

## Penetrating solar wounds to the foot: benefit of MRI in treatment decisions

### *Nageltred: voordelen van MRI bij de behandelingskeuze*

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## A BSTRACT

Penetrating injuries to the sole of the hoof are common in horses. Prognosis and treatment depend on the structures involved. In this report, nine horses are described with a penetrating injury to the sole of the hoof that then underwent magnetic resonance imaging (MRI) examination. The radiographic examination performed in seven of these horses provided information about the bone involvement and an MRI examination was performed in all cases to obtain information about the affected soft tissues. MRI has excellent soft tissue contrast and can provide detailed images in any anatomical plane. For all nine horses, the MRI examination provided a clear guidance toward prognosis and a treatment plan. For two of the horses, the MRI examination confirmed that only superficial debridement was required. In seven of the horses, the MRI findings indicated that a more invasive approach was needed, such as navicular bursoscopy or street-nail procedure.

This study illustrates that an MRI examination can provide useful additional information leading to an appropriate therapy and prognosis, and shows a good correspondence between MRI observations and surgical findings.

## SAMENVATTING

Nageltred komt veel voor bij paarden. De prognose en behandeling hangen af van de beschadigde weefsels. In dit artikel worden negen paarden met nageltred beschreven die een “magnetic resonance imaging” (MRI)-onderzoek ondergingen. Het röntgenologisch onderzoek, dat werd uitgevoerd bij zeven van de negen paarden, gaf een inschatting van de betrokkenheid van botstructuren bij nageltred. Om de weke-delenschade te kunnen beoordelen, werd een MRI-onderzoek uitgevoerd bij alle paarden. MRI geeft immers een uitstekend weke-delencontrast en kan gedetailleerde beelden in elk anatomisch vlak maken. In alle negen casussen was het MRI-onderzoek bepalend voor de prognose en therapiekeuze. Bij twee paarden bevestigden de MRI-beelden dat slechts een oppervlakkige uitruiming nodig was. Bij de overige zeven paarden was een meer invasieve aanpak geïndiceerd, zoals bursoscopie of een “street-nail” procedure. Deze studie illustreert dat door middel van MRI-onderzoek veel nuttige informatie kan verkregen worden om zo tot een gepaste therapie en prognose te komen. In deze studie is er een grote overeenkomst tussen de bevindingen van de MRI en de afwijkingen die tijdens chirurgie gevonden werden.

## INTRODUCTION

Penetrating injuries to the sole and frog of the hoof are common injuries in horses and can be serious or even life-threatening (Richardson et al., 1986; Smith, 2013). The location, direction and depth of the penetrating injury play an important role in the treatment and prognosis. The prognosis following a penetrating injury depends on the structures involved.

Puncture wounds to the hoof can carry a grave prognosis if the penetrating injury enters the frog or the collateral sulci, as important structures like the navicular bursa, navicular bone, distal phalanx, distal

sesamoid impar ligament (DSIL), deep digital flexor tendon (DDFT), digital flexor tendon sheath (DFTS) and distal interphalangeal (DIP) joint can be affected (Wright et al., 1999; Boado et al., 2005).

Plain radiography, radiography with a sterile metal probe placed in the tract, and contrast radiography like arthrography, bursography and/or fistulography are often used to evaluate the structures affected by penetrating injuries (Richardson, 1986; Lamb, 1991; Smith and Schramme, 1992; Stashak, 2002; Kinns and Mair, 2005; Smith, 2013). These examinations may be inconclusive, and in some cases, the puncture canal may be difficult to localize or not be accessible to the

full extent. Furthermore, such techniques are not reliable for assessing soft tissue damage within the foot other than the synovial structures. In particular, the DDFT, which is the most commonly affected structure in the foot following a solar penetration, cannot be imaged in detail by these imaging modalities (Mair et al., 2003; Kinns and Mair, 2005; Urraca del Junco et al., 2012; Smith, 2013).

Important synovial structures which are at risk following a penetrating injury to the foot, such as the DIP joint, DFTS and navicular bursa, can be investigated using synoviocentesis and synovial fluid analyses.

Diagnostic ultrasonography of the DDFT via the sagittal midline of the frog and distal pastern (Sage and Turner, 2000; Busoni and Denoix, 2001, Kristoffersen and Thoenfer, 2003) yields limited information. Lesions often cannot be identified because it is not possible to position the transducer perpendicular to the tendon fibres of the DDFT; only lesions that lie on the midline can be visualized (Kristoffersen and Thoenfer, 2003; Kinns and Mair, 2005).

Scintigraphy, computed tomography (CT) and MRI are becoming more accessible in equine practice and can be used for assessing solar penetration wounds (Urraca del Junco et al., 2012; Smith, 2013).

Of these three imaging modalities, MRI has the best soft tissue contrast and may provide detailed images in any anatomical plane. With the development of standing equine MRI, the anesthetic risk of an MRI examination under general anesthesia is no longer an issue. Provided the foot remains static, movement due to the “sway” of the leg does not introduce significant motion related image artifact. Movement correction software is available but in foot-cases rarely necessary. Low field MRI scanners have lower signal than high field scanners resulting in a lower image resolution. However, the advantages of scanning the horse without the need for general anesthesia outweighs these limitations (Kinns and Mair, 2005).

The prognosis and treatment of penetrating foot injuries depend on the structures involved. In the case of superficial solar puncture wounds, local debridement of the draining tract is often sufficient. In most cases, this can be performed in the standing horse. If a synovial structure, such as the DIP joint, the navicular bursa or the DFTS, is involved, arthroscopic lavage under general anesthesia is recommended (ter Braake, 2002). In cases with severe DDFT necrosis, with or without involvement of the navicular bursa, a more invasive solar approach is recommended; the so-called street-nail procedure. This procedure generally includes radical excision of the penetrating tract and fenestration of the DDFT, with or without lavage of the navicular bursa (Wright et al., 1999; Smith, 2013). These surgical interventions are mostly combined with systemic administration of antimicrobial drugs and the appliance of bandages.

