MRI in horses – application and indications of a modern imaging technique in veterinary medicine

Keywords: MRI, horse, veterinary medicine

Authors: Brice Donati[1], Stéphane Montavon[2]

1. Brice Donati, Clinic for Diagnostic Imaging, Vetsuisse Faculty, University of Zurich, Zurich, Switzerland
2. Stéphane Montavon, Veterinary Department of the Swiss Armed Forces, Bern, Schweiz

Address for correspondence:

Brice Donati, Clinic for Diagnostic Imaging, Vetsuisse Faculty, University of Zurich, CH-8057 Zurich, Switzerland

E-Mail: bdonati@vetclinics.uzh.ch

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Abstract

Veterinary medicine is experiencing an exciting development in every aspect, from increased knowledge about pathologies, to improved diagnostic tests and advanced therapeutic possibilities. This is also thanks to the increasingly important role of pets as life companions and the social benefits they provide. In the eyes of most people in western countries, animals and especially pets deserve excellent care, which results in increased willingness from owners to undertake complex and expensive medical steps for the health of their four-legged partners. One particularly relevant advance in veterinary medicine is the application of advanced diagnostic imaging modalities, originally developed for humans, for the workup and diagnosis of pathologies affecting animals. The purpose of this article is to present one aspect of this trend, the one concerning horses and the improved diagnostic imaging modality of magnetic resonance imaging (MRI) available to equine veterinarians for the characterization of pathologies mainly affecting the locomotor and nervous systems of horses. At the end, clinical case examples are presented to illustrate the advantages of MRI and a selection of pathologies best recognized in MRI.

Abstract

Die Veterinärmedizin erlebt in jeder Hinsicht eine aufregende Entwicklung, angefangen bei der Erweiterung des Wissens über Pathologien bis hin zu verbesserten diagnostischen Tests und fortschrittlichen therapeutischen Möglichkeiten. Dies ist auch der immer wichtigeren Rolle von Haustieren als Lebensbegleiter und dem sozialen Nutzen, den sie bieten, zu verdanken. In den Augen der meisten Menschen in den westlichen Ländern verdienen Tiere und insbesondere Haustiere eine hervorragende Pflege, was zu einer erhöhten Bereitschaft der Besitzer führt, komplexe und teure medizinische Massnahmen für die Gesundheit ihrer vierbeinigen Partner zu ergreifen. Ein besonders wichtiger Fortschritt in der Veterinärmedizin ist die Anwendung fortschrittlicher bildgebender Diagnoseverfahren für die Untersuchung und Diagnose von Krankheiten bei Tieren, die ursprünglich für den Menschen entwickelt wurden. In diesem Artikel werden Aspekte dieses Trends vorgestellt, so der des Pferdes und die verbesserte diagnostische Bildgebungsmethode der Magnetresonanztomographie (MRT), die Pferdetierärzten zur Charakterisierung von Pathologien zur Verfügung steht, die hauptsächlich den Bewegungsapparat und das Nervensystem von Pferden betreffen. Abschliessend werden klinische Fallbeispiele vorgestellt, um die Vorteile der MRT und eine Auswahl von Pathologien zu veranschaulichen, die mit der MRT am besten erkannt werden können.

Introduction

MRI is a modern diagnostic imaging technique based on physics principles about magnetic fields, discovered in the first half of the twentieth century by Isidor Rabi, which earned him the Nobel Prize in Physics in 1938, as well as by swiss-american Felix Bloch and Edward Purcell, which were awarded the same Prize in 1952. For further contributions to this technology and for the development of the method of high-resolution nuclear magnetic resonance spectroscopy, another swiss scientist, Richard Ernst, was awarded the 1991 Nobel Prize in chemistry. The medical application of magnetic resonance was developed in the second half of the twentieth century resulting in the first MR scanner in 1977. Findings concerning magnetic resonance imaging earned the two physicists Peter Mansfield and Paul Lauterbur the Nobel Prize in physiology and medicine in 2003.

