Outcomes of Medical Treatment for Pathologies of the Equine Foot Diagnosed with Magnetic Resonance Imaging

Santiago Daniel Gutierrez-Nibeyro, M.V.

Thesis submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Masters of Science

In

Biomedical Veterinary Sciences

Nathaniel A. White (Committee Chairman)
Kenneth E. Sullins
Jill McCutcheon
Natasha M. Werpy

July 15, 2008
Leesburg, Virginia

Keywords: Low-field MR imaging, foot pathologies, medical treatment, and horse

Copyright 2008, Santiago Gutierrez-Nibeyro
Outcomes of Medical Treatment for Pathologies of the Equine Foot Diagnosed with Magnetic Resonance Imaging

Santiago Daniel Gutierrez-Nibeyro, MV

ABSTRACT

A retrospective study was performed to determine the prevalence of foot pathologies of horses subjected to magnetic resonance imaging for foot lameness and to determine the long-term outcome of horses after medical treatment. The MR studies of 95 horses were interpreted retrospectively by a boarded certified radiologist. Follow-up information was obtained from medical records, owners and referring veterinarians via telephone questionnaires. Long term response to treatment (minimum of 12 months) was recorded. Horses were divided in two different groups based on the diagnosis and on the treatment using intrasynovial antiinflammatory drugs or not. Logistic regression analysis was performed to compare the outcome between the two groups.

The null hypothesis was that the proportion of horses treated successfully between treatment protocols was similar.

A diagnosis based on magnetic resonance imaging was made in all horses. Approximately 30% of horses had ≥ 4 lesions, which were determined to be responsible for the lameness and 70% of horses had navicular bone abnormalities. Treatment was
determined by individual clinician judgment. No significant difference was found in the long-term outcome between treatment groups. This result suggests that intrasynovial antiinflammatory drugs may not provide additional benefit over corrective shoeing, rest followed by controlled exercise in horses with lesions of structures associated with the navicular apparatus or the distal interphalangeal joint.
DEDICATED TO

Mauricio D. Gutierrez and Carmen E. Nibeyro

My mother and father who have provided never-ending support through my career and who gave me the opportunity to follow my dreams in life.
ACKNOWLEDGEMENTS

Nathaniel A. White II- my research advisor and mentor, for his support, patient and guidance through my residency and graduate programs.

Natasha M. Werpy- for her time dedicated to evaluate the magnetic resonance studies.

Kenneth E. Sullins- for his support and constructive criticism of the manuscript.

Jill McCutcheon- for her guidance and constructive criticism of the manuscript.

David Hoberman- for statistical analysis of the data
LITERATURE REVIEW

1. Diseases of the Equine Foot

Diagnosis
1.1. Disorders of the hoof capsule.................................1
1.2. Disorders of the distal phalanx...............................11
1.3. Disorders of the navicular apparatus and distal interphalangeal joint .............................................17

Treatment and Prognosis
1.1. Disorders of the hoof capsule.................................27
1.2. Disorders of the distal phalanx...............................37
1.3. Disorders of the navicular apparatus and distal interphalangeal joint .............................................44

2. MR imaging for diagnosis of orthopedic conditions
2.1 Background.................................................................49
2.2 Physics.................................................................50
2.3. Differences between low-and high-field magnet .......58
2.4. Pulse sequences used for orthopedic conditions.......61
2.5. Tissue appearance with different MRI sequences........67

Human Applications
2.6. Detection of human orthopedic injuries with MR.......70
2.6.1. Normal appearance and injuries tendon and muscles.................................................................70
2.6.2. Normal appearance and injuries of ligaments........74
2.6.3. Normal appearance and injuries of osseous structures.................................................................75
2.6.4. Normal appearance and injuries of joints ..............77
Application of MR imaging to Equine

2.7. Detection of equine orthopedic injuries with MR........78

2.7.1. Normal appearance and injuries of tendon and ligaments..............................................................78
Corroboration with other modalities:
Radiography.........................................................81
Ultrasonography.....................................................81
Scintigraphy..........................................................82
MR comparison with gross lesions.................................83
MR comparison with histologic lesions............................84

2.7.2. Normal appearance and injuries of the navicular apparatus.....................................................................85
Corroboration with other modalities:
Radiography.........................................................89
Ultrasonography.....................................................91
Scintigraphy..........................................................91
MR comparison with gross lesions.................................93
MR comparison with histologic lesions............................93

2.7.3. Normal appearance and injuries of the hoof capsule .................................................................96
Corroboration with other modalities:
Radiography.........................................................96
Ultrasonography.....................................................97
MR comparison with gross lesions and histologic lesions..................97

2.7.4. Normal appearance and injuries of bones and joints........................................................................97
Corroboration with other modalities:
Radiography.........................................................100
Ultrasonography.....................................................100
Scintigraphy..........................................................101
MR comparison with gross lesions.................................101
MR comparison with histologic lesions............................101
OUTCOMES OF MEDICAL TREATMENT FOR PATHOLOGIES OF THE EQUINE FOOT DIAGNOSED WITH MAGNETIC RESONANCE IMAGING

1. Introduction.................................................................125
2. Materials and methods..................................................128
3. Results........................................................................134
4. Discussion....................................................................141
5. References....................................................................150

12. CONCLUSIONS..........................................................175
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Sagittal GE T1-weighted image obtained from a horse with enlarged synovial invaginations in the distal border of the navicular bone. There is a large cystic-like lesion characterized by abnormal intermediate signal intensity at the distal half of the navicular bone outlined by a rim of decreased signal intensity (arrow). This is consistent with enlarged synovial invaginations and/or trabecular bone resorption at the attachment of the origin of the distal sesamoidean impar ligament.</td>
<td>153</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Transverse FSE T2-weighted image obtained from same horse of figure 1. The image was obtained at the level of the middle phalanx. Medial is to the right. There is marked effusion of the navicular bursa (arrows).</td>
<td>154</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Transverse FSE T2-weighted image obtained at the level of the middle phalanx. Medial is to the left. Although the image was obtained with a mild degree of obliquity which sometimes can cause distortion in size and signal intensity, there is enlargement and generalized increased signal intensity of the medial collateral ligament of the distal interphalangeal (arrow).</td>
<td>154</td>
</tr>
</tbody>
</table>
Figure 4: Sagittal FSE STIR image obtained from the same horse in figure 3. There is diffuse hyperintense signal in the navicular bone medulla (arrow). The horse was turned out in a small paddock for 8 months and returned to full work.

Figure 5: Transverse FSE STIR image of a horse with a 2 week history of severe right forelimb lameness obtained at the level of the middle phalanx. Medial is to the left. There is marked enlargement and generalized increased signal intensity of the medial collateral ligament of the distal interphalangeal joint (arrow). The periligamentous tissues are thickened with diffuse increased signal intensity and loss of definition of the tissue planes. The increased signal intensity is more prominent along the palmar margin of the medial collateral ligament indicating periligamentous edema and swelling (arrowhead). The horse had stall rest, was treated with extracorporeal shock wave therapy and shod with a wide webbed shoe; however radiographic changes of osteoarthritis of the distal interphalangeal joint was detected 3 months after MR examination and resulting in a poor outcome.
Figure 6: Transverse FSE T2-weighted image obtained at the level of the middle phalanx. Medial is to the right. The image was obtained with a slight degree of obliquity. The medial lobe of the deep digital flexor tendon is markedly enlarged and there is a linear area of abnormal intermediate to high signal intensity on the axial portion of the medial lobe (parasagittal lesion). Also, there is an area of abnormal intermediate to high signal intensity on the center of the medial lobe that extends through the dorsal margin of the medial lobe (core lesion and dorsal border lesions respectively; arrowhead). The normal fluid signal within the navicular bursa at the level of the tendon lesions has been replaced by an area of intermediate signal intensity which is compatible with synovial proliferation or focal adhesions. There is also effusion in the proximal lateral recess of the navicular bursa (arrow). Although the medial collateral ligament of the distal interphalangeal joint has normal signal intensity, it appears moderately enlarged, likely due to slight obliquity of the image and wide base stance. The horse was subjected to treatment 1 with an extensive period of rehabilitation but was still lame 24 months after MR examination.
Figure 7: Sagittal GE T1-weighted image obtained from a horse with a 3 week-old history of severe lameness. The distal phalanx has a linear area of increased signal intensity compatible with a distal phalangeal fracture (arrow). This linear defect has a contiguous area of marked low signal intensity, which is compatible with fluid accumulation or sclerosis of the adjacent bone; however comparison with FSE T2-weighted images is necessary to fully characterize this lesion.

Figure 8: Transverse FSE T2-weighted image obtained from same horse in figure 7 at the level of the distal phalanx. Medial is to the right. As in previous figure, the distal phalanx has a linear area of increased signal intensity (arrow). This linear defect has a contiguous area of diffuse low signal intensity, which is compatible with bone mineralization or sclerosis (arrowhead). The horse returned to full work after 14 months of rest and rehabilitation.

Figure 9: Sagittal FSE STIR image obtained from a horse with a chronic forelimb lameness. There is an extensive hyperintense signal area in the dorsodistal aspect of the middle phalanx compatible with fluid accumulation within the cancellous and subchondral bone. This finding is consistent with bone bruising (arrow). The horse returned to full work and remained sound after to 3 months of stall rest with increasing periods of handwaking.
Figure 10: Sagittal FSE STIR image obtained from a horse with a chronic forelimb lameness. There is marked effusion of the distal interphalangeal joint characterized by severe fluid distension of the dorsal pouch of the joint.

Figure 11: Sagittal GE T1-weighted image obtained from the same horse in figure 10. There is an irregular area of intermediate signal intensity at the dorsodistal aspect of the middle phalanx (arrow). This abnormal signal intensity is at the level of the distal interphalangeal joint capsule attachment to the middle phalanx and is consistent with osteophyte formation. Abnormalities of the articular cartilage of subchondral bone are not visible. The horse developed radiographic evidence of osteoarthritis of the distal interphalangeal joint 3 months after MR examination.

Figure 12: Sagittal GE T1-weighted image obtained from a horse with bilateral forelimb radiographic evidence of subchondral bone cyst in the distal phalanx. There is an elliptical focal area of intermediate signal intensity within the subchondral bone of the distal phalanx (arrow). The cyst is surrounded by a diffuse area of decreased signal intensity consistent with bone sclerosis. This horse developed osteoarthritis of both forelimb distal interphalangeal joints.
Figure 13: Transverse FSE T2-weighted image obtained from a horse with an acute and severe fore limb lameness. The image was obtained at the level of the distal phalanx with a mild degree of obliquity. Medial is to the left. There is an extensive area of intermediate to high signal intensity along the medial sulcus of the frog consistent with fluid accumulation between the cuneal corium and the sole. A subsolar abscess was found and drained after MR examination.

Figure 14: Sagittal GE T2*-weighted image obtained from a horse with a history of bilateral chronic forelimb lameness. There is an area of intermediate to low signal intensity outlined by a rim of decreased signal intensity in the level of the distal border of the navicular bone (arrow). This is consistent with enlarged synovial invaginations in the distal border of the navicular bone. In addition, there is moderate effusion of the dorsal and palmar pouches of the distal interphalangeal joint.
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Summary of abnormalities of the navicular bone detected with a high-field MR.</td>
<td>87</td>
</tr>
<tr>
<td>Table 2</td>
<td>Pulse sequence parameters.</td>
<td>165</td>
</tr>
<tr>
<td>Table 3</td>
<td>Summary of MR findings of 95 horses affected by foot lameness used to establish the presence of lesions in each anatomic structure.</td>
<td>166</td>
</tr>
<tr>
<td>Table 4</td>
<td>Criteria used for classification of deep digital tendon abnormalities based on its location (adapted from Murray et al. 2004).</td>
<td>167</td>
</tr>
<tr>
<td>Table 5</td>
<td>Criteria used for grading navicular bone lesions.</td>
<td>168</td>
</tr>
<tr>
<td>Table 6</td>
<td>Criteria used for grading the navicular bursa lesions.</td>
<td>169</td>
</tr>
<tr>
<td>Table 7</td>
<td>Radiographic, ultrasonographic and nuclear scintigraphic abnormalities detected in 95 horses prior to MR examination.</td>
<td>169</td>
</tr>
<tr>
<td>Table 8</td>
<td>Horse’s occupation, structures affected and mean number of structures with MR abnormalities detected in 95 horses.</td>
<td>170</td>
</tr>
<tr>
<td>Table 9</td>
<td>Results of logistic regression analysis.</td>
<td>171</td>
</tr>
<tr>
<td>Table 10</td>
<td>Percentages of MR identified lesions in each treatment group.</td>
<td>172</td>
</tr>
<tr>
<td>Table 11</td>
<td>Results of univariable regression model indicating association of abnormal MR findings with poor outcome.</td>
<td>173</td>
</tr>
</tbody>
</table>
LIST OF GRAPHS

Graph 1: Location of abnormal findings detected on MR images of 95 horses affected by foot lameness. 174
LIST OF ABREVIATIONS

MR= magnetic resonance
CT= computed tomography
DDFT= deep digital flexor tendon
DFTS= digital flexor tendon sheath
DIP= distal interphalangeal
PIP= proximal interphalangeal
NSAIDs= non steroidal antiinflammatory drugs
DSIL= distal sesamoidean impar ligament
CSL= collateral sesamoidean ligament
DMSO= dimethyl sulfoxide
MMPs = metalloproteinases
SBC= subchondral bone cyst
IRU= increased radiopharmaceutical uptake
OA= osteoarthritis
ESWT= extracorporeal shock wave therapy
RF=radiofrequency
TR=repetition time
TE=echo time
SE=spin echo
FSE=fast spin echo
STIR=short tau inversion recovery
FLAIR=fluid attenuated inversion recovery
GE=gradient echo
PD=proton density
ACL= anterior cruciate ligament
CL= collateral ligaments
LITERATURE REVIEW

1. DISEASES OF THE EQUINE FOOT

Multiple disorders affect the equine foot, especially the digit of the equine athlete. These can be arbitrarily divided into disorders of the (a) hoof capsule, (b) the distal phalanx, and (c) the navicular bone and surrounding structures. All of these conditions are characterized by pain that can be localized within the hoof [1].