The aim of the study was to illustrate how MRI examination helps in making an accurate assessment of the extent of the lesion, resulting in a more accurate

prognostication and treatment. Additionally, it was assessed whether the surgical findings corresponded with the MRI observations.

## MATERIALS AND METHODS

Patient records of horses presented at the Veterinary Clinic Emmeloord (the Netherlands) with a history of penetrating injury to the solar surface of the foot between 2005 and 2013 were reviewed. All horses with a penetrating solar injury that underwent an MRI examination were included in the study.

In eight out of the nine cases, plain radiographic examination of the foot was performed using routine lateromedial and dorsoproximal-palmarodistal oblique radiographic projections of the foot. If indicated, additional views were obtained. In the cases where the puncture tract was visible, a metallic probe was inserted and radiographs were obtained with the probe in place.

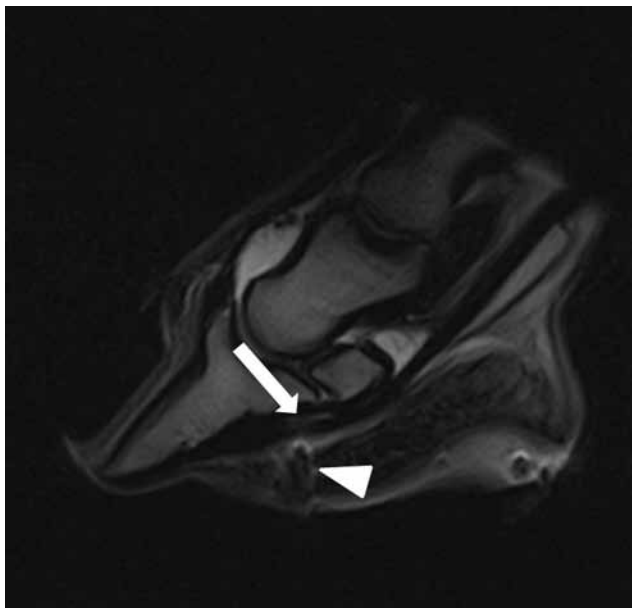
In all cases, an MRI examination was performed with the standing equine MRI, which uses a 0.27 Tesla low field permanent magnet. A standard imaging protocol was used including 3-D T2\*-weighted GRE sagittal images, 3-D T2\*-weighted GRE transverse images, 3-D T1-weighted GRE sagittal and Short Tau Inversion Recovery (STIR) sagittal images. Additionally, 3-D T2\*-weighted GRE frontal, 3-D T1 weighted frontal, STIR transverse and T2 FSE sagittal, transverse and frontal images were used if deemed necessary.

All horses were sedated with a combination of romifidine (0.04 mg/kg, Sedivet<sup>®</sup>, Boehringer Ingelheim B.V., the Netherlands) and methadone (0.2 mg/kg, Methadon<sup>®</sup>, Eurovet Animal Health B.V., the Netherlands). In the cases with a non-weight bearing lameness, an abaxial sesamoidean nerve block was performed before the scan, to reduce the pain in the foot and hence movement of the foot during the MRI examination.

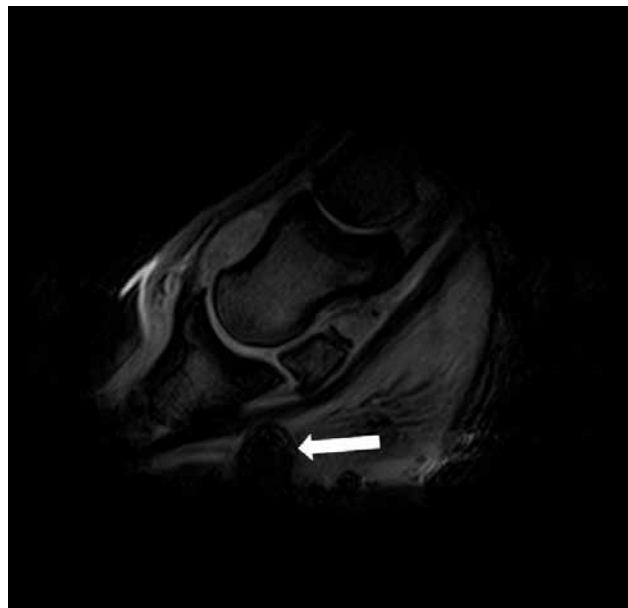
## RESULTS

### Case 1

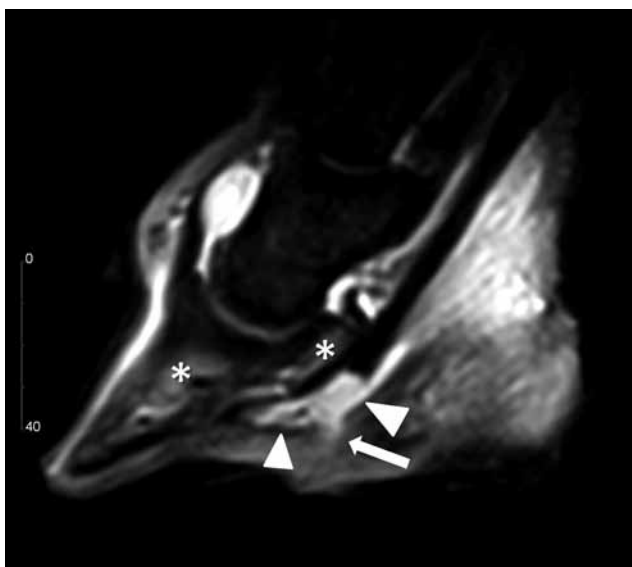
A ten-year-old Friesian stallion was referred to Veterinary Clinic Emmeloord (the Netherlands) with a history of a two-day-old puncture wound to the RH foot, entering the foot halfway along the frog. Lameness was graded as 3/5 at trot on a hard surface. On the standard radiographs of the foot, no significant radiological abnormalities were found. The MRI examination revealed an acute perforation of the sole, puncturing the DDFT and DSIL, as a linear hyperintensity on the T1, T2\* and STIR images. At the site of the disruption, the DDFT was mildly thickened. In the cuneal digital cushion distal to the lesion in the DDFT, a small hypointense area was seen on T1 and T2\* GRE sequences. Severe effusion of the navicular