MR images are generated with signal coming from hydrogen atoms, abundantly present in biological tissue being a major component of water molecules and fat, amongst others. With MRI, it is possible to produce sequences of images of very different appearance depending on settings on the scanner, highlighting specific kinds of tissue, depending on their magnetic behaviour. The combination and comparison between sequences aids the interpretation and differentiation of findings to create a better understanding of anatomy, physiology and pathology. The principles of magnetic resonance physics are much more complex than explained herein, and description of further details would be beyond the scope of this article. Nevertheless, one last important characteristic to keep in mind when talking about MRI are the unique hazards related to the strong magnets used in diagnostic imaging, such as ferromagnetic objects turning into projectiles when introduced in the faraday cage possibly causing accidents, as well as metallic implants possibly interfering with image formation, migrating or even causing thermal damage to the surrounding tissues because of implant heating during the examination.

MRI in veterinary medicine

MR technology was not used in veterinary medicine until the 1990s, when it was first introduced for the evaluation of small animal patients in general anesthesia or heavily sedated. First live equine patients were scanned in the late 1990s after purpose-built systems for accommodating horses in general anesthesia with a limb or the head stretched into the bore of the magnet were developed. The large size and weight of the patient as well as specific requirements of the magnet and faraday cage itself posed unique challenges. The rooms needed large doors, the tables on which the horses would be lying needed to be non-ferromagnetic and easy to move for adequate positioning of the patient. Some of these challenges were successfully addressed, while other limits could not be overcome, such as bore width and the inability to scan thicker body parts in large horses (Figure 1).

Risks associated with general anesthesia initially prevented the widespread use of MR technology in horses. General anesthesia is associated with up to 1 % fatalities in equine patients, mainly due to cardiac arrests, fractures during

Figure 1
Setup for high field MRI examination of equine patients in general anaesthesia. Dorsal recumbency for examination of the head on the left and lateral recumbency for examination of the limbs on the right. Photos by Tierspital Zürich

recovery and myopathies, even nowadays. Thus, veterinarians and horse owners were often discouraged to conduct an MRI as the information that could potentially be gained by the examination was not considered worth the risk. It was not until the first standing scanners were introduced in the early 2000s, when Hallmarq Ltd. brought on the market its 0.27 Tesla open magnet for scanning of the equine distal limb, that MRI really made the breakthrough in equine orthopedics. The range of pathologies recognized by MRI and the increase in knowledge has been surprising, and nowadays the technology is an important part of many lameness workups.

High field scanners with the patient in general anesthesia still inherently produce superior quality images with much higher spatial resolution compared to low field standing systems (Figure 2). This is mainly due to the important difference in main magnetic field strength, typically 0.27 Tesla in the standard equine standing system compared to 1.5 T or even 3 T in high field scanners. A higher main magnetic field will produce more detailed images of a larger area, which inherently give a clearer insight into the anatomy and lead to a more accurate diagnosis. Scans typically still performed in general anesthesia are those of regions which are not feasible in the standing open magnet such as the head. In addition, smaller patients such as foals or ponies are more often examined under general anesthesia with high-field systems, given the larger portion of the body that can be fitted into the bore and a higher probability of an uneventful recovery phase.

For the magnet to be used in standing equine patients, it must possess an open configuration, without typical bore or tunnel structure, but a shape which allows the horse to walk in and out of the isocenter of the magnet, and where it can escape if startled (Figure 3). Obviously, the horse should stand still in the magnet and not move the legs when images are acquired. This is achieved by sedating the horse and by good horsemanship skills and experience in standing sedation by the handling staff. Sedation is typically administered before entering the faraday cage and different protocols can be used. At our clinic, sedation protocol consists in a neuroleptikum such as acepromazine approximately 30 minutes before the beginning of the examination, followed by a combination of