Approximately one third of all forelimb lameness in horses originates from the caudal third of the foot[2]. Lameness originating from this particular region of the foot (which includes the navicular syndrome) has generally been associated with pain arising from the navicular bone or related structures; however, other structures in the foot can also cause lameness[3].

DIAGNOSIS

1.1. DISORDERS OF THE HOOF CAPSULE

Hoof Wall Cracks or Defects

Most commonly, a hoof wall crack or defect is a longitudinal disruption of the hoof wall parallel to the horn tubules and lamellae. However, hoof wall cracks can be oriented perpendicular to horn tubules and coronary band. In general, these defects can by classified by their location (toe, quarter, heel or bar), length (partial or full length), depth (superficial or deep), and the presence or absence of hemorrhage or infection [4, 5].
Lameness associated with hoof wall defects is due to irritation of the sensitive lamellae due to exposure, local infection, or shearing of the unstable hoof capsule. Hoof wall defects should be examined and probed to determine their depth and to determine involvement of the sensitive tissue[6]. Diagnosis is made by close visual inspection of the hoof and radiography. Radiography may be helpful in identifying gas under the hoof wall or bone lysis, which may indicate infection or undermined hoof wall[5, 6].

Lacerations to the Foot and Coronary Band

Coronary band and heel lacerations occur at the transition between the skin and hoof capsule[5]. Common complications of hoof lacerations with loss of germinal tissue, and either partial or total avulsions of the hoof wall, result in permanent hoof wall defects called horn spurs, permanent cracks, or hoof wall deformation[7, 8]. Complete examination of deep wounds is necessary to determine if involvement of underlying structures such as the navicular bursa; distal interphalangeal (DIP) joint; digital flexor tendon sheath (DFST); superficial digital flexor tendon (SDFT) and deep digital flexor tendon (DDFT); distal digital annular ligament; distal sesamoidean impar ligament (DISL); digital artery, vein or nerve; collateral cartilages of the distal phalanx [7].

Radiographic examination of the digit is used to rule out concomitant fractures of the distal phalanx, and contrast radiographic studies may be helpful to identify penetration of synovial structures [7, 9]. Alternatively, the use of an sterile probe under radiographic control has been recommended for determine what structures are affected, but it should be performed cautiously to avoid penetrating unaffected synovial structures with the probe [7].
Hoof Wall Separation (White line disease)

White line disease is characterized by deterioration of the white line of the hoof capsule resulting in loss of bond between the hoof wall and its laminar attachment [5, 9]. An abnormal defect within the white line predisposes to fungal or bacterial colonization and secondary infection which crates cavities between the laminae and the outer hoof wall [10], sometimes leading to complete separation of the hoof wall from the laminae [6, 11]. This condition appears to be more prevalent in geographic regions with warm and humid climates [12, 13].

Diagnosis is made on the basis of the characteristic clinical signs. The hoof wall damage can be extensive with lameness resulting from mechanical loss of horn support and concomitant lameness. Visual examination of the white line, assisted by probing, reveals a cavity with separation of the stratum medium. In severe cases, radiographic examination is helpful to determine the full extent of hoof wall separation and to determine the presence of distal phalanx rotation. Radiographic abnormalities in affected horses include an increase in the distance between the outer surface of the dorsal hoof wall and the dorsal surface of the distal phalanx, and a radiolucent area (air density) in the region of the stratum medium [11, 12, 14].

Keratoma

Keratomas are aberrant, hyperplastic, keratin masses that normally arise from the epidermal keratin-producing cells of the stratum germinativum of the coronary band but can also originate from any point of the inner surface of the hoof wall or from the
Keratomas are interposed between the stratum medium of the hoof wall and the underlying distal phalanx and cause pressure necrosis of the soft tissues and distal phalanx resulting in intermittent lameness. Persistent drainage from the white line or coronary band may be seen [6].

The etiology is uncertain but it has been associated with trauma or chronic irritation from direct hoof injury or sole abscess, but this theory has not been scientifically proven [18, 19]. Histologically, there are masses with abundant keratin and squamous epithelial cells with granulation tissue and occasionally inflammatory cells[19]. Some affected horses may have bulging in the hoof wall near the coronary band and some may have normal appearance of the hoof wall [18]. Inspection of the sole may reveal abnormal configuration of the white line because the lamellar horn of the white line is replaced by tubular horn and scar tissue [5]. Large masses can be located by radiography once the tumor has created a bone defect in the distal phalanx. The defect is normally a circular deformity with smooth edges in the distal phalanx. In some cases, this bone defect may be delineated by a sclerotic rim [17]. The characteristic ultrasononographic appearance of a keratoma has been reported and this imaging modality can be helpful in identifying keratomas at the coronary band [20].

Contusions of the Sole (sole bruising)

A bruise results from the rupture of blood vessels in the dermis (corium) beneath the sole, frog, or hoof wall [13, 21]. Contusion or impact injury that causes focal or generalized damage with subsequent hemorrhage of the solar corium is a common cause of lameness in horses [9]. The resulting hemorrhage is trapped within the solar tissues
and causes varying degrees of lameness. Sole bruising is caused by trauma to the sole or abnormal focal weight-bearing portion of the sole [9, 11]. Flat foot conformation appears to predispose to bruising, because the sole repeatedly strikes the ground surface. Other predisposing factors are improper trimming and shoeing [9].

Bruising can occur in any location on the bottom of the foot as well as the frog. The medial heel is the most common location for a bruise which is named “corn” [21, 22]. Careful hoof tester evaluation often reveals a focal painful response. Discoloration of the sole is a common feature, but if the bruise is deep, or if the horse’s sole is pigmented, bruises may be difficult to identify [9]. Removal of the shoe usually increases the degree of lameness. Radiographic changes are uncommon but persistent, chronic bruising may lead to demineralization and irregularity of the solar margin of the distal phalanx [21].

Sub-solar Abscess

Sub-solar abscess, which results from sepsis within the sensitive lamina of the foot, accounts for one of the most common causes of acute lameness in all horses [5, 9]. After penetration of bacteria into the sensitive lamina, a localized septic process results in accumulation of purulent material within the hoof capsule [5]. Hoof infection may originate from a penetrating wound in the sole, a nail hole, a deep sub-solar bruise, chronic laminitis, etc. Because the hoof capsule provides a solid external shield, pressure increases between the distal phalanx and hoof wall often leading to severe pain. Lameness is usually acute and severe, and may worsen over time until drainage of the
abscess is established. Drainage through the coronary band is common if the infection is located in the lamina of the hoof wall [5, 9].

Examination of the sole may reveal a tract, a sole puncture, or a soft and painful area overlying the abscess. Application of hoof testers to the affected sole usually results in a painful response directly over the abscess site [6]. Careful paring of the sole and frog may be helpful in localizing the abscess. Foot poultices and soaks with Epsom salts help to localize the affected area especially in horses with hard horn. Radiographic examination may be helpful to identify sites of gas or fluid beneath the sole or hoof wall, and to rule-out osteomyelitis or other causes of severe lameness of the distal limb. Abscess drainage confirms the diagnosis [5, 6, 9].

Penetrating Injuries to the Sole (Puncture wounds)

Puncture wounds of the foot are classified according to their depth and location. Superficial wounds penetrate only the cornified tissue and do not invade the corium, whereas deep wounds penetrate the germinal epithelium and damage deep structures of the foot such as navicular bursa, digital cushioning, digital flexor tendon sheath (DFTS), distal phalanx, or distal interphalangeal joint [9, 23].

The clinical signs may vary depending on the depth (superficial or deep), location, and chronicity of the injury. Superficial wounds tend to be asymptomatic for few days until inflammation and infection occurs, whereas deep wounds generally result in acute lameness. Careful examination of the sole (visual, hoof tester, and probing) and coronary band is fundamental to determine the extension and seriousness of the injury [9, 13].
Radiography and fistulography are standard methods for investigating penetrating wounds in the foot [23], however, in chronic cases a fistulous tract may not be present [24]. If a foreign body is present in the bottom of the foot, it may be left in place, unless there is danger of further penetration, and radiographic examination carried out to determine the depth and orientation of the wound. Sterile probing of the tract is useful to identify the depth and direction of the injury and it may be complemented with radiographs while probing. Swelling of the DFST and DIP joint may indicate synovial sepsis as a result of the puncture[13]. Distension of the navicular bursa, DIP joint, and DFTS with contrast medium through a needle inserted percutaneously at a distant location may also allow detection of a fistulous tract and contamination of these structures. This technique may be preferred over fistulogram because it minimizes further contamination [6, 25].

Radiographs may be repeated two to three weeks after injury because osseous change secondary to infection and inflammation, such as lysis, irregular margins, increased vascular channel size, and bone sequestrum formation may not be immediately evident [23]. Transcuneal ultrasonography may reveal some information after a penetrating injury to the frog and its sulci [24]. The technique can be used to image the DDFT, the DSIL, the navicular bursa, the flexor surface of the distal phalanx, and the navicular bone, but the technique is limited to the midline [26]. MR imaging appears to be a valuable diagnostic tool with obscure foot lameness associated with penetrating wounds because it provides excellent anatomical detail of the structures involved with the puncture [24, 27].
Canker

Canker is a chronic hypertrophic pododermatitis of the frog that may undermine the sole and heel bulbs. This condition is rarely seen in other areas of the hoof, but it can spread to the adjacent sole and even involve the hoof wall [5, 13]. The hallmark of this chronic inflammatory reaction is an abnormal keratin production, or dyskeratosis, which is seen as filamentous fronds of hypertrophic horn. The etiology of canker is uncertain, but affected horses often have a history of being housed in moist unhygienic conditions [28]. The causative organisms are thought to be *Fusobacterium necrophorum* and *Bacteroides spp* [29], however, spirochetes were identified histologically in proliferative pododermatitis in these horses more recently [30]. A presumptive diagnosis of canker is based on the gross appearance of the affected horny tissue along with a fetid odor, but a definitive diagnosis is confirmed with a biopsy, particularly in cases when the lesions do not have the characteristic appearance or they appear in unusual locations of the foot [31].

Thrush

Thrush is a localized infection within the central or lateral sulcus of the frog, which is characterized by the presence of a black necrotic foul odorous exudate in the affected areas [5, 13]. The infection may spread to involve deeper structures of the foot, such as the digital cushion, hoof wall, and heel bulb region, causing inflammation and breakdown of the structures resulting in swelling of the distal limb and lameness [28]. Unhygienic stable conditions, neglected foot care, lack of exercise, and inadequate or improper trimming, which promotes long contracted heels and deep sulci, appear to be
predisposing factors. *Fusobacterium necrophorum* is reportedly the most common isolated organism, but published data on the true incidence of the presence of this organism and others are lacking [9, 22]. Recently, keratino-pathogenic fungi were isolated from healthy and diseased hooves of horses, but the association of onychomycosis and thrush has not been proven [10].

Diagnosis of thrush is based on the presence of a black, malodorous discharge located within the frog. The central sulcus of the frog is often malformed and deep, and the infection may extend proximal to the hairline on the heels. Insertion of a hoof pick or tongue depressor between the heel bulbs towards the hair line frequently elicits pain and bleeding as it contacts the sensitive tissues of the frog. Lameness and pain with manipulation of the frog are variables findings [9, 13].

**Laminitis**

Laminitis refers to inflammation of the pedal laminae, which connects the hoof wall to the distal phalanx [32]. Continuous inflammation with subsequent necrosis of the digital laminae may lead to separation of the distal phalanx from the hoof wall and cause secondary rotation or distal displacement (sinking) of the distal phalanx [13, 32]. The laminar separation occurs at the junction between the connective tissue of the dermis (corium), and the basal cell layer of the epidermal lamellae, specifically at the level of the basement membrane. During the acute phase of lamellar inflammation, epidermal cell detachment and lysis of the lamellar basement membrane occurs, leading to failure of the lamellar structure and subsequently disruption between the hoof wall and the distal phalanx [32].
Several mechanisms for the laminar degeneration have been proposed but the pathogenesis of laminitis remains unknown. Researchers have developed models of laminitis (carbohydrate overload, black walnut, and traumatic/mechanical) to experimentally recreate the disease that mimics the naturally occurring disease clinically and histologically [33]. Three pathogenic theories have been proposed for the development of acute laminitis.

