover toe (Figures 4 and 5).

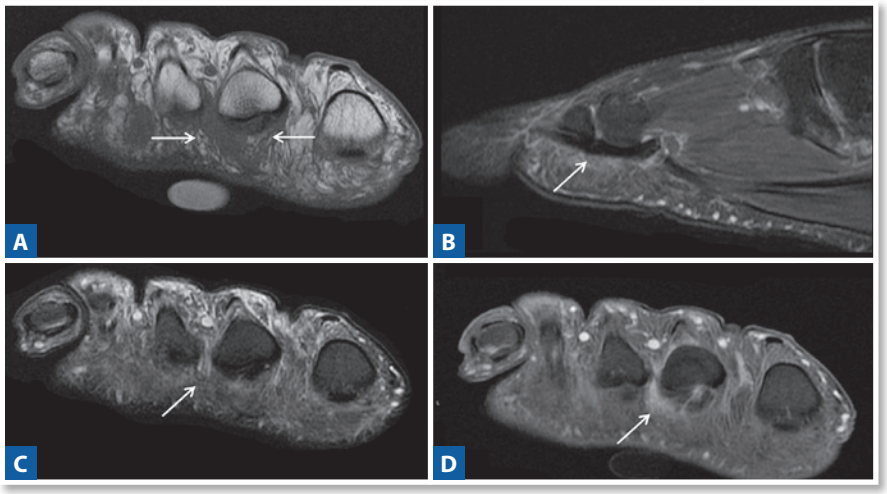

Figure 3 | Initial abnormalities of the plantar plate. MRI images. (A) In the T1-weighted sequence, there is asymmetric obliteration with indistinct limits of the fat pad of the plantar portion of the distal second intermetatarsal space simulating a neuroma (arrow). (B, C) No significant abnormalities can be seen in the T2-weighted fat-saturated coronal and sagittal sequences (arrows). (D) Following gadolinium administration, the inflammatory process adjacent to the lateral insert complex of the second metatarsophalangeal plantar plate is clearly evident.

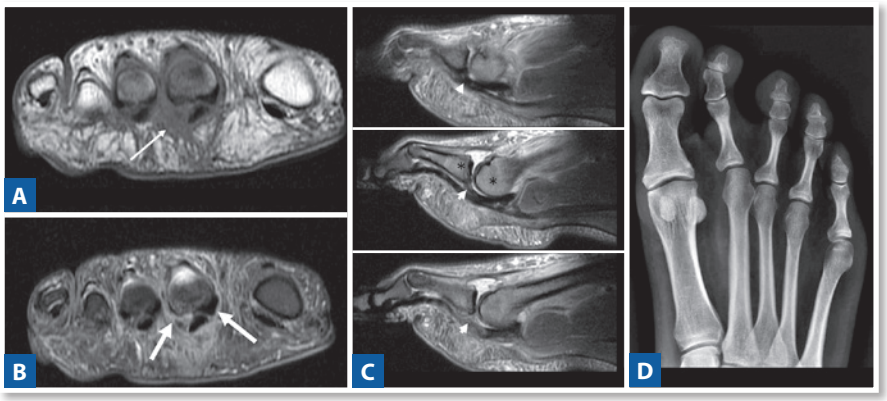

Figure 4 | Extensive partial rupture of the plantar plate. MRI images and radiographic study. (A) In the T1-weighted coronal image, there is extensive obliteration of both the adipose planes adjacent to the lateral insertion complex of the plantar plate and of the underlying plantar fat (thin arrow). (B) In the T2-weighted coronal image, there is extensive inflammatory process accompanied by discontinuity of the entire lateral insertion complex (plate, collateral and interosseous ligament); note that the medial insertion complex remains intact (thick arrows). (C) The sagittal images show that the plate remains inserted in its medial and central portions, but in the lateral direction (arrowhead) it is also possible to identify slight dorsal subluxation of the base of the proximal phalanx (asterisk). (D) The crossover second clear can be clearly viewed in the radiographic study.

It is essential to evaluate coronal images obtained using MRI, particularly following intravenous contrast agent administration, in the study of abnormalities related to the PP injury, since abnormalities start in the lateral aspect of the distal insertion of the PP, which is often poorly evaluated in sagittal images. PP rupture is only identified in sagittal MRI images when it is extensive. Failure to evaluate coronal MRI images greatly reduces the sensitivity of the method in identifying initial PP injuries.