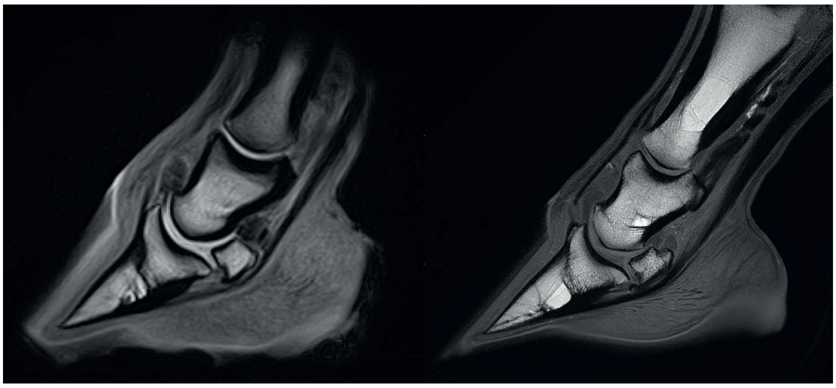

Figure 2
Comparison of low-field (left) and high-field (right) sagittal T1 planes of the hoof. Note the increase spatial resolution in the image on the right resulting in enhanced definition and increased appreciation of anatomic detail. Image by Tierspital Zürich

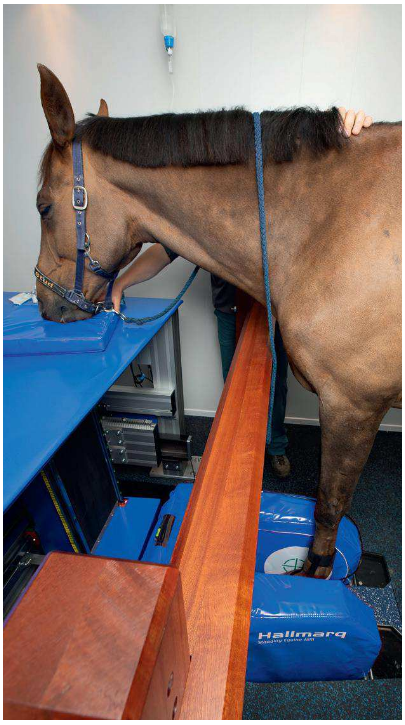

Figure 3
Standing low-field MRI system with open magnet (blue) for examination of the left front hoof. Note the open configuration of the magnet, which allows the horse to step in and out of the field of view. The horse is sedated with his head rested on a cushion, while a veterinary nurse is holding it in place and adjusts sedation as needed. @Vetsuisse Faculty, UZH / M.A. Oesch
Photo by Tierspital Zürich

alpha-2-agonists such as detomidine and an opioid such as butorphanol or morphinsulfate, and maintained through multiple intravenous top-ups as needed or by a constant rate infusion, both containing additional alpha-2-agonist. The staff handling the horse plays a crucial role for a successful MR scan. Fine-tuning of sedation by early recognition of it being too superficial or too deep, both possibly leading to patient movement, as well as a calm and quiet handling of the patient are of paramount importance to avoid the annoying situation in which sequences have to be repeated or even rescheduled if the limb to be scanned moves. Patient movement is not only problematic when the limb is lifted and replaced in another position. The mere swaying of the proximal aspect of the limb results in motion blurring, potentially leading to undiagnostic images (Figure 4). This wobble motion becomes more critical the more proximal the region to be scanned is, as the foot planted on the floor acts as the pivot point and the longer the distance from the foot, the higher the swaying amplitude. Particularly in low field scanners, MRI quality results in being operator dependent because interpretation by the radiologist often relies on symmetry of structures, which can only be assessed if planning of slices has been performed meticulously. Obliquely planned sequences will distort structures preventing assessment of shape and size, as well as aggravate partial volume averaging artifacts, which results in impaired spatial resolution and erroneous signal intensity (Figure 5). All of these factors contribute to the difficulties encountered in standing equine MRI imaging, and thus protocols and sequences have been developed and adapted to the specific needs of equine medicine, with special motion correction or fast scan techniques. The ongoing research is mainly focused on software aspects that will hopefully help to correct patient motion even more, and thus be able to reliably and easily scan more proximal regions such as the carpus or tarsus. Where both high- and low-field technologies are available, the choice is often the standing option, at least for a first examination.