**Figure 1.** Sagittal T2 FSE image of the foot. A hypointense puncture tract (arrowhead) surrounded by a hyperintense rim is present in the laminae and digital cushion near the insertion of the DDFT on the distal phalanx. A mild increased signal is present in the adjacent DDFT (arrow).

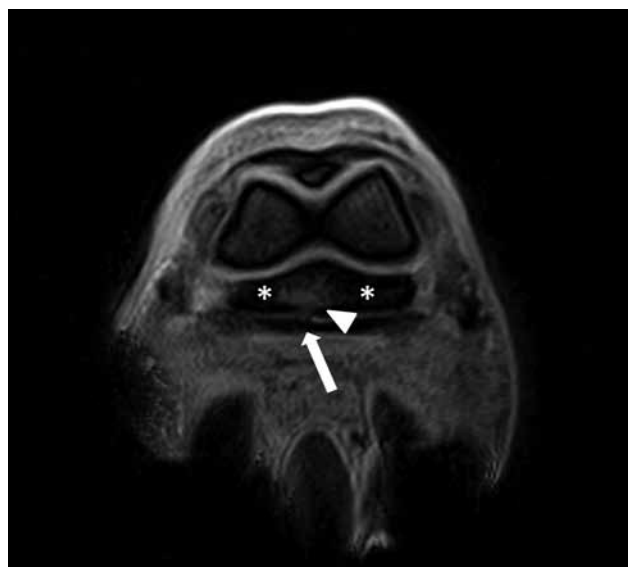


**Figure 2.** Sagittal T2\* image of the same foot as in figure 1. The hypointensity is larger and more rounded (arrow), consistent with a magnetic susceptibility artifact caused by hemosiderin in the puncture tract.



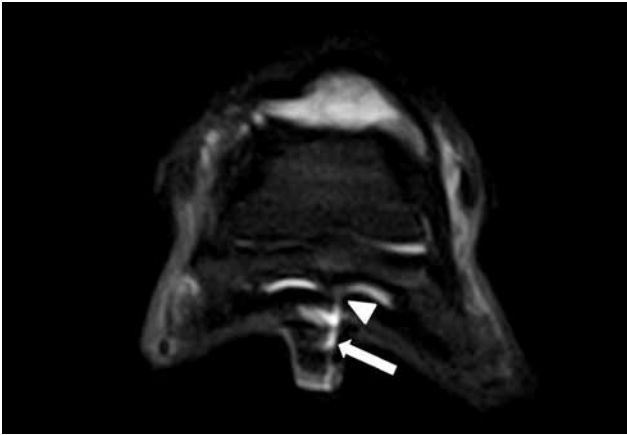
**Figure 3.** Sagittal STIR image of the foot. A large area of hyperintense signal is present in the distal DDFT, extending from the navicular bone until its insertion on the distal phalanx (arrowheads). Distal to the DDFT lesion part of the hyperintense puncture tract is visible (arrow). The medullary cavity of the navicular bone and the palmar part of the navicular bone is very hyperintense, consistent with a bone marrow edema-type lesion (asterisk).

bursa was present, suggesting involvement of the navicular bursa. MRI diagnosis was an acute perforation of the sole with puncture of the DDFT, DSIL and navicular bursa. Based on the MRI findings, it was decided to perform a bursoscopy of the navicular bursa via a direct approach (Wright, 1999). During surgery, the



**Figure 4.** Transverse T2\* image of the foot. The flexor cortex of the navicular bone has mid-sagittal a disruption (arrowhead) adjacent to the DDFT lesion (arrow). The medulla of the navicular bone presents the phase cancellation artifact (asterisk), which is highly suggestive of a bone marrow edema-type lesion.

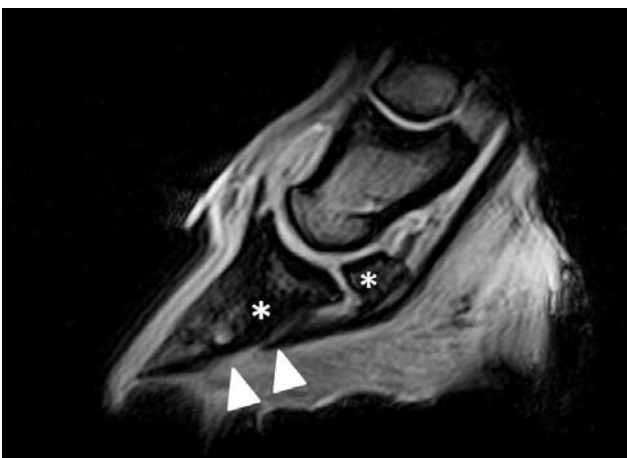
navicular bursa was distended and the synovial fluid was turbid. The synovial proliferation was shaved and a large amount of fibrin was removed. The navicular bursa was lavaged and surgical debridement of the puncture canal was performed. Postoperatively, antimicrobials (Sodium-Benzylpenicillin, Benzylpenicilline®, Eurovet Animal Health, the Netherlands; Gentamicin, Genta-Ject®, Dopharma Research B.V., the



**Figure 5.** Frontal STIR image of the foot. The parasagittal hyperintense puncture canal through the frog (arrow) and DDFT (arrowhead) is clearly visible.