The vascular ischemic hypothesis proposes that the blood supply is shunting away from the lamellae due to venoconstriction, microthrombosis, or perivascular edema. Such alterations in the blood flow of the digit results in ischemia and cellular death leading to dermal/epidermal separation [34]. The toxic/metabolic theory suggests that initiation of laminitis results from hematogenous delivery of a toxic trigger factors that activate endogenous enzymes of the dermal/epidermal region. Activated metalloproteinases (MMPs) degrade the extracellular matrix, basement membrane, and the molecular components of the extracellular matrix that attach the epithelial cells to the basement membrane. Breakdown of the epithelial/basement membrane compound leads to loss of supporting structure between the third phalanx and the hoof wall [35]. The systemic/digital inflammation theory proposes that systemic inflammatory stages, such as endotoxemia or sepsis, alter the function of the homeostatic mechanisms within various organs systems resulting in fluid imbalance, coagulopathy, and increased circulating inflammatory mediators. As a result, intravascular coagulation and microthrombi formation within the digital vasculature leads to decreased blood flow concurrent with the development of laminitis [33].
Diagnosis of laminitis is based on clinical signs and radiographic examination. The degree of lameness is variable and it may involve one or more feet. Horses may be reluctant to move and usually develop a distinctive gait characterized by postural efforts to shift weight from the affected feet as well as increased digital pulses and pain over the toe region [13]. Radiographic examination is critical to assess distal phalanx rotation or distal displacement (sinking). Rotation is the most common displacement and is caused by disruption of the dorsal laminar attachment and the force of the deep digital flexor tendon during weight bearing [12, 14]. Venograms of the digit have been described to identify perfusion deficits and to determine prognosis, although has not been proven in a large number of cases [36]. Recently, MR imaging has been proposed as a diagnostic imaging modality for early detection of laminitis [37]. In an experimental study, MR imaging examination of horses with chronic laminitis revealed laminar pathology which was not detected with conventional radiography [38]. In the future, MR imaging might be used in horses to recognize the developmental phase of laminitis allowing early treatment [37].

1.2. DISORDERS OF THE DISTAL PHALANX

Fractures of the Distal Phalanx

Fractures of the distal phalanx have been classified into seven different types [39-41], although a simple anatomic description is considered acceptable [42]. Type I is an abaxial fracture without joint involvement (non-articular wing fracture), whereas type II is an abaxial fracture with joint involvement (articular wing fracture). Type III is a sagittal or axial fracture with joint involvement. Type IV are fractures of the extensor
process and type V are comminuted or multifragment fractures. Type VI are fractures of the solar margin, and type VII are palmar process fractures.

Acute trauma, chronic fast or excessive work or laceration of the hoof capsule induces fractures of the distal phalanx [41]. Breed and athletic use of the horses will determine the type of fracture seen. However, regardless of the type, forelimbs are affected in more than 80 % of distal phalanx fractures [39]. Diagnosis is based on clinical signs and radiographic examination. Acute, moderate to severe lameness accentuated during turns and positive response to hoof testers are strongly suggestive of pedal bone fracture [5, 39]. The diagnosis is confirmed with radiographs in most cases, although occasionally is difficult to detect a fracture line because of minimal displacement. When a fracture is suspected but not visualized, stall confinement and recheck radiographs in 7 to 10 days are recommended to detect osteolysis at the fracture margins [39]. Scintigraphy, CT and MR imaging have been used to recognize distal phalanx fractures [43, 44].

Pedal Osteitis

Pedal osteitis has been defined as the inflammation of the distal phalanx characterized by osteolysis and classified as a non-septic or septic pedal osteitis [13]. Although non-septic pedal osteitis has been suggested as a source of lameness based on its radiographic appearance, several authors agree that non-septic pedal osteitis is a radiographic description of the structural changes at the solar margin or palmar process of the distal phalanx rather than a proven disease and cause of lameness. Additionally, the radiographic changes attributed to pedal osteitis can also be associated with conditions
such as severe or chronic sole contusion during exercise on hard surfaces, chronic laminitis, corns, deep sole bruises, or conformational defects [45, 46].

Septic pedal osteitis is characterized by purulent exudate with radiographic evidence of osteolysis of the distal phalanx [13]. It may be associated with chronic laminitis, sub-solar abscesses, avulsion of the hoof wall, and penetrating wounds that lead to introduction of pathogens deep into the soft tissues of the foot and subsequent extension of infection into the adjacent bone of the distal phalanx. Progression of the osseous infection results in sequestrum formation [9, 47].

Clinical signs attributed to non-septic pedal osteitis include lameness, which is accentuated after exercise or trimming, positive response to hoof testers around the solar margin of the distal phalanx, and elimination of the lameness after perineural anesthesia of the palmar digital nerves [13]. A definitive diagnosis of osteitis of the distal phalanx requires scintigraphic and radiographic evidence of inflammation of the affected bone. However, in a scintigraphic study evaluating the distal limb changes in horses whose lameness resolved with a palmar digital nerve block, researches found that changes associated with pedal osteitis were uncommon and suggested that the condition may be over diagnosed [48]. Horses affected by septic pedal osteitis tend to have more severe clinical signs associated with drainage or exudate from the foot [47]. Radiographically, pedal osteitis presents focal or generalized demineralization of the solar margin of the distal phalanx and widening of the vascular channels that result in radiographic loss of the normally smooth contour, although similar radiographic changes can be observed in apparently normal horses [28]. If infection is present, sequestrum, or separate mineralized fragments, and gas density shadows in contact with the bone are frequently seen [47].
Contusions of the Distal and Middle Phalanges (bone bruise)

Bruising of the distal or middle phalanx is a bone injury that results from trauma [52-54]. Specifically, the term bone bruise or bone edema describes areas in cancellous or subchondral bone with a hyperintense signal in MR imaging fat-suppressed sequences [49]. These areas have abnormal fluid accumulation that may be caused by hemorrhage, inflammation, edema, or microtrabecular fracture [50, 51]. Horses affected by bone bruises of the distal or middle phalanx show similar clinical signs such as unilateral lameness that responds poorly to intra-articular medication and short period of rest [52-54].

Lameness is localized to the foot by clinical signs and diagnostic anesthesia. Radiographic examination of the affected area is usually unremarkable and there may be focal IRU[53]. MR imaging allows detection of bone bruises that are not detectable by any other imaging modality [52].

Subchondral Bone Cyst of the Distal Phalanx

A subchondral bone cyst (SBC) is a radiolucent area of bone commonly accompanied by a thin well- demarcated sclerotic rim that may or may not result in lameness [55, 56]. Distal phalanx cysts vary in size, shape, and are generally located adjacent to the articular surface but do not always communicate with the joint space [13, 55]. The etiology of SBC is unknown, although several theories have been proposed including infection, developmental defects, and trauma with resulting inflammation [55, 57]. Currently the most commonly accepted etiologies of SBC are osteochondrosis and local trauma [56, 58].
Clinical signs include lameness of variable duration with or without joint effusion; lameness is attributed to increased intracystic or intraosseous pressure, or both. Intra-articular anesthesia of the DIP joint or perineural anesthesia at the base of the sesamoid bones should resolve the lameness [56, 59]. Radiography usually localizes the subchondral bone lucent area within the distal phalanx, but, early cases, SBCs cannot be visualized using routine radiographic techniques, and CT or MR imaging can be used for to detect the cyst [63,64]. Scintigraphy may or may not be helpful for detection of SBC because not all SBC that cause pain have an active bone turnover; therefore, scintigraphy may not be helpful in determining whether a long-standing SBC is the current cause of lameness or not [53].

Ossification of the Collateral Cartilages of the Distal Phalanx (Sidebones)

Sidebones refers to mineralization of the collateral cartilages of the distal phalanx and is commonly seen in heavy horses [60]. The medial or lateral collateral cartilages ossify equally in Draft horses, whereas the ossification of the lateral collateral cartilage is overrepresented in Warmbloods [60]. Some authors consider that the tendency to develop mineralization of the collateral cartilages is partially hereditary in certain breeds [61, 62]. Others consider sidebones as a part of the normal aging process, and factors such as heavy body weight, working on hard surfaces, repetitive concussion, poor conformation, improper shoeing, and other foot problems, as a possible causes [5]. The significance of sidebones as a source of lameness remains controversial; sidebones may accompany other source of lameness associated with the caudal heel region and may be mistaken for the actual cause [13].
Lameness associated with sidebones is uncommon, unless clinical signs, diagnostic analgesia, and radiography definitively confirm the diagnosis [13]. Radiographic examination reveals the extent of ossification of the affected cartilage or cartilages; occasionally a fracture of an ossified cartilage may be associated with lameness [63], but radiolucent lines between separate center of ossification should not be misinterpreted. Scintigraphy may confirm the clinical significant of ossification of the collateral cartilages [66,68]. Evaluation of ossified collateral cartilages with the use of CT and MR imaging to assess damage of the surrounding soft tissues structures may provide additional useful diagnostic information [64].

Desmopathy of the Collateral Ligaments of the Distal Interphalangeal Joint

Inflammation and fiber disruption of the collateral ligaments of the DIP joint is a possible cause of acute or chronic lameness [65-68]. Avulsion fractures at the ligament attachment to the distal phalanx may also accompany this injury [69]. In a recent report, desmopathy of the collateral ligaments of the DIP joint was the second most common soft tissue injury diagnosed by MR imaging examination [54]. Jumper horses appear to be at higher risk of suffering forelimb desmopathy of the collateral ligaments of the DIP joint [70].

Frequently, no specific localizing clinical signs are identified, although subtle soft tissue swelling on the dorsomedial or dorsolateral aspect of the middle phalanx immediately proximal to the coronary band may be seen [68]. Severe ligament injury results in joint instability which worsens the prognosis [70, 76]. Lameness may be acute or chronic in onset, moderate to severe in degree, and increases as the horse turns [70].
Radiography is usually negative, although in chronic cases, enthesophyte formation, avulsion of a bone fragment from the middle or distal phalanx, or radiolucent areas in the distal phalanx may be seen [68]. Ultrasonography may detect lesions of the proximal portion of the collateral ligament [68], but if the distal portion is affected, false negative diagnosis can occur [65]. Scintigraphy is useful for detection of insertional lesions, but it does not determine the extent of the injury. MR imaging is useful for both characterization of the lesion and identification of any concurrent soft tissue injuries that may affect prognosis [54, 65, 66].

1.3. DISORDERS OF THE NAVICULAR APPARATUS AND DISTAL INTERPHALANGEAL JOINT.

Synovitis/Osteoarthritis of the Distal Interphalangeal Joint

Synovitis is the inflammation of the synovial membrane that results in joint effusion and articular pain. Persistent or chronic synovitis leads to osteoarthritis (OA) because the continue production of cytokines and degradative enzymes alters the intra-articular environment [71]. Osteoarthritis of the DIP joint is the degeneration and loss of articular cartilage accompanied by changes in the bone and soft tissues of the joint [71, 72]. Horses with OA of the DIP joint may present similar clinical signs to those with primary synovitis, but the response to treatment tends to be shorter or less effective [73]. Septic arthritis, chronic synovitis, articular fractures, osteochondrosis, subchondral bone cysts, and traumatic injury to the periarticular ligaments and soft tissues may result in irreversible OA and articular pain [59].
Lameness is predominately unilateral accompanied by distension of the dorsoproximal pouch of the DIP joint capsule [53, 79]. Positive response to intra-articular anesthesia confirms the DIP joint as a source of lameness, but the heel region of the sole and navicular apparatus is also desensitized with intraarticular anesthesia making a definitive diagnosis difficult. Intraarticular administration of low volume of local anesthetic may prevent diffusion of local anesthetic from the joint and may decrease desensitization of the heel region [74]. Radiography is helpful in severe or advanced cases of OA, although it should be considered that radiographic evidence of OA of the DIP joint can be associated with other causes of lameness, such as navicular disease. Scintigraphy may be helpful in the diagnosis of early subchondral bone lesion associated with OA. Though limited in the amount of the joint that can be visualized, diagnostic arthroscopy of the DIP joint provides a definitive diagnosis when there are no radiographic lesions in the acute phase of the disease, and remains the gold standard in human and equine OA [72]. In horses affected by OA, joint effusion can be easily visualized with MR imaging as well as periarticular osteophyte formation [75]. Currently synovial fluid and serum biomarkers of equine joint disease are being investigated to assess the degree of articular cartilage damage. Even though it is still in early stage for assessment of the condition of the cartilage and other tissue of the joint, a combination of multiple determinations of specific markers with other diagnostic techniques, such as arthroscopy and MR imaging seems promising [76].
Primary Deep Digital Flexor Tendon Lesions within the Hoof Capsule

Primary deep digital flexor tendon (DDFT) lesions can be associated with injuries of the navicular apparatus and occur in horses with clinical signs of caudal heel pain [3, 77, 78]. Lesions associated with navicular disease are evident on the palmar flexor surface of the navicular bone, whereas primary DDFT lesions can occur in any area proximal and distal to the navicular bone including the insertion into the distal phalanx [3]. Primary lesions of the DDFT can be a separate diagnosis in horses with little or no involvement of the navicular bone. Singular lesions have a better prognosis than horses affected by combined lesions in the DDFT and navicular bone [54]. In recent reports primary lesions of the DDFT and associated soft tissue injuries were over-represented in jumpers compared to the general clinic population [77, 78].