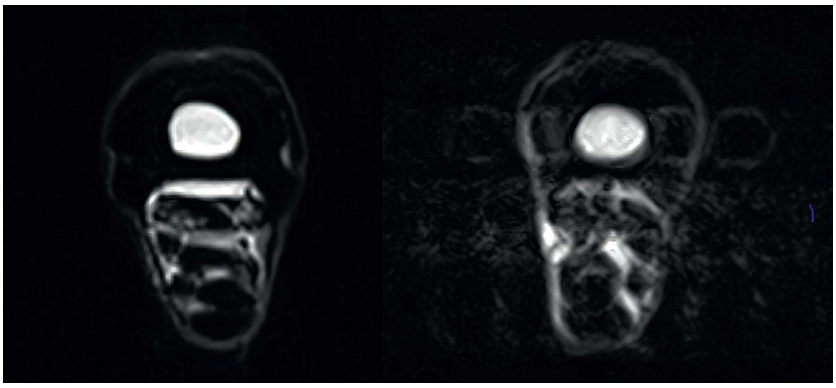

Figure 4
Comparison of two T2 transverse planes through the proximal metacarpal area showing the effect of swaying and resulting motion blurring. Assessment of fine structures such as the fat bundles present in the proximal suspensory ligament or differentiation from small areas of fluid accumulation is not possible in the image on the right. *Image by Tierspital Zürich*

Indications for MRI in horses

Compared to other imaging modalities, magnetic resonance imaging is superior with regards to soft tissue structure as well as the soft tissue component of bones and has the inherent advantage of being a cross sectional imaging modality resulting in images without superimposition. Ultrasonography surely is a valuable tool for the examination of soft tissue structures as well, and has the advantage of being fairly cheap, widespread, as well as fast and straightforward in interpretation with appropriate

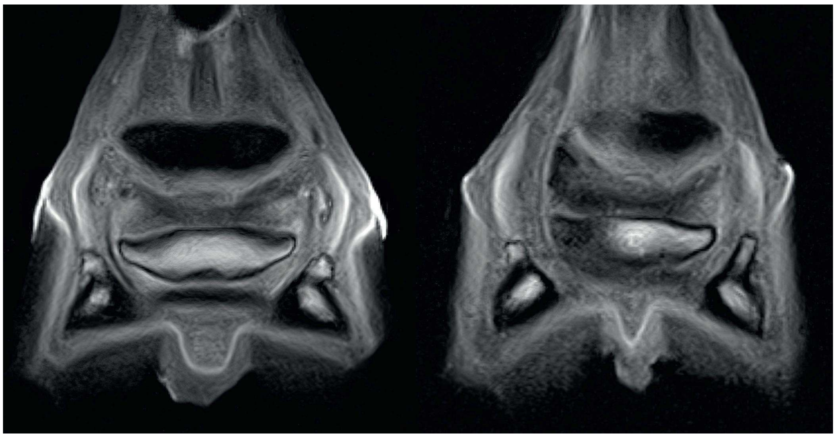

Figure 5
T1 dorsal slices at the level of the navicular bone highlighting the importance of good planning. The distal sesamoid bone, or navicular bone, on the right can only partially be assessed due to obliquity. Note distortion of size and shape as well as the perceived lower signal intensity on the left aspect of the bone. The latter could be interpreted as bone sclerosis or fluid accumulation in this area, whereas it probably just represents partial volume averaging with the compact bone of its flexor surface. On the left, there is almost perfect alignment of the plane through the navicular bone, which appears symmetrical in size, shape and signal pattern.
Image by Tierspital Zürich