**Figure 6.** Frontal STIR image of the foot. Lateral is to the left. The lateral part of the distal phalanx is hyperintense (asterisk) adjacent to the abaxial DDFT lesion (arrowhead). This is a bone marrow edema-type lesion.



**Figure 7.** Sagittal T2\* image of the foot. A hyperintense tract is present in the distopalmar cortex of the distal phalanx extending in the DDFT at his insertion on the distal phalanx (arrowheads). The medulla of the navicular bone and distal phalanx shows the phase cancellation artifact (asterisk), which is highly suggestive of a bone marrow edema-type lesion.

Netherlands) and an anti-inflammatory drug (Meloxicam, Metacam®, Boehringer Ingelheim, the Netherlands) were administered. Two weeks after surgery, the horse was discharged from the hospital. Six weeks postoperatively, the horse returned for a check-up and was sound in walk and trot. The horse returned to normal work and three years following surgery, the horse is still in full work.

### Case 2

An eight-year-old Oldenburger mare was referred to the hospital with a history of a 2-day-old penetrating wound to the medial frog of the right hindlimb, caused by a long screw. The lameness was graded 4/5. Standard radiographs of the foot were performed, including radiographic views with a metallic probe in the puncture wound. The puncture canal was visible, ending at the medial extremity of the navicular bone. After two days of conservative treatment, the horse showed no clinical improvement. The radiographs of the foot were repeated, and this time, the metallic probe entered a second puncture canal, which extended more sagittally, towards DDFT and the navicular bone. Subsequently, an MRI examination was performed to evaluate the extent of the damage. A puncture wound to the frog was visible as low-signal areas surrounded by hyperintensity on T2 FSE and STIR-weighted images (Figure 1). On both the T1 and T2\* GRE, the hypointensity was larger and more rounded (Figure 2). Both the DDFT and the DSIL were disrupted by a hyperintense line on the T1, T2\*, T2 FSE and STIR weighted images, and severe effusion of the navicular bursa was present. The adjacent part of the distal phalanx was mildly hyperintense on STIR. The MRI diagnosis was a puncture to the frog penetrating the DDFT, DSIL, distal recess of the navicular bursa and the distal phalanx. For this case, a bursoscopy was recommended as the best treatment possibility. The owner declined surgery given the extent of the lesions and the guarded prognosis. The horse was euthanized.

### Case 3

An eleven-year-old, mixed breed mare was referred to the clinic with a history of a penetrating wound to the frog of the left forefoot, caused by a nail two weeks earlier. The mare was treated at home with wet bandages and antimicrobials (Trimethoprim Sulfadiazin sodium, Trimethosulfmix 50%®, Eurovet Animal Health, the Netherlands). On presentation at the clinic, the lameness was graded 3/5. Extensive dermatitis of the pastern was present as a result of the treatment with wet disinfecting bandages. Standard radiographic examination of the foot, including radiographs with a metallic probe in the wound tract, was performed. A puncture canal directed proximal and ending palmar to the navicular bone and the DDFT was visible.



Synovial sampling of the navicular bursa could not be performed due to the extensive dermatitis. Synovia of the DIP joint did not show any abnormalities. The outcome of the radiographic study did not correspond to the severity of the lameness and subsequently, an MRI examination was performed. The MRI examination revealed the penetrating wound to the sole as a very hyperintense line with small areas of hypointensity on T1, T2\* GRE and STIR-weighted images. The distal part of the DDFT had a very hyperintense signal in the lateral lobe, extending from the navicular bone until its insertion on the distal phalanx, most likely representing severe inflammation possibly with necrosis (Figure 3). Adjacently, a small area of disruption of the flexor cortex of the navicular bone was present. The medullary cavity of the navicular bone and palmar distal phalanx had an abnormal signal on STIR, T1 and T2\* GRE-weighted images. The navicular bursa was severely distended.

The MRI diagnosis was a chronic penetration wound to the sole with severe inflammation and possible necrosis of the lateral lobe of the distal DDFT, and severe inflammation of the navicular bursa. Bony involvement was suspected caused by direct puncture of the flexor cortex.

Because of the severe lesion of the DDFT and the extensive dermatitis, it was decided to perform a 'street-nail' procedure guided by the MRI findings instead of endoscopy of the navicular bursa. During surgery, a large amount of abnormal tissue of the DDFT was debrided. The flexor cortex of the navicular bone revealed subchondral bone changes compatible with the changes visualized by MRI. The navicular bursa was severely distended. Marked synovitis with a fair amount of pannus was present. Lavage and debridement of the navicular bursa were performed. The horse was treated with pressure bandages until the defect in the sole had closed. The horse improved steadily and returned to normal work.

#### Case 4

A six-year-old Dutch Warmblood mare was referred to the clinic with mild right forelimb lameness in walk following an acute puncture wound to the foot. Standard radiographic examination of the foot including radiographs with a sterile metal probe placed in the wound tract was performed. The probe entered the sole in the dorsal part of the frog in a proximal and palmar direction and ended distal to the distal part of the DDFT in the region of the navicular bone. An MRI examination was performed the next day. The hypointense signal of the penetrating tract was identified within the frog and proceeded in two different directions. One tract was visible in a distoproximal direction towards the lateral lobe of the DDFT, distal to the navicular bone. An adjacent small hyperintense line bisecting the lateral lobe of the DDFT was visible on both T2\* and STIR sequences. The second tract

was in a more palmar direction and approached the lateral lobe of the DDFT at the level of the navicular bone. This tract was consistent with the puncture canal seen on the radiographs. The lateral lobe was hyperintense at this location on the T2\* images, and the palmar border of the lateral lobe was hyperintense on STIR images. Mild distension of the navicular bursa with mild synovial proliferation was visible. The MRI diagnosis was a repetitive puncture injury of the sole, which caused damage to the DDFT at two different locations. The most proximal lesion had signs of mild local inflammation. Treatment consisted of superficial debridement of the puncture canal, pressure bandages and systemic antimicrobial therapy. After eight days, the horse went home on oral antibiotics (Trimethoprim Sulfadiazin sodium, Trimethosulfmix 50%®, Eurovet Animal Health, the Netherlands) and was sound in walk.