The etiology of DDFT injuries may result from acute trauma or repetitive over stress and cumulative fatigue micro-damage of the tendon matrix [79]. A recent report describing the histologic appearance of the DDFT of horses with chronic foot pain revealed a variety of abnormalities such as fibrillation, crevices and splits of the dorsal surface of the DDFT, vascular occlusion within the interstitium of the tendon, and changes in matrix composition. Similar degenerative changes were not identified in matched control horses [80]. Several predisposing factors have been postulated including degenerative ageing changes, heredity, or an increase in the proteoglycans contents of the DDFT occurring as an adaptation to stress [88-90]. An association between navicular disease and DDFT lesions has been recognized in clinical cases, and during postmortem examinations [54, 80, 81].
Affected horses may have unilateral or bilateral lameness of variable intensity that worsens with work but improves with rest or light work. Generally, no substantial abnormalities are palpable and the response to diagnostic local anesthesia is variable. Bilateral palmar digital nerve anesthesia markedly improves or resolves the lameness while an abaxial sesamoid nerve block resolves any remaining lameness. Response to intra-articular anesthesia of the DIP joint is unpredictable. Analgesia of the navicular bursa usually improves the lameness, but rarely alleviates it completely [77, 78]. Analgesia of the DFTS may be a useful diagnostic technique in horses with DDFT injuries, although other structures may be desensitized [3, 82].

Deep digital flexor tendon lesions can rarely be detected on radiographs while ultrasonography may be helpful when lesions are present in the pastern area. Ultrasonographic examination of the DDFT through a transcuneal approach has been described but the window of the evaluation of the DDFT is limited to the midline [83]. The use of this approach has a limited value because the majority of DDFT lesions diagnosed with either MR imaging or bursoscopy occurred off the midline [83, 94]. Soft tissue and bone phase scintigraphic lateral and solar images of the foot may reveal areas of IRU at the insertion of the DDFT or further proximal within the DDFT; however, scintigraphy has been shown to have low sensitivity (40%) for DDFT lesions [77]. CT may provide useful information of the soft tissues within the foot, especially lesions of the DDFT characterized by abnormal shape, dystrophic mineralization, and enthesophyte formation, but this modality requires general anesthesia [84]. Contrast-enhanced CT appears to be a useful alternative imaging technique for diagnosis of soft tissue lesions in the foot. The use of an appropriate soft tissue window and intravascular contrast material
increases the sensitivity of CT for detection of primary DDFT lesions. In addition to soft-tissue lesion diagnosis, contrast-enhanced CT may be helpful to direct intra-lesional administration of medication into the DDFT [85].

MR imaging has a high sensitivity and specificity (95% and 100% respectively) for detection of moderate and severe lesions of the DDFT lesions defined by histologic and macroscopic examination [50]. MR imaging allows detection of active inflammation or scar tissue at a specific anatomic site in the tendon [86], and it represents the lesion in three planes [87].

Endoscopic examination of the navicular bursa and/or DFTS allows visualization of the tendon surface within the bursa [88]. If the tendon surface presents extensive fibrillation accompanied by inflammation of the synovial lining of the navicular bursa with villous proliferation, core lesions may be present [89]. However, this technique is both, invasive and provides limited information about the internal architecture of the tendon.

**Navicular Disease**

Navicular disease is characterized by degenerative changes in the structure, composition, and mechanical function of the navicular bone and the supporting soft tissues including distal sesamoidean impar ligament (DSIL), collateral sesamoidean ligament (CSL), navicular bursa, and apposed DDFT [13, 90]. Navicular disease causes chronic forelimb lameness with pain arising from the navicular bone or supporting soft tissue structures [81]. Advanced navicular disease is associated with fibrillation of the
opposing dorsal aspect of the DFFT, with or without adhesion formation between the tendon and the navicular bone [91, 92].

The aetiopathogenesis of navicular disease is multifactorial and it appears to result from a complex interaction of abnormal conformation, excessive biomechanical stress, and heredity [92]. Conformational abnormalities commonly seen in Quarter horses and Warmblood horses such as narrow, upright, boxy feet, small relative to their body size remain as anecdotal associations. Navicular disease is common in Thoroughbred horses, which have flat feet with low collapsed heels [13]. Recent evidence suggests that there is a hereditary tendency towards the development of navicular disease in Holstein and Hanoverian Warmblood horses [93, 94]. Biomechanical factors that may cause navicular disease include nonphysiologic forces exerted on the navicular bone and supporting soft tissue structures that result in degeneration of the navicular apparatus [95, 96]. Interruption of the blood flow to and from the navicular bone was proposed as a contributing factor in the development of navicular disease [97, 98], but this theory has been rejected by several studies [81, 91, 99-101]. No one has been able to confirm the presence of thrombosis or infarcts in horses with navicular disease. A report of aging changes in the navicular bone of normal immature and mature horses suggested that there is a degenerative aging process similar to that seen in joints [91], although a more recent report contradicts this theory [80, 81, 102].

Traditionally, diagnosis was based on clinical examination, a positive response to palmar digital nerves anesthesia, DIP joint and/or navicular bursa, and radiography. Abaxial sesamoid nerve analgesia may be required to fully eliminate the lameness in
horses with navicular disease [90]. It is important to point out that analgesia of the palmar digital nerves is nonspecific, since it eliminates pain arising originating from all the structures in the palmar half of the foot, the DIP joint, entire sole, proximal interphalangeal joint (PIP) joint, collateral ligaments of the DIP joint and distal portion of the DFTS [103-106]. Besides, desensitization of the DIP joint or navicular bursa should be interpreted with caution because it desensitizes the DIP joint and associated ligaments, navicular bursa, and the toe region of the sole [112,113]. When a large volume of local anesthetic is used, the heel region of the sole can also be desensitized [74]. Even with the limitations of digital palmar nerve analgesia for specific detection of navicular disease, it is a valuable tool to initially isolate the source of lameness within the foot.

Radiographic changes associated with navicular disease remain controversial and abnormal radiographic findings often correlate poorly with clinical evaluation [100]. However, enlarged synovial invaginations and/or fragmentation of the distal border of the navicular bone, elongation of the medial or lateral extremities of the navicular bone (enthesophyte), lost of trapezoidal shape of the navicular bone, medullary sclerosis, erosions of the flexor cortex, lost of cortico-medullary junction of the navicular bone, and the presence of cyst-like radiolucent structures appear to indicate pathology related to lameness [108]. Generally, the larger number of radiographic changes within the navicular bone, the more likely it is that the horse has clinical navicular disease [107].

Ultrasonography evaluation of the navicular region is limited by the hoof capsule. Although a transcutaneous approach through the pastern and central sulcus of the frog has been described for assessment of the navicular apparatus[26, 83], recent studies have shown that many lesions within the navicular apparatus diagnosed with MR imaging are
missed with ultrasonography [54, 89, 108]. Nuclear scintigraphy may reveal increased bone mineral turn over in association with navicular disease in the absence of radiographic abnormalities [109], although IRU may also reflect remodeling of the navicular bone associated with functional adaptation to foot conformation and biomechanical forces on the navicular bone [110]. Consequently, false-positives results with scintigraphy are possible.

Modern complementary diagnostic imaging techniques such as nuclear scintigraphy, CT, and MR imaging allow precise characterization of pathology within the navicular apparatus and concomitant injuries of the foot [111]. CT provides good detail of the navicular cortex and trabeculae, and it may detect early pathologic changes within the navicular bone not detected on routine radiographs. The disadvantages of CT are the low sensitivity for detection of soft tissue injuries of the navicular apparatus, and the necessity of general anesthesia [84]. Contrast-enhanced CT of the equine foot improves the sensitivity for detection of soft tissue injuries within the foot and it may be used to guide intra-lesional administration of medication into the DDFT [85]. However, contrast-enhanced CT is more invasive than MR imaging, and it has not been proven to be superior to MR imaging.

MR has revolutionized imaging of the equine foot because it allows visualization of the soft tissues and bony structures of the foot in all three possible planes, and it has become the gold standard imaging technique for detection of acute and chronic injuries within the equine foot [3, 110]. Navicular disease now can be accurately diagnosed because MR imaging specifically differentiates lesions of the navicular bone and associated structures from other injuries of the foot that cause clinical signs similar to
navicular disease (caudal heel pain syndrome) [3]. Recently, a comparative MR imaging and post mortem study found good correlation between the lesions identified using MR imaging and histopathological findings [50]. MR imaging, performed under general anesthesia or standing, identifies precisely abnormalities of the navicular apparatus such as enlargement of the CSL of the navicular bone and thickening of the DISL with abnormal increased signal in the ligaments or their insertions, increased or decreased fluid signal in the navicular bone, adhesions between the navicular bone and the DDFT, increased fluid signal within the navicular bursa, etc [27, 50].

Schneider and coworkers have challenged the “classical” definition of navicular disease based on recent MR imaging examinations of horses with clinical signs compatible with “navicular disease”[3]. The authors hypothesized that the final diagnosis of navicular disease should be applied to horses with MR evidence of excessive fluid within the navicular bone since that was a frequent observation in horses with classical clinical sings of navicular disease. The authors also proposed that horses affected by injuries to supporting tissues of the navicular apparatus should be defined by a different diagnosis [3].

Endoscopic evaluation of the navicular bursa permits evaluation of the fibrocartilage on the flexor cortex of the navicular bone, the navicular bursa itself, the overlying dorsal surface of the DDFT ,and depending on the approach a limited view of the DSIL [89]. This surgical procedure allows confirmation of adhesions between the DDFT and navicular bone, thinning or full thickness erosion of the flexor fibrocartilage of the navicular bone, fibrillation of the dorsal surface of the DDFT, and synovitis of the bursa [90]. Recently, bursoscopic debridedment of dorsal border DDFT tears was
reported as a valuable treatment option for horses with lesions of the DDFT [89]. It is important to point out that, for horses showing the typical clinical signs of navicular disease, the combination of the positive response to diagnostic analgesia and the results of diagnostic imaging now allow a variety of pathologic entities within the palmar foot area to be identified. Consequently, navicular disease should not be used to describe all pain isolated to the caudal aspect of the foot and horses with the typical clinical signs of navicular disease may be better identified as horse with palmar foot syndrome [110].

Fracture of the Navicular Bone

Fractures of the navicular bone are an uncommon cause of lameness in horses [111]. According with few reports, there is no breed or athletic activity that predisposes horses to such type of fractures [111, 112]. Forelimbs are commonly affected and four different fracture configurations may occur: avulsion (chip) fractures, simple complete fractures, comminuted complete fractures and congenital separation bipartite or tripartite sesamoid bones which should not be considered a true fracture because horses are not often painful [5,13]. Navicular bone fractures may result from concussion [113], although it is not always possible to identify the specific cause. It has also been proposed that many fractures are pathological secondary to severe bone resorption associated with advanced navicular disease [112].

Diagnosis is based on clinical signs and radiographic examination. Clinical signs may vary depending on the configuration of the fracture. Avulsion fractures of the navicular bone may be presented with typical clinical sings of navicular disease [13]. In general, lameness is severe with an acute fracture and the lameness may be exacerbated
as a horse turns [5]. All standard radiographic views of the navicular bone should be taken to rule out the potential presence of bipartite or tripartite navicular bone or other bony abnormalities.

**TREATMENT AND PROGNOSIS**

1.1. DISORDERS OF THE HOOF CAPSULE

**Hoof Wall Cracks or Defects**

The treatment should eliminate or correct the problem that causes the hoof defect. Initial treatment is performed to stabilize the defect and prevent its further extension in the hoof capsule [4, 5, 9, 114]. Debridedment of the defect is necessary to remove contamination of the hoof capsule and deeper laminae [6]. To prevent further cracking of the hoof wall, the hoof wall defect should be immobilized with the use of a bar shoe [9, 114]. The bar may be a full bar or diagonal bar and the affected portion of the hoof can be trimmed to prevent contact with the shoe during weight bearing [6]. In addition, clips placed in either side of the defect helps to prevent hoof expansion and to immobilize the crack. The use of impression material on the entire surface of the sole can provide additional stabilization by decreasing the drop of the sole during weight bearing and further decreasing the movement of the hoof capsule until the crack has been replaced with new horn [9, 114]. Grooving the hoof wall perpendicular to the defect deflects stress away from the crack [22]. Numerous agents are available for repairing hoof wall defects including fiberglass, rubber, thin metal sheets, leather, screws and wire, and
acrylic/epoxy materials. Bonding or acrylic repair of a crack is a cosmetic and successful method used to obliterate the crack [4, 6].

The prognosis for healing of hoof wall defects is favorable. With adequate hoof care, proper time and follow-up care, the defect should heal without complications, however, when large defects are present and predisposing factors are not resolved, reoccurrence of the crack is likely which requires continuous treatment [4-6].

Lacerations to the Foot and Coronary Band

Wounds of the foot heal slowly due to high degree of contamination and because contraction of the wound in this particular area is minimal, therefore treatment varies with duration, severity, and type of injury. Incomplete superficial hoof wall lacerations without coronary band involvement are treated by excision of the separated hoof wall and the use of a bar shoe until healing occurs [5, 9]. Incomplete, clean, and acute injuries involving the coronary band can be treated by cleaning and debriding the displaced flap of tissue and suturing back on place [7, 13]. Open synovial structures may be lavaged daily and managed for sepsis. Antibiotic-impregnated beads and regional limb perfusion with antibiotics may be necessary with severe contamination. Complete avulsion injuries that appear stable during movement are treated by daily cleaning and bandaging until healed. The use of a bar shoe may be indicated if the hoof wall is unstable[6, 9]. Immobilization is an important component of the therapy and it can be achieved with the use of a lower limb or foot cast for two to three weeks [6].