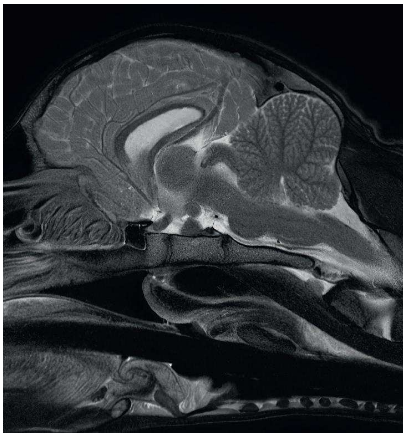

Figure 6
High field sagittal T2 slice through the skull of a juvenile horse; note the high contrast resolution that allows differentiation between cerebral and cerebellar structures, the high signal intensity of cerebrospinal fluid within the ventricular system as well as the conspicuity of cerebral vasculature.
Image by Tierspital Zürich

experience and knowledge. However, technical limits such as the limited penetration depth of acoustic waves as well as the impossibility to examine structures beneath bone or keratinized layers restrict this technology to superficial layers of tissue. With MRI, deeper structures and structures beneath keratinized or mineralized layers can be imaged. This is particularly helpful for structures within the cranial vault, within the vertebral canal and in the distal limb of horses, where soft tissue structures are hidden in the hoof capsule and cannot be assessed otherwise. This is useful for example in the rare but important cases of neurological patients with a suspected central neuroanatomical location of the pathology. The brain, cerebellum, brainstem and spinal cord as well as other neurologic structures can be depicted with very high detail in MRI due to the large water and fat amount that can be found in these organs (Figure 6). The main advantage of MRI compared to CT for imaging the central nervous system is the inherently higher contrast resolution as well as the range of available sequences for highlighting specific tissues, tissue properties and lesions. Fortunately, this examination is only indicated in rare instances, due to the risks in performing long general anesthesia in an equine patient with central nervous symptoms.

As previously stated, another region where first line imaging modalities reach their limits in depicting soft tissues are those found within or that extend distally into the hoof capsule. Ultrasonography is helpful down to the region of the pastern but structures such as the most distal aspect of the deep digital flexor tendon, the collateral ligaments of the distal interphalangeal joint and of the distal sesamoid bone as well as the many smaller ligaments of the hoof are hidden to acoustic waves behind the thick keratinized hoof capsule. Some techniques have been described for imaging the insertion of the deep digital flexor tendon with ultrasonography by trimming and soaking the sole of the hoof, but this is rarely practicable and yields low quality images. Magnetic resonance signal instead, is not affected by overlying layers and can be detected from deep structures, just as showed in figure 7.

Apart from being superior in imaging the soft tissues within the hoof capsule and cranium, a particular advantage of MRI in equine orthopedics is that it can assess composition of bone. For assessing bone pathologies, radiography is surely the most readily available and easily performed diagnostic imaging step. A large part of bone is composed of mineral, mainly calcium, which is highly x-ray-attenuating. The very high spatial resolution which x-ray based imaging is able to achieve is therefore ideal for depicting fine trabecular structures

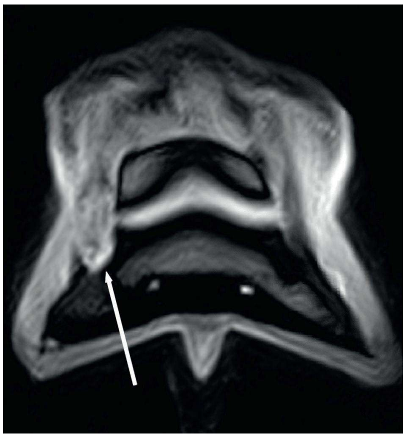

Figure 7
Frontal T2 slice of the hoof, showing severe enlargement and signal abnormalities of the medial (left) collateral ligament of the distal interphalangeal articulation in comparison to the lateral. Note also the larger concavity and thinner cortex in the area of the collateral fossa of the distal phalanx at the ligaments insertion and the diffuse signal changes within the spongious bone. These structures are located within the hoof capsule.
Image by Tierspital Zürich