#### Case 5

A 21-year-old Standardbred broodmare was presented at the clinic with non-weight bearing lameness of the left forelimb of unknown duration. The frog was undermined with a draining tract exiting between the heel bulbs. Standard radiographic examination of the foot was within normal limits. Given the suspicion of an old puncture wound to the lateral frog without a clear puncture tract, it was decided to perform an MRI. A hyperintense area was present on T1, T2\* and STIR images, extending from the lateral frog in a proximal direction towards the navicular bone. On these images, the lateral lobe of the DDFT was hyperintense from the navicular bone to its insertion on the distal phalanx, and in this area, loss of cortical demarcation of the distal phalanx was present. The navicular bursa and DIP joint were not distended. The medulla of the navicular bone and the middle and distal phalanx were hyperintense on STIR and hypointense on T2\* GRE. The MRI diagnosis was severe inflammation with possible necrosis of the lateral lobe of the distal DDFT with bony involvement of the navicular bone, middle and distal phalanx, most likely due to an old puncture wound to the lateral frog. The therapy suggested in this case was debridement of the puncture canal and the necrotic tissue in the DDFT using the street-nail procedure under general anesthesia. The owner declined any therapy given the poor prognosis, the age of the horse and clinical condition. The horse was euthanized.

#### Case 6

A ten-year-old Friesian mare was presented to the clinic with severe lameness of the right forelimb of a ten-days duration. She was non-weight bearing lame and reacted to percussion on the lateral aspect of the right fore hoof. The lameness improved after an

abaxial sesamoidean nerve block. The next day, intra-articular anesthesia of the DIP joint was performed and found positive. Standard radiographic examination of the foot was within normal limits and an MRI examination of the right forefoot was performed. On the MRI examination, the lateral part of the distal phalanx and mid-sagittal part of the navicular bone were hypointense on T1 images and mixed signal on T2\* images. The lateral lobe of the DDFT at its insertion on the distal phalanx had a hyperintense lesion on T1, T2\* and STIR, extending in a distoproximal direction. Loss of cortical demarcation of the distal phalanx was present in this area. The flexor cortex of the navicular bone had mid-sagittal disruption (Figure 4). There was no sign of a puncture tract at either the distal phalanx or the navicular bone. The navicular bursa was not distended. The MRI diagnosis was a puncture wound to the sole, penetrating the DDFT and damaging the distal phalanx and the flexor cortex of the navicular bone. Therefore, it was concluded that the navicular bursa had to have been involved in the process. The position of the lesions in relation to each other is suggestive of two separate puncture canals. Alternatively, the foot may have been in a flexed, non-weight bearing position when it was punctured.

Based on the MRI findings, treatment consisted of debridement of the lesion under general anesthesia using the street-nail procedure, with open lavage of the navicular bursa. Preoperative synovial sampling of the navicular bursa and DIP joint did not show an elevated white blood cell count. During exploration of the puncture canal with a probe, two different canals were found. The second canal extended in the direction of the DFTS. This was followed by needle lavage of the DIP joint and the DFTS to determine any connection with the puncture canal. A piece of foreign material (1 cm x 0.2 cm) and hair was found within the puncture canal. Following the procedure, the foot was put in a pressure bandage. The horse received antibiotics (Marbofloxacin, Marbox<sup>®</sup>, Ceva Santé Animale B.V., the Netherlands) and anti-inflammatory drugs (Phenylbutazone, Equipalazone<sup>®</sup>, Dechra Limited, United Kingdom). After 40 days, the foot of the horse was put in a shoe with a hospital plate and went home for further treatment. Initially, the horse improved, but was euthanized three months post surgery because of persistent lameness, for which the owner did not want further examination or treatment.

### Case 7

A nine-year-old Warmblood gelding was presented to the clinic with a nail penetration of the right forefoot the previous day. The horse was 4/5 lame RF in walk. Standard radiographic views of the right forefoot were made with a metallic probe in the puncture canal, which did not confirm involvement of important structures. The horse was treated conservatively. The

next day, the lameness was still present, and DDFT involvement was suspected. An MRI examination was performed and on T1, T2\* and STIR images, a hyperintense tract was present in the distopalmar cortex of the distal phalanx, extending into the DDFT at its insertion on the distal phalanx. The adjacent area of the distal phalanx and medulla of the navicular bone were hypointense on T1 and T2\* images and hyperintense on STIR images. The navicular bursa was not distended. The MRI diagnosis was a penetrating wound to the sole, damaging the distal phalanx and penetrating the DDFT, with bony involvement, most likely inflammation. No involvement of the navicular bursa was suspected. Treatment consisted of debridement of the lesion under local anesthesia of the foot in the standing horse using the street-nail procedure. The tract could be followed to the distal phalanx, and full length of the tract including the cortex of the distal phalanx was debrided. The foot was put in a pressure bandage. The horse received pre- and postoperative antimicrobials (Trimethoprim Sulfadiazin sodium, Trimethosulfmix 50%<sup>®</sup>, Eurovet Animal Health, the Netherlands) and anti-inflammatory medication (Phenylbutazone, Equipalazone<sup>®</sup>, Dechra Limited, United Kingdom). After 19 days, the horse returned home for further revalidation.

At recheck after one month, the horse was sound at walk and trot. After 3.5 months, the horse gradually returned back to work, and currently, the horse is back in full work.