The prognosis for these injuries is favorable for soundness, however, even though the foot has a great capacity for healing, the prognosis for returning to full function
dependents on the severity of tissue destruction, the structures involved, and the structural integrity of the hoof after debridement [6, 13]. Deep wounds that extent to the middle or distal phalanx, DDFT, DFTS, DIP joint and navicular bursa are more problematic and warrant a guarded prognosis because of potential complications [9, 13].

**Hoof Wall Separation (White line disease)**

Treatment consists of debridedment and cleaning of the infected area, followed by topical application of a fungicidal-bactericidal preparation after the area has dried. In severe cases, the separated hoof wall can be removed and the exposed laminae treated topically with iodine or merthiolate until infection is resolved [11]. Once the infection is resolved, the hoof wall can be repair with plastic acrylic such as Equilox (Equilox International, Pine Island, MN) [5, 114]. The use metronidazole and gentamicin powder added to the plastic acrylic used to reconstruct large hoof wall defects at an earlier time has been reported in experimental and clinical cases [115]. Shoeing is fundamental when treating hoof wall separations because it provides protection to the remaining unaffected hoof wall, unsupported sole, and exposed lamellar tissues. The design of the shoe is dictated by the remaining shape of a give foot but a bar shoe may stabilize the foot and provide enough support [11, 114]. The prognosis for recovery is favorable in most cases, depending on the underlying cause, but recurrence is possible, particularly in horses with poor hoof quality [9, 11, 115].

**Keratoma**

Although conservative therapy has been reported [116], surgical excision of the keratoma is the treatment of choice. Surgical treatment involves complete removal of the
abnormal tissue from the hoof wall and corium followed by support of the hoof wall [16, 18]. Two surgical techniques have been reported; 1) complete hoof wall resection from the coronary band to the sole and 2) partial wall resection directly over the mass [15, 18]. Complete hoof wall resection involves extensive resection of hoof wall from the coronary band to the sole to expose and remove the keratoma, whereas partial hoof wall resection creates a window in the hoof wall centered over the keratoma. The last technique is indicated when the abnormal tissue is localized within a specific region between the coronary band and the sole [16, 18]. Postoperative complications such as excess granulation tissue formation, hoof wall instability, hoof crack formation, and keratoma recurrence at the surgery site have been reported. Partial hoof wall resection appears to result in fewer postoperative complications and more rapid return to athletic activity than complete hoof wall resection [18].

The prognosis for future athletic performance is favorable with complete surgical excision of a keratoma. Adequate stabilization of the hoof wall defect and complete removal of the lesion are important to ensure a good outcome [13, 18, 116].

Contusions of the Sole (sole bruising)

Decreasing or eliminating weight-bearing at the site of the bruise is the accepted treatment. In case of severe lameness stall rest might be considered. Corrective or proper shoeing is fundamental to shift the weight-bearing forces away from the damaged area of the sole [9]. The use of a cut-out rim pad attached to the shoe or a deeply concave sole surface of the shoe has been recommended [22]. A shoe that is concave around the entire shoe (wide-web shoe) may be used for a horse with a flat foot [6, 9, 22]. Hoof cushion
(silicone) injected between a pad and the sole may provide relief on a short-term basis and it may prevent severe sole bruising [117]. The prognosis is favorable if the inciting cause of bruising can be corrected, although, horses with flat feet or long toe-low heel conformation have frequent recurrence is unless the foot conformation is modified [9, 13].

Sub-solar Abscess

Treatment consists of establishing adequate drainage and protecting the foot from the environment with a foot bandage. If drainage occurs at the level of the coronary band and solar surface, through-and-through lavage is beneficial to accelerate healing. Foot soaks in warm water with povidone-iodine and Epsom salts should be continued until infection and inflammation are eliminated. Rarely, extensive prolonged sole abscesses must be treated with localized, partial hoof wall or sole resection, and/or curettage of the distal phalanx [6, 9]. The prognosis is favorable and significant improvement of the lameness is expected within 2 to 3 days after drainage of the abscess. The prognosis is guarded if the condition becomes chronic and there is extensive undermining of the hoof wall or extension to deeper structures [5, 13].

Penetrating Injuries to the Sole (Puncture wounds)

Treatment of superficial penetrating wounds includes adequate drainage, removal of infected or necrotic tissue, and protection the site from subsequent contamination [13]. Additional therapy includes, local periodic flushing with a sterile solution and foot dressing. Foot baths or soaks (warm water with povidone-iodine or Epsom salts) should
be continued until resolution of infection and inflammation [13]. Deep penetrating wounds should be treated aggressively; broad-spectrum antibiotics, NSAIDS, and tetanus prophylaxis should be administered initially [13, 23]. With established infections of deep punctures, superficial curettage with local flushing is generally unsuccessful and more aggressive surgical procedures are preferred [13]. Wounds that penetrate the distal phalanx are opened for drainage with concurrent curettage until healthy bone is visualized to ensure elimination of the sepsis and prevention of infection [47]. If osteomyelitis is established and a sequestrum is present, the necrotic bone is surgically removed in the same fashion and samples should be taken for culture and antibiotic sensitivity [118].

If the DDFT is affected (septic tendonitis), debridedment and removal of the frayed and infected tendon fibers is recommended and the postoperative use of a four to eight degree wedge shoe to decrease the tension of the DDFT may be beneficial. The degree of the wedge pad is then gradually lowered over several months as the DDFT heals and strengthens [9]. After perforation of the DSIL and penetration of the DIP joint, resection of the affected portion of the ligament [5], however, resection is controversial because full recovery after puncture of the DSIL and DIP joint is possible with arthroscopic lavage of the navicular bursa and DIP joint [119].

If the navicular bursa or navicular bone is involved, prompt surgical exploration, lavage, and debridedment are recommended; the “street nail procedure” is the surgical technique described to access the navicular area. This procedure involves surgical opening of the puncture site down to the navicular bursa by creating a window in the
DDFT [120]. An endoscopic technique to lavage and treat deep puncture wounds that penetrate the navicular bursa or DIP joint has been described. The advantages of this technique are visualization of the DDFT, removal of pannus and foreign bodies, synovial resection, and debridedment of lesions of the navicular bone or the DDFT. This technique is less invasive that the previously described “street nail procedure” and reduces postoperative morbidity [119, 121]. Postoperatively, the wound can be packed with antibiotic-impregnated polymethylmethacrylate beads for short term to achieve high concentration of antimicrobial locally [8], or gauze sponges soaked in dilute antiseptic, such as betadine, followed by application of a foot bandage or a shoe with a treatment plate [120]. Additionally, regional limb perfusion is recommended because it provides high antimicrobial concentration in the lower limb and greatly contributes to the elimination of the infection [122].

The prognosis is favorable for superficial and deep puncture wounds that do not involve vital structures, whereas the prognosis is guarded for those that involve vital structures that have not been treated early and aggressively [123, 124]. Bursoscopic treatment appears to decrease the morbidity associated with “the street nail procedure”, however is difficult to compare results from different studies [119]. The prognosis for horses with septic osteitis of the distal phalanx is favorable if laminitis is not associated with the osteitis [125].

Canker

Canker is resistant to treatment and involves debridedment of the proliferative tissue, cleaning the foot surface, and systemic and topical antibiotics [29, 126]. Both
superficial and deep debridement have been used in the treatment of canker depending on the location and extension of the infection, however superficial debridement is preferred because it decreases the risk of deeper infection, and delays healing through unnecessary loss of germinal epithelium [126]. Currently, conservative debridement of obviously diseased tissue, the use of different topical treatments, and foot bandaging is recommended due to excellent results obtained in 56 consecutive cases. The topical treatment consisted on 10 % benzoyl peroxide in acetone solution, combined with several crushed metronidazole tables [31]. In another report, eight horses diagnosed with canker resolved with superficial debridement of the lesion and topical application of 2% metronidazole ointment [29]. Alternatively, a mixture of ketoconazole, rifampin, and DMSO may be used topically [127].

The prognosis is favorable for complete resolution of the problem if superficial debridement and topical treatment is performed early in the course of the disease [29, 31]. The prognosis is unfavorable for chronic cases in which there is extensive infection of the foot [29].

**Thrush**

Eliminating predisposing factors as well as debridement of the diseased tissue and topical application of astringents or caustics agents is recommended for thrush [6]. Affected horses should be moved to a clean and dry environment and their feet should be cleaned daily. The affected portion of the frog should be debrided and cleaned using a hoof knife followed by foot bandaging if debridement is extensive [9, 114]. Several caustic materials have been recommended, including copper sulfate, equal parts of phenol
and iodine, formalin, and methylene blue [9, 13]. Foot soaks in chlorine bleach, betadine with white sugar or 10 to 15% sodium sulfapyridine solution have also been recommended [13]. The use of chlorine dioxide to treat thrush is a popular choice and there is anecdotal evidence of its effectiveness to remove refractory infections of the foot. The prognosis is favorable if the disease is diagnosed early, before the foot has suffered extensive damage. The prognosis is unfavorable if there is extensive involvement of the corium [9, 13].

Laminitis

The treatment objectives for laminitis include eliminating the inciting cause, decreasing inflammation, maintaining or re-establishing blood flow to the laminae, and preventing displacement of the distal phalanx [13, 128]. Inciting causes of laminitis such as enteritis, colitis, strangulating colic, pleuroneumonia, retained placenta, etc, require aggressive treatment in attempt to prevent or decrease clinical signs of foot pain [128]. NSAIDs administration is recommended to reduce inflammation and provide analgesia. DMSO is also used to prevent reperfusion injury of the laminae[13]. Cryotherapy of the distal limb has been used to prevent experimentally induced laminitis and may be helpful for horses at risk of developing laminitis [129, 130]. Blood flow to the laminae may be enhanced with peripheral vasodilators, such as acepromicine, isoxsuprine, pentoxifyline, and nitroglycerin, although their effects are controversial [131-133]. The use of antithrombotic and anticoagulant medication (aspirin and heparin) has been recommended to enhance small blood vessel flow [134]. Distal phalanx supported is commonly used to prevent rotation or distal displacement during laminitis. Several
material options exist, such as Lily pads, thermoplastic frog support, or Styrofoam pads (Equine Digit Support System Inc. Columbia Falls, MT) [13]. Alternatively, deep sand footing is a simple method to maintain good sole contact [6].

Therapeutic shoeing for laminitic horses included heart bar shoes, reverse shoes with pads, egg bar shoes, shoes with pad, and reverse glue-on shoes [13, 135-137]. Several devices are available that reduce to excessive tension of the DDFT and prevent further rotation of the coffin bone during the acute phase of the disease. A Redden shoe with a 20 degrees heel wedge (R.Redden, Box 507, Versailles, KY) or the Ultimate Wedge shoe (Kentucky Blacksmith Supply, KY) raises the heel and decreases the DDFT stress. Alternatively, tenotomy of the DDFT has been used as a salvage procedure for non-responsive cases of laminitis with severe rotation [138]. In horses with chronic laminitis, the heels tend to grow more quickly than the toe, and regular trimming of the heel and shortening the toe are fundamental to re-establish correct alignment of the distal phalanx within the hoof capsule [137].

Predicting the prognosis and survival of horses with acute laminitis can be difficult. It appears that prognosis for resolution of laminitis depends on the degree of rotation of the distal phalanx, severity of initial clinical signs, and distal displacement of the distal phalanx [139-141]. Prognosis is favorable for horses with rotation < 5.5 degrees, but unfavorable for rotation > 11.5 degrees [139]. Contrarily, a different study found no correlation between the degree of distal phalanx rotation and outcome, however lameness severity based on the Obel score was more accurate in determining final outcome suggesting that lameness severity during laminitis probably correlates with the severity or quantity of permanent laminar damage that has or is likely to occur [140].
Both studies found that horses with distal displacement have a poor prognosis for survival [140, 141]. For horses which have overcome that acute phase of laminitis and had marked rotation of the distal phalanx, nearly always suffer chronic hoof problems that may limit soundness [6].

1.2. DISORDERS OF THE DISTAL PHALANX

Fractures of the Distal Phalanx

Distal phalanx fracture treatment is based on the fracture type and may involve stall rest, fragment removal, therapeutic shoeing, internal fixation, and palmar digital neurectomy [5, 142-147]. Abaxial fractures (types I and II) and comminuted fractures (type V) are treated with fiberglass cast around the hoof capsule (foot cast) or therapeutic shoeing such as a bar shoe with toe, quarter and heel clips, or with a full rim shoe to limit hoof expansion during loading. Adding a full pad may prevent trauma and concussion to the distal phalanx [143, 147]. Stall rest and decreased level of exercise is recommended initially and, as the fracture healing progresses, the workload is gradually increased. Neurectomy of the digital nerves frequently allows continued athletic performance once the fracture is healed. Intra-articular medication of the DIP joint may be necessary to alleviate synovitis resulting from the articular fracture [143]. Axial or sagittal fractures (type III) may be managed conservatively or surgically [5, 148]. If the fracture can be reduced, internal fixation seems a logical treatment in horses with radiographic evidence of a step deformity at the articular surface [59]. For foals younger than six months, stall confinement results in successful return to soundness and radiographic evidence of fracture healing [142]. Stall rest and therapeutic shoeing have been successful in
managing horses with type III fractures although younger horses, with a grater potential for healing, appear to have a better prognosis for soundness [148]. A recent report found that age of the patient in horses affected by type II or III fractures treated conservatively did not influence the outcome in horses not used for racing [149].