as well as many other changes primarily involving the mineral portion of the bone, be it its density, pattern or distribution. This is true for example for fractures, osteo-arthropathies, periosteal reactions and many other osteolytic or osteo-proliferative pathologies. However, some more subtle pathologies are not associated with a change of the mineral part of the bone or only develop such alterations in the chronic stage and thus may go overlooked in an early radiographic examination. This is due to the fact that bone is not only made of mineralized tissue. A large part of it is made up of soft tissue within the medullary cavity as well as in the intertrabecular space. Just as every other tissue, it can change its composition after a variety of insults by accumulation of fluid in the form of edema, hemorrhage or inflammation (figure 8). Fluid accumulation or edema within bone marrow is a highly relevant finding in MRI, which cannot be detected otherwise.

All of these considerations make MRI the imaging modality of choice when first line imaging fails to identify pathology and a soft tissue lesion or subtle osseous lesion is suspected. In the next section of this article, equine cases in which MRI helped to make the final diagnosis are presented.

Case examples

Case Example 1

A five-year-old Arabian horse was presented for evaluation of an acute to subacute intermittent moderate lameness of the right anterior limb. Diagnostic analgesia was performed at the level of the lateral and medial digital palmar nerves, which was positive and abolished lameness. On radiographs, the sagittal and proximal aspect of the proximal phalanx showed minimal abnormality of the subchondral bone in the region of the sagittal groove, with a small rounded ill-defined radiolucent lesion. No other abnormalities were

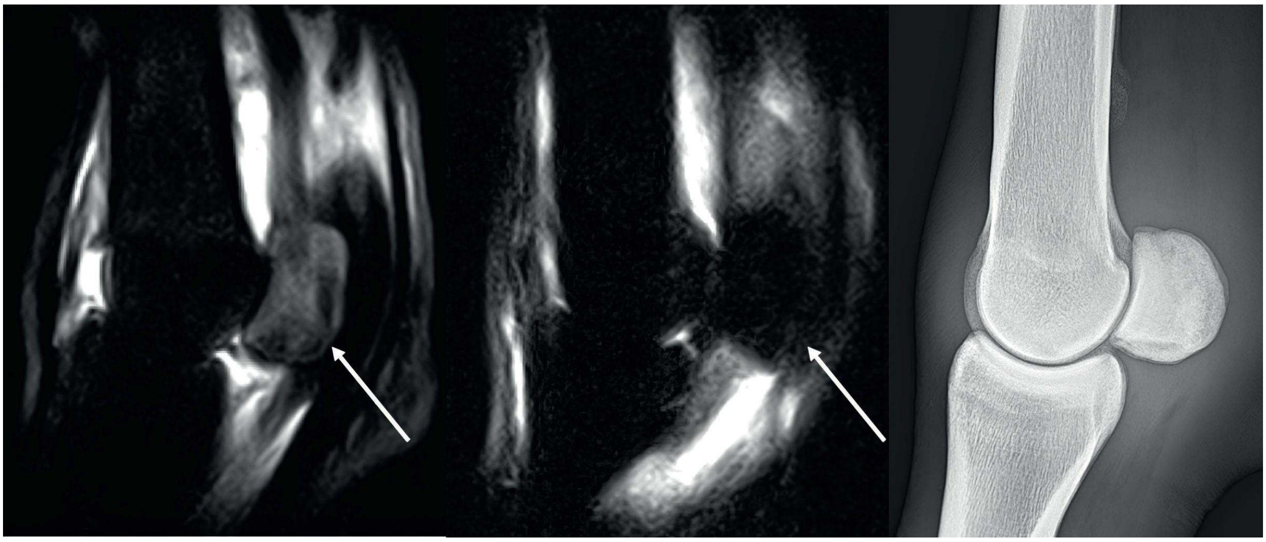

Figure 8
Parasagittal STIR slices through the metatarsophalangeal joint showing conspicuity of fluid accumulation within bones (left and center). Note the diffuse increase in STIR signal in the lateral proximal sesamoid bone on the left (left image) compared to the right (center image). An acute osteitis with accumulation of fluid within the bone was present and resulted in severe changes in signal intensity. No changes were detected on radiographs of the fetlock (right image). *Image by Tierspital Zürich*