### Case 8

A six-year-old Warmblood broodmare was presented to the clinic with a 4-5/5 lameness due to a two-week-old puncture wound to the right hind foot. Standardized radiographic examination of the foot was within normal limits. Synovial samples of DIP joint, DFTS and navicular bursa were taken. White blood cell count and total protein were within normal limits. To better define the prognosis, an MRI examination was performed. A penetrating wound to the sole entering the distal DDFT was visible as a hyperintense region on T1, T2\* GRE, T2 FSE and STIR images. Within this tract, hypointense areas were visible, more extensive on the T1 GRE and T2\* GRE. The medial lobe of the DDFT was hyperintense on T1 and T2\* GRE images, extending from proximal to the navicular bone until its insertion on the distal phalanx. The navicular bone and distal phalanx were hyperintense on STIR images. The navicular bursa was mildly distended. The MRI diagnosis was a chronic penetration wound to the sole with associated necrosis of the medial lobe of the distal DDFT and inflammation of the navicular bursa and bony involvement. A street-nail procedure was performed under general anesthesia. The medial part of the frog was resected and a canal surrounded by necrotic tissue was found. All necro-

tic tissues along the canal were debrided, the medial lobe of the DDFT was reached and necrotic tendon tissue was removed. A pressure bandage was applied. Pre- and postoperatively, the horse was administered antibiotics (Sodium-Benzylpenicillin, Benzylpenicilline<sup>®</sup>, Eurovet Animal Health, the Netherlands, Gentamicin, Genta-Ject<sup>®</sup>, Dopharma Research B.V., the Netherlands) and anti-inflammatory drugs (Flunixin Meglumine, Meflosyl<sup>®</sup>, Zoetis B.V., the Netherlands). After three weeks, the horse returned home for further revalidation and has returned to her previous use as a broodmare.

### Case 9

A five-year-old Warmblood stallion stepped into a nail with his right forefoot and was presented the next day at the clinic. The horse was free of lameness in walk, but sensitive to hoof testers over the medial frog. A canal was visible on the medial side of the frog. Subsequent MRI examination of the foot revealed a hypointense puncture tract on T1 and T2\* images, extending from the medial frog in a proximopalmar direction. The penetrating wound did not show any contact with the DDFT, the navicular bursa or the navicular bone. The MRI diagnosis was an acute puncture wound to the foot with bleeding, but without involvement of any vital structures. The MRI images showed that no important structures were involved. Treatment consisted of superficial debridement of the puncture canal and the horse was discharged. The stallion is currently in full work.

### DISCUSSION

In this report, nine horses are described that underwent an MRI examination, all with a history of penetrating injury to the solar surface of the foot. In eight of these cases, a standard radiographic examination was performed. Additional radiographs with a metallic probe inserted in the puncture tract were made in four of these eight horses.

Radiographic examination of the foot may provide information about gross damage to the bony structures. However, it also has limitations. Bone lysis can only be recognized radiographically after 7-10 days, and 30-60% of the mineral content of the bone must be lost before it is detectable on a radiograph (Richardson et al., 1986; Dennis et al., 2010). A metal probe inserted into the puncture tract may fail to demonstrate multiple tracts or the degree of soft tissue involvement (Urraca del Junco et al., 2012), as shown in the present cases. In case 2, a second tract was only detected at the second radiographic examination two days after the initial examination. In case 3, the metallic probe ended palmar to the DDFT, but on MRI examination, both the DDFT and flexor cortex of the

navicular bone were damaged. In case 7, radiographic examination with a metallic probe placed in the puncture canal failed to reveal DDFT involvement, later seen on MRI examination. In case 4, radiographic examination suggested one puncture tract ending palmar to the DDFT at the level of the navicular bone, but the MRI examination revealed a second puncture tract in a different, more distoproximal direction damaging the lateral lobe of the DDFT distal to the navicular bone. MRI also demonstrated a true DDFT lesion at the end of the first puncture tract at the level of the navicular bone.

Contrast radiographic examination was not performed in any of the present cases. Therefore, it cannot be excluded that in a contrast study, it might have been possible to demonstrate the degree of soft tissue involvement in this case series.

Ultrasonography was not performed in any of these cases. Ultrasonography of the distal DDFT via the frog (transcuneal window) or the distal pastern has been described (Sage and Turner, 2000; Busoni and Denoix, 2001; Kristoffersen and Thoenner, 2003). The transcuneal approach requires good preparation of the foot and provides a limited window of view. As only the midline of the DDFT can be imaged, lesions confined to the lateral or medial lobe cannot be seen. Because it is impossible to position the transducer perpendicular to the DDFT, subtle tendon lesions are often missed (Kristoffersen and Thoenner, 2003; Kinns and Mair, 2005). Additionally, in order to achieve a correct placement and adequate contact, it is necessary to prepare the frog thoroughly and soak it for a long period of time (Kristoffersen and Thoenner, 2003; Smith, 2013); inadequate preparation may lead to ultrasound images of unsatisfactory quality. In the acute cases of the present report, the lesions were small, parasagittal and often without enlargement of the DDFT, which, hence, most likely would not have been visible on ultrasound. Imaging from the palmar/plantar aspect of the pastern might have been useful in the chronic cases with extensive DDFT lesions in this study, but often, these horses had already been treated with disinfecting bandages and had developed extensive skin dermatitis, which would interfere with the ultrasound beam.

Synoviocentesis was performed in only three of the nine cases (case 3, 6 and 8). Based on the radiographs using a probe, the navicular bursa was suspected to be the most likely infected synovial structure in the present cases. In the authors' experience, the retrieval of sufficient synovia from the navicular bursa for diagnostic testing is often disappointing, especially, when the structure is open and draining. Bursal synoviocentesis also carries an additional risk in cases with significant dermatitis and/or inflammatory swelling in the pastern area.

Horses that develop synovial infection following penetrating wounds are likely to have multiple bacteria involved (Schneider et al., 1992). Hence, the syner-

gistic combination of penicillin and gentamicin is in most circumstances an appropriate systemic antimicrobial regimen (Wright et al., 2003). All nine horses in this case series were started on broad spectrum antibiotics immediately following submission.