Internal fixation of sagittal fractures (type III) with a lag screw provides improved stability and compression and decreases the articular gap that remains with conservative therapy [143]. A 4.5mm or 5.5 mm cortical screw placed in a lag fashion achieves appropriate axial compression of the fractured fragments, although an in-vitro study comparing axial compression generated by cortical and cancellous lag screws in the distal phalanx found that a 6.5 mm cortical screw was superior to any other screw tested [150]. After surgery, stall confinement and therapeutic shoeing are necessary for at least two months followed by small paddock turn out [5, 143].

If fractures of the extensor process (type IV), are a source of lameness, they should be removed via arthroscopy (small fragments) or via arthrotomy (large fragments) [146, 151]. In case of large fragments, division of the fragment in small fragments and consequently arthroscopic removal will reduce the period of convalescence [5]. Internal fixation of large extensor processes has been described, although the technique is limited by fragment size, fragment orientation, and chronicity [151, 152].

Treatment of fractures of the solar margin (type VI) depends on whether the condition is primary or secondary to a chronic foot disorder, such as laminitis or pedal osteitis. A wide-webbed shoe and a full pad combined with stall rest or small paddock turn out are indicated for unrelated marginal fractures [13]. If the cause is secondary, treatment is direct at the underlying cause [13]. Palmar process fractures (type VII),
which occur commonly in foals, are believed to be caused by shear forces generated by tension of the DDFT and compression due to weight bearing [153]. Foals should be confined to a stall for 6 to 8 weeks, and no therapeutic shoeing is required [142].

The prognosis for soundness of non articular fractures (types I, VI, VII) is favorable, although complete healing of the fracture may not be evident radiographically for several months but most fractures eventually heal [39, 59]. The prognosis for soundness of articular fractures (types II, III, IV, and V) is guarded due to the likelihood of DIP joint arthritis [6]. All fractures in foals have a very favorable prognosis for soundness [142].

Pedal Osteitis

Treatment of non-septic pedal osteitis depends on the cause, the use of the horse, and environmental factors. If severe or chronic solar bruising is the primary cause, NSAIDs administration and stall rest, to reduce inflammation and minimize the concussion of the foot, as well as protective shoes such as a wide-webbed egg bar shoe and a full pad are recommended [45]. Exercising on softer ground may allow continuing training until lameness resolves depending on the underlying cause [13]. Surgical debridedment of septic pedal osteitis is used to open the draining tract and remove the infected bone. Once debridement and curettage is complete, the tract is packed with gauze soaked in diluted povidone-iodine, and a protective bandage or treatment plate applied [13, 16].
The prognosis for non-septic pedal osteitis is favorable if the underlying condition can be resolved and the concussive forces affecting the feet reduced. The prognosis for septic pedal osteitis is favorable if the infection is controlled [47].

**Contusions of the Distal and Middle Phalanges (bone bruise)**

Bone bruises require rest, or reduced exercise, followed by a rehabilitation program.[54] An extended period of rest allows the subchondral or cancellous bone to heal, and prevent possible collapse of the articular cartilage, which has been observed with early return to athletic performance in humans [154]. In humans, recheck MR imaging examination is advisable in 6 to 12 months to determine if bone healing is completed [155, 156], however, in horses the precise time for recheck MR imaging examination to assess bone healing has not yet been determined. In cases of severe lameness, some form of restrictive coaptation device to the foot such as hoof cast or bar shoe with clips and packing of the solar surface with polyurethane may be considered. [59] The prognosis is favorable with appropriate period of rest and restricted activity [54], nonetheless long term outcome of many more cases is required to accurately determine the prognosis for return to exercise in horses affected by these types of lesions.

**Subchondral Bone Cyst of the Distal Phalanx**

Conservative treatment of subchondral bone cysts includes stall rest combined with intraarticular medication of the DIP joint. If conservative treatment fails, arthroscopic guided debridedment of the cyst when it is near the extensor process, and/or intralesional deposition of corticosteroids are recommended [55-56]. Currently, on going
research is focused on bone substitutes to fill the cyst after debridement, such as combination of chondrocytes and growth factors grafts and autogenous cancellous bone graft, with or without composites of calcium sulfate or calcium phosphate [157].

The prognosis is favorable for young horses subjected to arthroscopic debridement of the cyst [56], however the prognosis is uncertain when the cyst is not accessible arthroscopically. Prolonged periods of rest do not appear to carry a favorable prognosis for long term soundness [58]. In horses with concomitant degenerative changes in the DIP joint have an unfavorable prognosis [59].

Ossification of the Collateral Cartilages of the Distal Phalanx (Sidebones)

If sidebones are confirmed as the source of lameness, rest and administration of NSAIDs are logical treatments. The foot should be balanced and breakover should be moved caudally on the foot by rolling the toe [5, 13]. Corrective shoeing such as, a wide-webbed shoe and a full pad with, or without, hoof cushion (silicone) is a recommended treatment [117]. A fracture of an ossified collateral cartilage is managed conservatively with a period of stall rest however, refractory cases often require a unilateral digital neurectomy to resolve the lameness [5].

The prognosis for clinically significant sidebones depends on the underlying cause and whether that problem can be effectively managed. The prognosis is favorable for horses with fractures of ossified cartilages managed conservatively [63].
Desmopathy of the Collateral Ligaments of the Distal Interphalangeal Joint

The predominant treatment of desmopathy of the CL of the DIP joint includes strict stall rest for a minimum of 2 to 3 months followed by controlled exercise [70]. Immobilization is important when there is any destabilizing injury of the DIP joint and a half limb or distal limb cast may improve initial patient comfort by providing limb support [158]. Intralonesional injection with urinary bladder matrix powder (ACell-Vet®, Inc. Jessup, MD) appears beneficial for the treatment of ligament and tendon injuries [159], although the use of this product lacks scientific support of a controlled clinical trial and/or in vitro studies in horses [160]. Alternatively, extracorporeal shock wave therapy over the affected ligament may facilitate ligament healing by improving neovascularization [161], although there is no recommended protocol for this type of injuries. The DIP joint can be medicated with sodium hyaluronate or polysulfated glycosaminoglycans to decrease inflammation [68]. Trimming and shoeing each affected horse is different, but the goal is to maintain the mediolateral hoof balance and to provide support with the use of half-round or extended egg bar shoe, or a shoe with an extended web on the affected side of the foot [67, 68, 70].

The prognosis for return to athletic use of horses affected by desmopathy of the CL of the DIP joint is controversial. For horses with mild lesions and no radiographic changes that are managed with adequate periods of rest, a favorable prognosis can be expected [68, 162]. However, a most recent case series reported a guarded prognosis for returning to previous level of exercise [54]. Although the prognosis probably is determined by the site and extent of the injury, the results between studies are difficult to compare.
Synovitis/Osteoarthritis of the Distal Interphalangeal Joint

Once osteoarthritis (OA) of the DIP joint is diagnosed, treatment is aimed at relief of articular pain to regain functional use of the diseased joint and to arrest the disease progression [163]. Treatment may include corrective shoeing, intraarticular medication of the joint, ESWT, and systemic NSAIDs administration [164, 165]. Corrective shoeing includes careful evaluation of the foot conformation and correction of any foot imbalance. Affected horses are shod with a relatively short, rockered toe shoe to ease the breakover, and the pastern-foot axis is reestablished to prevent dorsiflexion of the joint [164]. Currently administered treatments for intra-articular medication are sodium hyaluronan, polysulfated glycosaminoglycans, and corticoidsteroids [163]. Recently a new product, autologous conditioned serum (Orthokine IRAP®, Arthrex Biosystems, Bonita Springs, FL) for intra-articular treatment of OA has been used with beneficial results reported anecdotally [166]. ESWT may be an option for the treatment of OA when other modalities are ineffective. Although there are numerous anecdotal reports of favorable results, little information is available about mechanism of action and duration of action when ESWT is used for the treatment of OA of the DIP joint [165]. The prognosis is favorable for horses with transitory synovitis; however the prognosis for horses with OA of the DIP joint, with or without radiographic changes, is unfavorable [53].
1.3. DISORDERS OF THE NAVICULAR APPARATUS AND DISTAL INTERPHALANGEAL JOINT

Primary Deep Digital Flexor Tendon Lesions within the Hoof Capsule

Prolonged rest and rehabilitation allow some horses with DDFT lesions to return to their use but does not improve most horses with concomitant navicular disease [3, 54]. Medication of the navicular bursa and/or DFTS with sodium hyaluronan and corticosteroids are have been recommended options [3], although their benefit in horses with primary DDFT lesions remains uncertain. The use of intrathecal corticosteroids for horses with acute injuries of the DDFT has been questioned due to its inhibitory effects on collagen formation during the healing phase of acute injuries [59]. Currently, the prognosis is unfavorable for horses affected by primary deep digital flexor tendonitis, although the number of cases with adequate follow-up is limited [54, 162].

Navicular Disease

Historically, treatment of navicular disease has included corrective shoeing, controlled exercise; administration of NSAIDs, isosxuprine and tiludronate; intra-articular and intra-bursal medication; ESWT; desmotomy of the CSL; and palmar digital neurectomy [111]. Rest is not traditionally recommended for horses with navicular disease but this option should be considered for some cases based upon results of MR examination [3]. Horses with acute lesions of the DDFT or acute desmitis of the supporting ligaments of the navicular bone may benefit from rest and a rehabilitation
Correction of any preexisting hoof abnormalities (hoof imbalance, under run heels, contracted heels, broken hoof/pastern angle, etc) is recommended [167]. Several shoeing techniques have been employed in an attempt to improve lameness of horses with navicular disease. The most common technique is raising the hoof angle by increasing heel length which decreases the tension of the DDFT, resulting in decreased compressive force exerted on the navicular bone. Also, extension of the shoe outside of the hoof wall at quarters and heel and beyond the caudal extent of the heel provides additional heel support and potentially decreases biomechanical forces on the navicular region [168]. Additionally raising the heel and rolling the toe is reported to relieve the pressure on the navicular bone though the forces in the foot have not been measured in relation to hoof angle [110]. The use of an eggbar shoe has been shown to decrease the forces acting on the navicular bone in horses with navicular disease [168, 169]. Alternatively, a natural balance shoe can be used to pulls the toe of the shoe back, creating and earlier breakover [96].

NSAIDs such as phenylbutazone, flunixin meglumine, carprofen or firocoxib, have been used for medical management of horses with navicular disease [13, 172]. According with recent studies, flunixin meglumine, phenylbutazone and firocoxib have similar analgesic effects for navicular pain [170, 171]. Isoxsuprine hydrochloride has been recommended for horses with navicular disease and laminitis because of its vasodilatatory effects [172, 173]. The drug has been shown to be an effective vasodilator program but this has not been documented with a large number of cases and adequate follow-up [3].
when administered intravenously although the effects were short-lived. Oral administration has not been shown to provide adequate plasma concentration to induce cardiovascular effects, which may be due to its low bioavailability (2.2%) [174]. Reports of administration of oral isoxsuprine for treatment of navicular disease are available but are not controlled studies [172].

Medication of the DIP joint and navicular bursa has been advocated for the treatment of navicular disease [13, 167], and recent evidence suggests that injection of 6 mg of triamcinolone into the DIP joint decreases lameness score in horses affected by navicular disease [175]. Tiludonate, a biophosphonate that reduces bone resorption in humans, was beneficial as a therapeutic agent in the treatment of navicular disease in a double-blind placebo-controlled clinical trial [176]. ESWT seems to be an effective non-invasive treatment option for navicular disease when the pulses are focused between the heels and through the frog [177, 178]. An experimental study proposes that ESWT provides a transient analgesic effect, caused by damage to the peripheral nerves resulting in slower nerve conduction and impaired perception of the peripheral pain [179]. However, investigation of the immediate analgesic effect of extracorporeal shock wave therapy for treatment of navicular disease in horses revealed that ESWT did not produce immediate analgesia, or any pain relief during the week after treatment [180]. Another study which investigated the long-term effect of ESWT in horses with navicular disease showed that ESWT was effective treatment to decrease the lameness associated with navicular disease six months after treatment [178].

Surgery is usually reserved for cases of navicular disease that have not responded to conservative treatments or have become unresponsive to conservative therapy. The
surgical options are desmotomy of the CSL, palmar digital neurectomy, and periarterial sympathectomy [5, 13]. The theory behind desmotomy of the CSL is that transection of the ligament modifies the biomechanical forces acting on the navicular bone, but clinical improvement can also be the result of transection of the sensory fibers that course within the CSL [5]. Palmar digital neurectomy is the most common surgical technique used for treatment of refractory navicular disease, but careful patient selection is necessary to achieve a favorable outcome [5,288]. Periarterial sympathectomy has been used in Germany to treat clinical cases of navicular disease which resulted in an increased blood supply to the digit and improvement of the lameness score [5]. This technique has not become popular and results are not well documented.