Figure 9
Comparative imaging showing a radiographically inconspicuous lesion in the subchondral bone at the proximal aspect of the proximal phalanx, which revealed marked changes on magnetic resonance imaging. Dorsopalmar radiographic projection of the right metacarpophalangeal articulation (right image). Dorsal plane STIR slice through the mid aspect of the same region with diffuse hyperintensity surrounding the sagittal groove of the proximal phalanx (left image). Frontal plane T2 sequence through the same region showing marked signal changes of the subchondral bone surrounding the sagittal groove of the proximal phalanx, mainly hypointensity with faint central hyperintensities (center image).*
Image by Tierspital Zürich

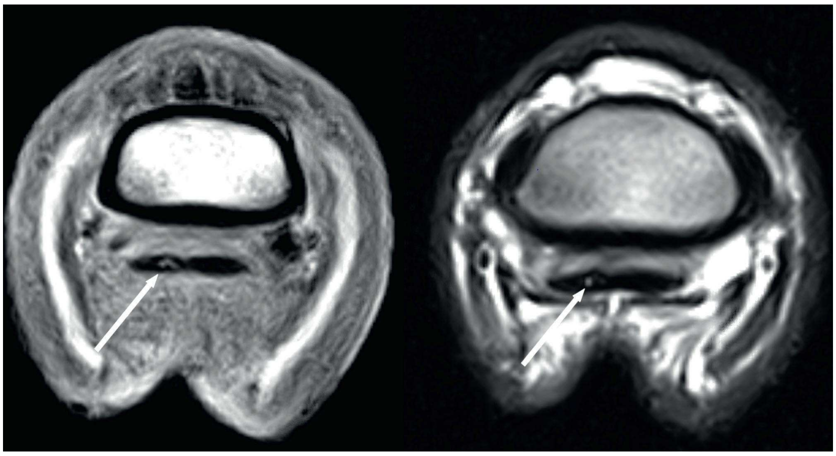

Figure 10
Transverse T1 (left) and T2 (right) weighted images through the proximal aspect of the hoof. Note the distorted size and shape of the medial (left) lobe of the deep digital flexor tendon, and the focal hyperintensity in its center, compatible with fibre disruption and fluid accumulation. This lesion would be impossible to diagnose with radiography and would be also only partially be visible in ultrasonography due to its distal location and extension into the hoof capsule.
Image by Tierspital Zürich

appreciated by performing ultrasonography of the region. Given the subtlety of findings and the questionable correlation with the lameness, a standing low-field MRI examination was performed. This confirmed marked changes within the subchondral bone at the site of the radiographically presumed lesion, and the horse went on to computer tomography in general anesthesia and screw fixation of the short sagittal fissure of the proximal phalanx (figure 9).

Case example 2
A 16 year old warmblood horse was examined because of a moderate lameness that had been going on for 1 month. The lameness was more pronounced when trotting on a soft ground. Clinical examination revealed mild effusion of the digital flexor tendon sheath. Lameness disappeared after a block of the digital palmar nerves but neither radiography nor ultrasonography revealed changes compatible with the clinical presentation of the horse. As a soft tissue lesion in the distal limb, possibly within the hoof capsule, was presumed, the choice for a magnetic resonance examination was made. This showed a hyperintense lesion of the medial lobe of the deep digital flexor tendon with disruption of the tendons shape, and thus the diagnosis of a tendinopathy was made (figure 10).