A penetrating tract was visible on MRI examination in eight of the nine cases (89%). In a recent study, a tract was detected in 64% (35/55) of the cases, and all of these tracts appeared as signal voids (Urraca del Junco et al., 2012). In the present study, of the eight visible puncture canals, only three cases had the appearance of a signal void. Two had a hyperintense signal (Figure 5), and a mixed hyperintense and hypointense signal pattern was present in three cases. Hemorrhage may result in both high and low signal intensity depending on the age of the hemorrhage. Hemoglobin breakdown results in hemosiderin and this causes a magnetic susceptibility image artifact, visible as a low signal area or even a signal void (Figure 2). T2\* GRE sequences are most susceptible to this artifact. Comparing T2\* GRE images to T2 FSE images (Figure 1) can hence confirm the likely past occurrence of hemorrhage (Boado et al., 2005; Murray and Werpy, 2011). However, T2 FSE sequences have a longer scanning time and are therefore more susceptible to motion artifact. Additionally, the slices of 2-D T2 FSE imaging sequences are thicker, and therefore more prone to slice thickness volume averaging image artifacts. Air or dystrophic mineralization are also differentials for low signal areas, but were less likely in these cases because no changes were detected where radiographic examination was performed. Fluids, recent hemorrhage or necrosis in the puncture tract are differentials for a high signal.

Lesions within the DDFT were seen as hyperintense regions on T1, T2\*, T2 FSE and STIR weighted images, and are compatible with hemorrhage, edema or necrosis (Blunden et al., 2009). In the acute cases, a narrow hyperintense line was visible within the DDFT, whereas in the more chronic cases, longer and broader lesions in the DDFT were detected. These MRI results were compatible with the MRI results of the chronic longstanding cases described by Boado et al. (2009). In the cases where the lesion was a narrow hyperintense line, the inflammation was considered to be confined to the puncture site, while more widely spread hyperintensity extending over the DDFT was considered to be a severely infected tendon with most probably necrosis.

Although the DDFT had an increased signal from the site of the puncture tract to its insertion on the distal phalanx in both T1 and T2\* sequences, this is not due to the magic angle effect. Tendons and ligaments usually have a low signal intensity on all pulse sequences. The structure of the collagen restricts the motion and orientation of the water protons, which causes fast transverse relaxation (very short T2 relaxation time) due to the high polar interaction between protons (Spriet et al., 2007). This interaction is minimal

when the ligament is oriented at approximately 55° relative to the main magnetic field ( $B_0$ ), increasing the T2 relaxation time. This leads to an increased signal intensity with pulse sequences using a short time of echo (TE), such as PD and T1- and T2\*-weighted sequences, while sequences with a longer TE are less affected. The phenomenon of increased signal intensity in fibrous structures aligned at or near 55° is called the magic angle effect, and has been described in both high and low field magnets (Busoni, 2002; Spriet et al., 2007; Spriet and McKnight, 2009).

In high field systems, the main magnetic field is parallel to the long axis of the limb, and the magic angle effect may lead to a diffuse increased signal intensity in the distal part of the DDFT (Busoni, 2002). In most low field MRI scanners, the main magnetic field is perpendicular to the long axis of the horse's limb, leading to a different appearance. In low field systems with horses in recumbency, slight angulation of the long axis of the limb may result in a focal linear hyperintense DDFT signal, which is not seen on high field scanners, at the palmar aspect of one lobe and the dorsal aspect of the other lobe. This effect is due to the local fiber orientation of the tendon, the palmar aspect of the DDFT having fibres in a diverging orientation from proximal to distal and the dorsal aspect having converging fibers (Spriet and McKnight, 2009).

In low field standing MR systems as used in this study, angulation in the long axis of the limb is unlikely because of the weight bearing position. However, rotation of the foot in the solar plane can cause similar changes in signal intensity in the DDFT as those observed in the recumbent low field MR system, because the relative orientation between the long axis of the tendon fibres and the main magnetic field has to be considered in three dimensions and may again approach 55° (Spriet and Zwingenberger, 2009). Rotation of the foot may be due to positioning of the leg but natural toe-in and toe-out conformation can also result in sufficient rotation relative to the main magnetic field to observe these changes in signal intensity.

The signal changes observed in this study are not compatible with the magic angle artifact and are visible on both the short echo-time and long echo-time MRI pulse sequences.

In five cases (3, 5, 6, 7 and 8), hyperintense areas within the medullary cavity of the bony structures of the foot were present on STIR MRI sequences (Figure 6). These signal changes have been called bone marrow edema-type (BMO-t) lesions (Powell, 2011) and are compatible with fibrosis, bone edema, hemorrhage or bone necrosis (Dyson et al., 2005; Murray et al., 2006; Powell, 2011). The results of the STIR images in a study of Boado et al. (2005) are similar to some results of the present study. However, Boado et al. (2005) did not perform histopathology on the bone marrow lesions. The prognosis of bone marrow lesions is very variable (Werpy, 2009; Powell, 2011). In the present study, it is shown that multiple bone mar-



row edema-type lesions in cases of penetrating injury do not necessarily indicate a grave prognosis.