Historically, navicular syndrome, also know as caudal heel pain, has had a guarded to favorable with approximately 50 % of affected horses remaining sound for 1 to 2 years [110]. However, the term navicular syndrome includes multiple pathologies of the equine digit that causes similar clinical signs, therefore the prognosis for pathologies of the navicular apparatus (navicular disease) is difficult to determine based on the current literature. Currently, MR imaging is being used to accurately diagnose navicular disease because it differentiates injuries of the navicular apparatus from other injuries of the foot that cause similar clinical signs of navicular disease [54]. Unfortunately, there are limited reports of long term outcomes of horses diagnosed with navicular disease with the use of MR imaging; however the prognosis for long term soundness appears unfavorable [54, 66, 162].
Fracture of the Navicular Bone

Depending on the fracture configuration, treatment options for fractures of the navicular bone include conservative management, surgical repair or neurectomy. Stall rest combined with therapeutic shoeing such as a bar shoe with quarter clips. Alternatively, a bar shoe with or without a full wedge pad or elevated bar shoe, which protects the navicular bone has been recommended for comminuted or simple complete fractures [111, 181]. External immobilization using a fiberglass cast and stall rest is another conservative treatment option [5]. For comminuted or simple fractures treated conservatively, healing requires up to 12 months and carries an unfavorable prognosis for soundness [111]. Treatment of avulsion fractures is similar to that described for navicular disease [13]. Palmar digital neurectomy may provide symptomatic relief in some horses but development of severe osteoarthritis of the DIP joint is likely [111, 112]. The surgical option includes screw fixation and neurectomy [5]. Fracture reduction of the navicular bone is difficult because precise screw insertion through the hoof wall is critical to avoid penetration of the distal articular surface or the flexor surface. Recently, a computer-assisted screw insertion technique was described which improves accuracy of screw insertion in fractures of the navicular bone, but its use on clinical cases has not been reported [182].

With conservative therapy, the prognosis is unfavorable for returning to athletic performance [111], but the prognosis for soundness is improved with surgical reduction and internal fixation using inter-fragmentary compression to encourage bony union [113]. Internal fixation using a cortex screw in a lag fashion for simple navicular fractures resulted in a favorable short-term outcome in five horses [183]. In a larger study, internal
fixation of simple fracture of the navicular bone secondary to trauma carried a favorable prognosis when repaired soon after fracture occurred [113].

2. MAGNETIC RESONANCE IMAGING FOR DIAGNOSIS OF ORTHOPEDIC CONDITIONS

2.1. BACKGROUND

MR imaging has had a profound impact on the evaluation of several human orthopedic disorders, including traumatic, neoplastic, degenerative, and inflammatory disorders involving the spine and appendicular musculoskeletal system [184]. MR imaging allows evaluation of cortical bone, bone marrow, ligaments, joint capsule, articular cartilage, muscle and tendons with a higher sensitivity than has been possible with any other modality [185, 186]. Consequently, MR imaging has become the gold standard imaging modality in human orthopedics and sports medicine. The reported high accuracy of MR imaging in the knee has resulted in MR imaging being preferred to diagnostic arthroscopy by most leading orthopedic surgeons which reveals the huge impact that this imaging modality has had in sports medicine [187].

Advantages of MR imaging include visualization of the anatomy in multiple planes with thin section images; superior soft tissue detail, and excellent depiction of cancellous bone. The disadvantages of MR imaging are the nonspecificity of many of the findings, the high cost of examinations, and the limited number of available MR systems[184]. Due to the nonspecificity of many MR imaging findings, MR images should be performed and interpreted with knowledge of the results of other imaging examinations, such as radiographs, and physical examination results [184, 185].
2.2. PHYSICS

The Magnetic Resonance Phenomenon

Hydrogen is the atom used for magnetic resonance imaging because it is very stable and it accounts for two thirds of all the atoms in the human body. The ‘magnetic, or dipole, moment’ of an atom is the tendency to produce motion, and is the result of the atom’s angular moment or net spin of the nucleus. In the absence of an externally applied magnetic field, the vectors of these magnetic dipole moments are randomly orientated. Once exposed to a magnetic field, such is present in a magnetic resonance scanner, the dipoles tend to align with the field and become magnetized [185, 188]. In addition to spinning, hydrogen atoms or protons ‘precess’ or wobble a few degrees off the axis of the applied magnetic field, similar to the spinning of a gyroscope under the influence of the earth’s gravitational field. The frequency of this ‘precession’ is known as the resonance frequency and is proportional to the strength of the applied magnetic field [185].

Magnetic Resonance Image Formation

Fast spin echo imaging is the most commonly used method of MR image formation and it represents a good technique for description of MR image formation. Before the MR signal of a sample of tissue within the magnet can be generated and detected, the protons must undergo three additional manipulations: (1) the net magnetic vector of the protons must be flipped 90° from the parallel position into the transverse plane; (2) the spins of the protons must be spinning in phase together; and (3) the spins must be moved into a higher energy level. All of these conditions are accomplished by
the application of electromagnetic energy offset 90° from the main magnetic field which is called radiofrequency pulse. The application of a radiofrequency (RF) pulse that causes resonance to occur is called excitation [184, 188]. When the RF pulse is turned off, the protons move back to a lower energy state and thus emit RF energy which is the MR signal. This process is called relaxation. The amplitude of the MR signal is proportional to the number of spins in the sample or its proton density. When more protons are present, the intensity of the magnetization is greater, and the signal detected by the RF receiver coil is greater [185, 188].

In order to obtain an image, the system must be able to locate signal spatially in three dimensions, so that it can position each signal at correct point on the image. The first step consists in location of the slice (slice selection). Once the slice is selected, the signal is located or encoded along both axes of the image (frequency and phase encoding). These tasks are performed by the gradients [189].

Gradients are alteration to the main magnetic field and are generated by certain areas of the bore of the magnet from were current is passed. The passage of current induces a gradient magnetic field around it, which either subtracts from, or adds to the main static magnetic field \( B_0 \). The magnitude of \( B_0 \) is altered in a linear fashion by the gradient coils, thereby the magnetic field strength and the precessional frequency experience by the nuclei situated along the axis of the gradient can be predicted (spatial encoding) [189].

Depending on the location on the bore of the magnet, the nuclei will have an increase precessional frequency or decreased precessional frequency. Therefore the position of the nucleus along a gradient can then indentified according to its precessional
frequency. There are 3 gradient coils situated within the bore of the magnet, Z (long), Y (vertical) and X (horizontal) [189]. Another important term is the magnetic isocentre which is the center of the axis of all tree gradients, and the bore of the magnet. The magnetic field strength and precessional frequency remain unaltered even when the gradients are switched on. When a gradient coil is switched on, the magnetic field strength is either subtracted from or added to \( B_0 \) relative to the isocentre [189, 190].

The application of all the gradients selects an individual slice and produces a frequency shift along one axis of the slice and a phase shift along the other. The system is now ready to locate an individual signal within the image. When data of each signal position are collected, the information is stored as data points in the K space. K space is a spatial frequency domain where information about the frequency of a signal and where it comes from the patient is stored. In order to obtain an image, it is necessary to fill different lines of K space with data, however the K space is not the image. Each data point contains information for the whole slice as the frequencies that represent it come from the whole echo and the echo comes from the whole slice [189]. The final step to produce an image from the acquired data, is mathematical process called fast Fourier transform (FFT). Through this FFT, data is converted into signal amplitude versus its frequency. This assigns a grayscale for each pixel in the matrix of the image [189].

**Pulse Sequencing**

After the RF stimulation (excitation), the spins are moved into the higher-energy transverse orientation. As they fall back into a lower-energy longitudinal orientation, energy is dissipated into the surrounding environment. This is via two relaxation
processes called spin-lattice and spin-spin relaxation. T1 (spin lattice relaxation time) is the time in milliseconds required for 63% the longitudinal magnetization to recover following a RF pulse. T1 relaxation times vary with the main magnetic field strength of the imaging system and increased slightly with stronger magnets. T2 relaxation (transverse or spin-spin relaxation) is due to randomly varying inhomogeneities in the magnetic field created by adjacent nuclei within the sample. It characterizes the interaction of a nucleus with surrounding nuclei of the same kind. T2 is the time in milliseconds necessary to reduce the transverse magnetization to 37% of its original value following the RF pulse. Because it reflects the chemical environment of a proton, T2 relaxation is independent of the field strength [185, 191].

Image Contrast

Magnetic resonance signal intensity is a reflection of T1 and T2 relaxation values. The relative contributions of these values may be manipulated by controlling the timing of the RF pulses which are the time of repetition (TR) and time of echo (TE). TR is the time in milliseconds between 90° RF pulses and it determines the amount of relaxation that is allowed to occur between the end of one RF pulse and the application of the next one. TE is the time in milliseconds between application of the 90° RF pulse and recording the signal (echo) produced by the sample. T1-, T2- and PD-weighted images can be produced depending on the choice of TR and TE. The selection of appropriate TR and TE weights an image so that one contrast mechanism predominates over the other two. T1-weighted images result from a combination of short TR and TE, whereas T2-
weighted images result from a combination of longer TR and TE. Proton density images are obtained by using a pulse sequence with a long TR and short TE [185, 191].

Tissues behave differently according to the pulse sequence and the MR system chosen for imaging. These characteristics are fundamental for determination of normal and abnormal tissue when both, T1- and T2-weighted imaging are used. Interestingly, there are several degrees of T1- and T2 weighting, which allows for a wide spectrum of tissue appearances. The specific type of pathology being investigated will determine the ideal choice of pulse sequencing used.

T1-weighted images provide the highest signal-to-noise ratio and therefore it provides excellent anatomic detail. Tissues with short T1 value (high signal intensity) include fat and lipid-containing materials and proteinaceous fluid. Also, on T1-weighted images sub-acute hemorrhage have high signal intensity. Tissues with a long T1 value (low signal intensity) include normal body fluids, calcium (cortical bone), and most ligaments and tendons [186].

T2-weighted images distinguish normal from abnormal soft tissues. Tissues with a short T2 value (low signal intensity) include calcium (cortical bone) and most ligaments and tendons. Tissues with a long T2 value (high signal intensity) include most fluids, and consequently most pathologic processes (e.g., tumors, infection, injuries) often are highlighted on T2-weighted imagines due to the increased fluid content. Fat is less bright than on T1-weighted images (intermediate signal) and muscle remain of intermediate signal intensity [186].

Proton density, which are intermediate weighted images, demonstrate the differences in proton density (number of protons per unit) between different tissues and
provides good anatomic detail but they have less contrast than either, T1 or T2-weighted images, and therefore they may not be as informative as T1 and T2 images. However, PD images are still part of orthopedic MR imaging protocols because PD images can be acquired together with T2-weighted FSE images in a sequence called ‘dual echo’ [186, 191]. Basically, T2-weighted FSE images require a long TR, and therefore they take a long scanning time. In the mean time, it is possible to create another echo at shorter TE which produces an image at the same slice location and within the same scan time, but with PD weighting instead of T2 weighting. So PD images are ‘free’ if you want a T2 image [191].

**Image Quality**

Image quality is controlled by four factors; signal to noise ratio (SNR), contrast to noise ratio (CNR), spatial resolution and scan time. Of these, the signal to noise ratio has the largest effect on image quality [192]. The signal to noise ratio is the ratio of the amplitude of the signal received to the average amplitude of the noise. Signal is defined as information generated from the tissues that is representative of the anatomy and is used to produce the image. Noise is false information produced from the tissues or the MR system that is also incorporated in the image [193]. There are several factors that determine the SNR, however the magnetic field strength of the system plays an important part in determining the SNR. The SNR increases almost linearly with the field strength, thereby as the field strength increases, the MR system is able to acquire more information from the imaged tissues which results in a higher resolution images. In contrast, images with low SNR appear grainy and smaller structures are difficult to delineate clearly.
Contrast to noise ratio is the difference in the SNR between two adjacent areas and it is controlled by the factors that affect the SNR. The CNR is an important factor affecting image quality as it directly determines the eyes’ ability to distinguish areas of high signal from areas of low signal [192]. CNR is determined by selecting two different tissues and measuring the difference in the signal intensity produced by those tissues relative to the amount of noise. The degree of difference between the signal intensities of the two tissues determines the ease or difficulty in identifying them as different tissue [193]. The contrast between different tissue types is influenced by the MR sequence selected to produce the image. For example, T2-weighted image in which fluid is bright relative to the surrounding soft tissues provides more contrast than a T1-weighted image in which fluid and soft tissue have similar signal intensity [192, 194].

The spatial resolution is the ability to distinguish between two points as separate and distinct, and its controlled by the voxel size. Small voxels results in good spatial resolution, as small structures can be easily differentiated. Contrary, larger voxels result in low spatial resolution, as small structures are not resolved so well. In larger voxels, individual signal intensities are averaged together and are not represented as distinct within the voxel. This results in partial voluming [192].

The scan time is important in maintaining image quality because a long scan times gives patient more chance to move during image acquisition. Any movement of the patient degrades the images since it causes blurring of edges and ghosting of structures [192, 193].
Difference between Gradient Echo and Spin Echo Sequences

In order to decrease the scan time required for image acquisition, especially for T2-weighted images, a gradient echo (GE) technique was developed. For this technique, shorter TE-TR, and a flip angle smaller than the 90° pulse of conventional spin echo (SE) imaging are used, and also the 180° rephasing pulse is replaced with an echo generated by gradient reversal [185]. When a flip angle other than 90 degrees is used, only part of the longitudinal magnetization is converted to transverse magnetization, which precesses in a transverse plane and induces a signal on the receiver coil [194]. The GE sequences are usually associated with much shorter scan times than SE sequences because of the lower flip angle and the absence of the 180° rephasing pulse. With low flip angles, full recovery of the longitudinal magnetic vector occurs sooner than with large flip angles, therefore the TR can be reduced [188]. Conversely, in the SE sequences, the spins rephase naturally after the 90° pulse for a certain time and then a second positive 180° pulse is applied which flips all the spins through 180° about the Y axis. After a time equal to the delay between 90° and the 180° pulse, all the spins come back into phase along the positive Y axis forming the spin echo [190]. Disadvantages of GE sequences include increased susceptibility to artifacts and decreased soft tissue contrast. GE sequences are more susceptible to specific artifacts from magnetic field inhomogeneity than are the spin echo or inversion recovery sequences because no 180° pulse.
2.3. DIFFERENCES BETWEEN THE HIGH-FIELD AND LOW-FIELD MAGNET

Magnetic field strength, or flux density, is measured in Tesla (T) which is the equivalent of 10,000 gauss (G). Based on their magnetic field strength, scanners are categorized as low-field (under 0.3 T), mid-field (0.3-0.6 T), and high-field (1 T and over) [195]. Currently, magnets for clinical MR imaging are available with field strengths from approximately 0.2 to 3 T [196].