Case example 3
A 25 year old mule was presented for recurring hoof abscesses at the same location and chronic lameness on its front right foot. Compression of the hoof capsule elicited discomfort and there was moderately increased pulsation of the digital arteries compared to the contralateral limb. Diagnostic anesthesia of the digital palmar

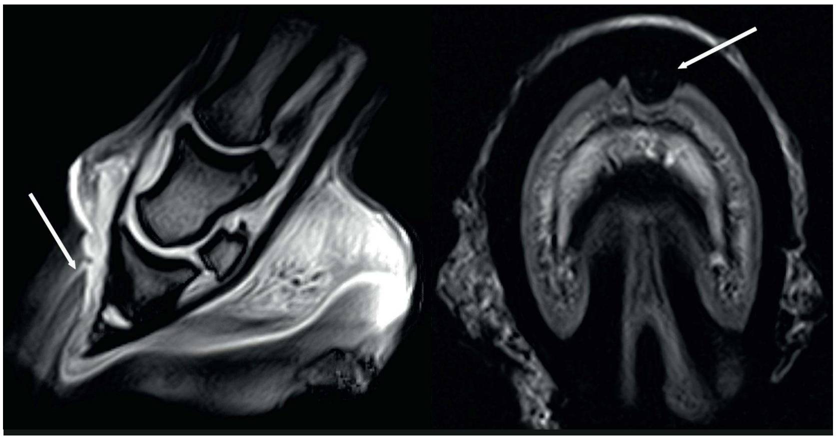

Figure 11
Sagittal (left) and distal transverse (right) T2 slices of the hoof showing a large hypointense vertical tubular space occupying lesion within the lamellar tissues of the hoof capsule with moderate mass effect on the adjacent distal phalanx creating a concave defect of the bone, compatible with pressure atrophy.
Image by Tierspital Zürich

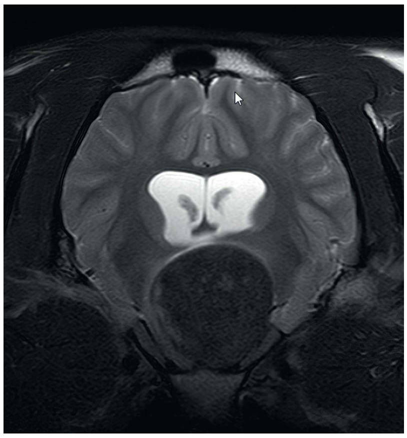

Figure 12
Transverse T2 slices through the mid aspect of the skull, showing a very large, well defined and smoothly marginated round space occupying lesion centered in the area of the sella turcica and hypophysis, with marked mass effect and compression of the thalamus and resulting marked enlargement of the ventricular system.
Image by Tierspital Zürich

nerves abolished the lameness. On radiographs, a faint and ill-defined area of bone lysis was present at the distal phalanx, which prompted the suspect of a benign mass originating from the lamellar and horn-producing tissue resulting in pressure atrophy of the adjacent bone. Magnetic resonance imaging was chosen as the next diagnostic step to confirm the suspect of a chronic keratoma and aid in surgical planning (figure 11).

Case example 4
A 19-year-old warmblood gelding was presented for exercise intolerance and severe progressive reduction of mentation. Neurologic examination resulted in the suspect of a central nervous system neurolocalization of the pathology with involvement of the thalamus. Laboratory diagnostic tests and skull radiographs showed no abnormalities. Given the superiority of MRI for characterization of abnormalities affecting the nervous system, a high-field examination with the patient in general anesthesia was chosen and a large expansile mass could be visualized in the region of the hypophysis, most likely compatible with neoplasia (figure 12).

Conclusions

Magnetic resonance imaging is nowadays a rather widespread diagnostic tool available to equine surgeons and radiologists and can help in the diagnosis of previously unrecognized pathologies of bone and soft tissues. The technique and quality of results are still subordinate compared to human medicine, but the technology greatly aids in the correct and precise diagnostic workup of many clinical, mainly orthopedic, complaints. Given the technical difficulties and expenses associated with this modality, MRI still is a second line diagnostic tool, although increasingly used in earlier stages of the disease. There is still much to learn from this technology in horses and research is focused on optimizing the scanners to be able to perform examinations of additional regions of the equine body as well as to correct motion artifacts in standing systems. This trend is exciting and equine veterinarians as well as radiologists can look forward to an exciting future thanks to the advances of this technology.

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