In cases where the amount of water in the bone marrow equals the amount of fat, an artifactual signal void can occur on T2\* GRE images. This phenomenon is known as the phase cancellation artifact and results from equal amounts of signal from water and fat cancelling each other out (Figures 4 and 7). The signal is indicative of a bone marrow edema-type lesion. Such lesions may also present as a region of intermediate signal surrounded by a distinct low signal rim, where the phase cancellation is not complete in the area with intermediate signal because the amount of fluid exceeds the amount of fat. STIR sequences can be used to definitively indicate the presence of fluid, and assessing T2 FSE or proton density images of the same area can rule out sclerosis (Olive et al., 2009; Werpy, 2009; Murray and Werpy, 2011). According to Urraca del Junco et al. (2012) T2\* GRE is the most useful imaging sequence for assessing sole penetrations because of the minimal scanning time and the possibility of identifying hemorrhage (magnetic susceptibility artifact). As mentioned above, this sequence also allows for the fat-water phase cancellation artifact, which is highly suggestive of a bone marrow edema type-lesion. Therefore, bony involvement should be considered. In confirmation, additional imaging sequences should be used. Adding a T2\* GRE sequence in the MRI protocol is recommended whenever a sole penetration is suspected.

In five cases of the present study, the MRI images of some sequences were suboptimal. Previous therapy with wet disinfecting bandages resulting in very wet coat and skin caused the images to be grainy in some sequences. Motion artifacts were another reason for suboptimal images, as these horses were sometimes very painful and difficult to keep still during MRI examination. Although local anesthesia was used in these cases, weight bearing could not always be maintained. Some horses stepped out of the magnet and although they could be repositioned, this sometimes led to shortened, suboptimal, but still diagnostic MRI studies.

Of the nine cases, two horses (2 and 5) were euthanized because of the guarded prognosis. Case 2 showed a small lesion in the DDFT and involvement of the navicular bursa and DSIL. In this case, a bursectomy combined with superficial solar debridement was recommended as the best treatment option, but was declined by the owner. Case 5 showed very extensive necrosis of the DDFT and involvement of the navicular bone, the distal phalanx and the middle phalanx. A street-nail procedure was suggested, but considering the advanced age of the horse, the costs and the chronicity of the lesions, the owner decided not to continue the treatment. In both cases, the MRI examination helped to obtain a detailed diagnosis and prognosis, based on which the owner could make an advised decision. Synoviocentesis of the navicular bursa would probably also have shown the involve-

ment of this structure but the involvement and extent of involvement of the other structures, like DSIL and DDFT, could not have been assessed thoroughly without MRI. Their involvement has a negative influence on the prognosis.

The owners of the other seven cases decided in favor of treatment, which consisted of superficial debridement in two cases (4 and 9), bursectomy in 1 case (1) and surgical debridement using the street-nail procedure in four cases (3, 5, 6 and 7). In these cases, the extent of the street-nail procedure was guided by the MRI observations.

According to Urraca del Junco et al. (2012), MRI findings correspond poorly with surgical findings in patients with a penetrating sole injury. In the present study however, a significant correspondence for most of the MRI findings was found. Bone marrow lesions visible as bone marrow edema-type lesions cannot be assessed during surgery without bone histology; hence, correspondence between these findings cannot be expected. In two of the three cases, cortical bone lesions visible on MRI (cases 3 and 7) were confirmed during surgery (Figure 7). In case 6, the cortical bone lesions of both navicular bone and distal phalanx could not be observed during surgery due to the surgical technique used. In the authors' experience, cortical bone lesions present on MRI images showed a significant correspondence with the surgical findings.

The piece of foreign material (1 cm x 0.2 cm) and hair present in the puncture canal of case 6 were not visible on MRI. This could have been due to the relatively small size of both foreign objects, but might also have been caused by insufficient signal difference with the surrounding tissues.

In three cases (cases 1, 2 and 3), the navicular bursa was severely distended on MRI. In cases 1 and 3, this finding was confirmed during surgery. The horse of case 2 was euthanized. In cases 4 and 8, the bursa was mildly distended on MRI, and it was decided not to perform a synoviocentesis. In case 8, a negative synovial sample was obtained prior to surgery. It is debatable whether this should also have been performed in case 4.

Of the eight cases with a visible puncture tract on MRI, six cases underwent surgery. Of these six cases, three cases had large areas of high MRI signal in the puncture tract and extensive necrotic tissue was removed from the puncture tract during surgery (Figure 5). This suggests that the high signal was due to necrosis. The other three cases had low MRI signal in the puncture tract and only a small amount of dead tissue was found.

Two puncture tracts were visible on the MRI images in case 4, and suspected in case 6. However, this could not be confirmed during surgery in case 4 because only superficial debridement was performed. In case 6, two different canals were found during surgical exploration of the puncture canal.

In eight (cases 1-8) of the nine cases, a lesion in

the DDFT was diagnosed during MRI. Of these eight cases, five cases (cases 1, 3, 6, 7 and 8) underwent surgery, in which the DDFT was explored, two horses were euthanized (cases 2 and 5) and in one horse (case 4), only superficial debridement was performed. In cases 3 and 8, a large hyperintense area in the DDFT was visible on MRI, and a large portion of necrotic tendon was removed during surgery. In the other cases, a small DDFT lesion compatible with the MRI images was visible during surgery.

According to the literature, the prognosis after endoscopic lavage of the bursa is considered better than using the street-nail procedure, because it is less invasive and the recovery period is shorter (Wright et al., 1999; Smith, 2013). In the present cases, the authors decided to perform the street-nail procedure when a larger area of the DDFT was necrotic or when, based on the MRI images, bony structures were directly involved, because debridement of these structures is limited via bursoscopy. Nevertheless, the street-nail procedure can be guided by the MRI images and therefore be as minimally invasive as possible, hence improving recovery.

Case selection, based on a detailed MRI assessment of the structures involved, is very important to determine the most appropriate surgical procedure.

Although in this study, only a small number of cases are described, it shows that MRI is a very helpful tool in assessing the number of puncture tracts, their direction and the soft tissue and bony structures involved. Additionally, it gives an indication of the severity of the damage and the extent of the resulting infection. This may lead to a more effective surgical approach. Therefore, in the authors' opinion, MRI examination should be performed whenever practically possible, as the findings of the present study suggest that MRI is helpful in deciding the best possible therapy for horses with a penetrating wound to the sole of the foot.

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## Persbericht

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