DIFFERENTIAL DIAGNOSES

The main differential diagnoses are Morton's neuroma, stress fracture, degenerative joint disease, Freiberg's infraction, and bursitis. Considering MRI aspects, Morton's neuroma usually generates more confusion about PP injuries, yet the findings are quite different. Neuroma is much more common in the third interdigital space, unlike PP injuries which are predominantly located in the second ray, have a well-defined shape and are frequently unaccompanied by significant adjacent inflammatory process, except in cases where there is associated intermetatarsal bursitis (Figure 6).

CONCLUSION

Magnetic resonance imaging is useful in the diagnosis of plantar plate injuries in the early stages of the process,

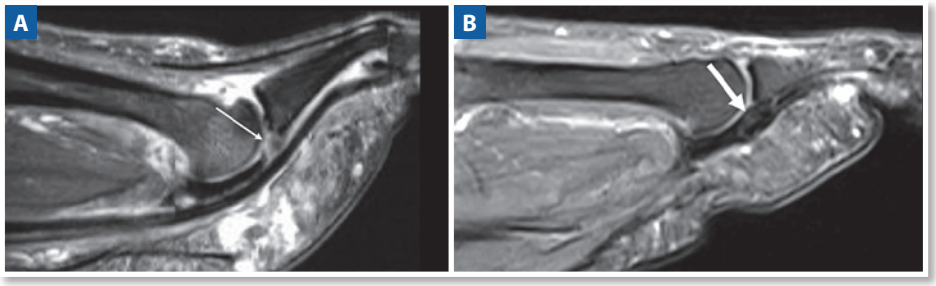

Figure 5 | Complete distal rupture of the plantar plate of the second metatarsophalangeal joint in different patients. T2-weighted fat-saturated sagittal MRI images. (A) The complete rupture is clear and well defined (thin arrow). Unfortunately, we are not always able to clearly delineate the rupture in sagittal images, as they are often eccentric and may be filled by inflammatory/scar tissue. Note, the scar tissue with slightly higher signal intensity than the plate in the rupture bed in (B) (thick arrow).

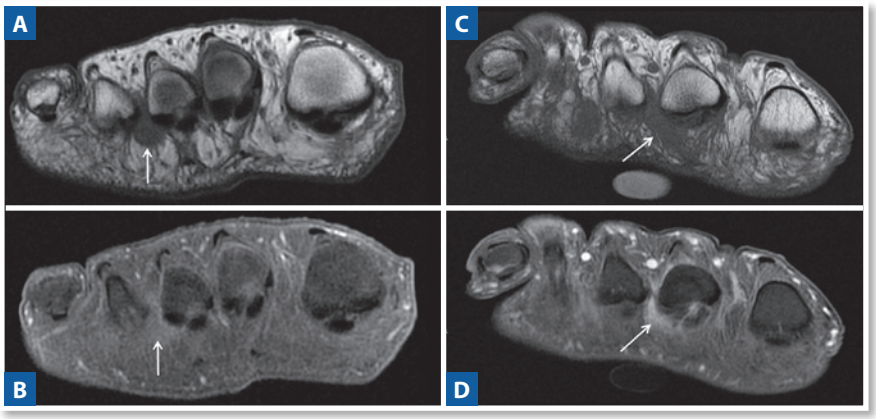

Figure 6 | (A, B) Typical Morton's neuroma. Coronary MRI images. Note the nodular obliteration of well-defined limits in the middle of the third intermetatarsal space in the T1-weighted sequence (A), with minimal post-intravenous contrast enhancement and slight inflammatory component in the T1-weighted fat-saturated sequence (B) (arrow). (C, D) Typical abnormality of the metatarsophalangeal plantar plate. Coronary MRI images. Note the uneven and asymmetric obliteration of the second intermetatarsal space in the middle of the lateral insert complex of the plantar plate, in the T1-weighted sequence (C), and frequently with extensive inflammatory process following administration of intravenous contrast in the T1-weighted fat-saturated sequence (D) (arrow).

contributing to an early diagnosis and avoiding delays in the initiation of the specific treatment.

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