High-field magnets are the most common magnets used in human medicine [195]. High-field magnets are superconducting magnets that use special properties of certain materials, which temperatures approaching absolute zero. Superconducting magnets are constructed from a number of coils, usually four to eight, which are wrapped with special superconducting filaments when immersed in liquid helium. A disadvantage of high-field magnets is that the liquid helium continuously boils off and therefore periodic refill is necessary. To overcome this problem, modern superconducting magnets incorporate novel materials that have higher transition temperatures and consequently do not utilize cryogens such as liquid helium [196].

In general, low-field magnets are permanent magnets that utilize magnetic materials to induce a magnetic field. The magnetic field is constructed from magnetic materials such as high-iron carbon which generates a large intrinsic magnetic field, and therefore current is not required to create the magnetic field [196]. Permanent magnets usually have an open design (C or H shape) and so they are used in human medicine for claustrophobic or obese patients [195]. Also, they offer the possibility of MR imaging-guided interventional procedures, since the physician has access to the patient during scanning [197]. Permanent magnets have no running cost, but they have poor thermal
stability requiring operation in temperature-controlled rooms [196]. However, even without temperature changes, low-field magnets have less uniform magnetic field. Also, low-field magnets have a smaller field of view compared with high-field magnets [193].

One of the advantages of a high-field system over a low-field system is the higher signal-to-noise ratio which results in better image resolution. High-field strengths obtains higher spatial resolution images (high-resolution images with small field of view and thinner slices) and higher temporal resolution images (high-speed multiple sub-second images). These images result in better anatomical and physiological detail that could result in better disease definition [195, 198]. In theory, the lower signal-to-noise ratio observed with low-field systems can be compensated for to a certain extent by increasing the image time. However, this increases the acquisition time for clinically adequate diagnostic images approximately three times longer at 0.1 T than at 1.0 T. Although this example may be extreme, the acquisition time of low-field magnets tend to be longer than high-field magnets. Unfortunately, longer acquisition times increase the risk for patient movement and consequent image degradation [195]. An alternative option to compensate for the lower signal-to-noise ratio is to increase the voxel volume by increasing the slice thickness, although detection of signal abnormalities is more difficult [199].

Fat-saturation and inversion recovery (IR) are both fat suppressed techniques which facilitate identification of abnormal fluid in bone and soft tissues. Although the signal intensity of fat is suppressed with both techniques, there are important differences between them. The difference between MR signals from fat and water is called ‘chemical shift’. Fat-saturation sequences take advantage of the chemical shift between fat and water to excite only the fat protons, leaving the water protons unexcited. These
results in images where the signal from the fat is eliminated a difference from the surrounding soft tissues where their signal remain [200]. The resultant images have soft tissue contrast characteristic to the sequence and hyposignal from the fat.

The chemical shift between fat and water increases with the strength of the magnetic field, therefore fat and water resonant frequencies are closer together in low field MR systems. This results in a less reliable fat-saturation technique because it is difficult to achieve fat saturation without also producing water saturation [201].

Although high-field MR systems produce better quality images, the impact of these images on clinical efficacy and humans patient’s outcome remains to be seen [195]. A limited number of clinical studies have directly compared accuracies of different high and low-field MR systems in the diagnosis of joints disorders. Early studies, which focused on traumatic injuries of the cruciate ligaments and menisci of the human knee, showed comparable results for 0.2- 0.5 T and 1.5 T magnets in the detection of meniscal and ACL tears [202-204]. Additional comparative studies focused on pathologies of the shoulder have demonstrated comparable sensitivity and specificity of both systems for detection of rotator cuff lesions and labral pathologies [205-208]. However, high field MR systems allow detection of small and low contrast lesions that cannot be identified with low-field MR systems [193]. High-field MR systems have been shown to be superior to the low-field MR systems for detection of small lesions such as articular cartilage lesions in clinical and experimental studies [199, 202, 209].

In equine medicine, literature review of clinical studies using the low-field or high-field MR system for detection of equine foot pathologies shows that a similar range of lesions can be detected with both systems [78,248,252,254,273]. These findings
suggest that the low-field MR system is useful diagnosis technique for detection of pathologies of the DDFT, navicular bone, ligaments of the navicular bone, and CL of the DIP joint. However, there are no studies in the equine literature that compare the diagnostic performance of both magnets in the detection of equine foot pathologies.

2. 4. PULSE SEQUENCES USED FOR ORTHOPEDIC CONDITIONS

The specific imaging parameters selected for a single scan are called a pulse sequence, and there are many different pulse sequences available (each is designed for a specific purpose). A typical musculoskeletal examination will include at least 3 different sequences in various anatomic planes (transverse, dorsal, and sagittal). Three different types of sequences are commonly used in MR imaging: spin echo or fast spin echo, gradient echo, and inversion recovery [186]. Although the images produced by these sequences may have a similar appearance, they are created quite differently [210].

Spin echo (SE) is the simplistic clinical imaging sequence and used to be the basis for many of the commonly used sequences. Spin echo uses a 90° excitation pulse followed by one or more 180° rephasing pulses to generate a spin echo and it can produce T1-, T2-, or PD-weighted images depending on the choice of TR and TE. If only one echo is generated, a T1-weighted image can be obtained using short TR and short TE. For PD- and T2-weighting images, two rephasing pulses, generating two spin echoes, are applied. The first echo has a short TE and a long TR to achieve PD weighting, and the second has a long TE and a long TR to achieve T2 weighting [191, 194].

SE (SE) pulse sequences used to be the gold standard for most imaging protocols however they have been fallen out of favor and now are being replaced by FSE sequences
because of their relatively shorter time of acquisition [186, 211]. T1-weighted are useful for demonstrating anatomy because they have a high signal-to-noise ration, whereas T2-weighted and STIR images also demonstrate pathology. Tissues that are diseased are generally more edematous and/or vascular. They have increased water content and consequently have a high signal on T2-weighted images and can therefore be easily identified [194].

Fast spin echo (FSE), also known as turbo spin echo, is a spin echo pulse sequence, but with scan times that are much shorter than conventional spin echo. In FSE sequences the scan time is reduced by using multiple radiofrequency pulses to affect the position of protons within the tissues creating a detectable signal [210]. FSE sequences can be T1-weighted T2-weighted, or proton density. Proton density and T1-weighted sequences will produce images with good anatomical detail, although proton density images usually have a higher contrast when compared to T1-weighted images. The appearance of bone is similar in proton density and T1-weighted images. Fluid is dark gray (intermediate to low signal intensity) on T1-weighted images and light gray (intermediate to high signal intensity) on proton density images. In comparison, T2-weighted images have slightly less anatomic detail and higher contrast. Fluid is light gray to white (intermediate to high signal intensity) on T2-weighted images. Adipose tissue is usually light gray on T1-weighted and proton density images [210].

Gradient echo (GE) sequences use variable flip angles so that the TR and therefore the scan time can be reduced without producing saturation. Also, a gradient rather than a 180° rephasing RF pulse is used to rephase the loss of signal due to relaxation (free induction decay) [194]. Gradient echo pulse sequences produce images
with good definition of bone structure but poor definition of some soft tissue structures.[75] Spin echo sequences and GE sequences can produce images with T1-, T2-, or PD-weighting, although GE images have contrast that is different that seen with SE images. Gradient echo images can be of a great value in a given orthopedic MR imaging protocol because this sequence allows for a reduction in the scan time as the TR is reduced and permits the acquisition of much thinner sections than SE sequences, however this difference is minimized with software updates [191, 212]. An interesting feature of GE sequences is a heightened sensitivity to susceptible effects. This refers to artifactual signal loss at the interface between the tissues of widely different magnetic properties, such as metal and soft tissue, and so that subtle areas of hemorrhage can be identified due to susceptible effects of the hemoglobin breakdown products within the tissue [186].

Gradient echo sequences are classified according to whether the residual transverse magnetization is in phase (coherent) or out of phase (incoherent). Coherent GE sequences are commonly used to assess body fluids and blood flow (angiographic effect), therefore these sequences are rarely used in human orthopedic protocols, whereas, incoherent GE (spoiled) sequences produce T1- or PD-weighted images with good T1 anatomic detail being useful in human orthopedic protocols [194].

Inversion-Recovery (IR) is a technique by which the signal from certain tissue types, such as fat, white and gray matter, and CFS fluid, can be suppressed. Inversion recovery was developed in the early stage of MR imaging to provide good T1 contrast on low-field systems; however when the high-field systems became popular, this sequence fell out of favor. Inversion recovery is a SE type of sequence and is produced in a similar
fashion, although the first step of an IR sequence is to rotate the protons 180° instead of 90°.

Briefly, IR consists in applying a 180° inversion pulse at the beginning of the sequence. The 180° inversion pulse changes the direction of the longitudinal magnetization vector to its opposite. Then, the longitudinal magnetization is going to recover as defined by T1 relaxation. At time TI (inversion time), a regular spin echo sequence is performed, starting with an excitation pulse. The TI is defined so that the longitudinal magnetization of a chosen tissue is suppressed. Consequently, this tissue will have a null transverse magnetization after the excitation pulse, resulting in a signal suppression of this tissue. The optimal TI for eliminating the signal of a given tissue depends on the tissue's characteristic T1 time. The displayed image usually shows the magnitude of the signal, which corresponds to the absolute value of the signal instead of the signed value. Tissues with no magnetization appear in black and tissues with magnetization (positive or negative) appear in gray or bright. Inversion-Recovery eliminates the signal of tissues according to their T1 time by choosing an appropriate TI [186].

The short tau inversion recovery (STIR) sequence is a fat-suppression technique that results in decreased signal intensity from fat and increased signal from fluid and edema. The short tau inversion recovery is an inversion recovery sequence that uses an inversion time (TI) that corresponds to the time it takes fat to recover from full inversion to the transverse plane so that there is no longitudinal magnetization corresponding to fat [194]. This sequence is extremely important in musculoskeletal imaging because it is highly sensitive for detecting most types of soft tissue and bone pathology such as bone
bruises, tumors, etc. It is also very useful sequence for suppressing fat in general MR imaging. Currently, fast spin echo STIR (FSE-STIR) is very popular in MR imaging protocols because this technique does not suffer from the long imaging times or limited number of slides [194].

Fluid attenuated inversion recovery (FLAIR) is an inversion recovery sequence commonly used for neurological imaging. This sequence, with a different inversion time, produces T2-weighted images with suppressed CFS signal, and allows critical evaluation of the periventricular tissues of the brain. This type of sequence is rarely used for orthopedic imaging [191].

The efficacy of different pulse sequences for detection of articular cartilage lesions has been an area of active research, and many ‘cartilage specific sequences’ have been proposed, tending in general to be gradient echo based, with or without fat-suppression [219-221]. These sequences display articular cartilage with high signal intensity, and when combined with fat-suppression techniques, they produce a marked cartilage-bone interface. In addition to a high contrast between the cartilage and joint fluid, GE sequences avoid chemical shift artifacts, which is a spatial misregistration of signal from protons in fat relative to those from water [213]. This artifact distorts morphology at fat-water interfaces and can simulate cartilage thinning or thickening. However, GE cartilage specific sequences are relatively insensitive for evaluation of the underlying bone, as well as of the other soft tissue structures of the human knee such as ligaments and tendons. Popular 3D GE cartilage specific sequences are spoiled gradient recalled (SPGR) or fast low-angle shot (FLASH) [214].
With the use of SE or FSE sequences, a high contrast at the cartilage-fluid or synovium interface is generated, which facilitates a better appreciation and evaluation of the articular cartilage. The articular cartilage shows low to intermediate signal intensity, whereas the surrounding synovial fluid shows high signal intensity on PD- and T2-weighted images. Superficial cartilage changes, such as fissures and fibrillation, become much more obvious in a low signal background (cartilage) increasing the diagnostic accuracy of these sequences [215]. However, initial reports using conventional SE sequences appeared of limited value for detection of articular cartilage defects of the human knee; detection rates from 13-52% for T1-weighted, and 28-73% for PD and T2-weighted SE sequences were evident in clinical and cadaver studies [216-218]. Lately, the diagnostic accuracy of cartilage defects appears superior by the used of T2-weighted FSE sequences which provide higher detection rates (92-98%). In these studies both the transverse and dorsal planes combined offered sufficient coverage of articular surfaces to provide a high sensitivity and specificity for chondral defects [219, 220]. The disadvantage of FSE sequences is the difficult evaluation of the cartilage-bone interface (both appear with low signal). To improve evaluation of this interface, fat-suppressed techniques are used, which increases the contrast between the basal layer of the articular cartilage and subchondral bone. Indeed FSE T2 weighted images with fat-suppression allow identification of subchondral bone edema or hyperemia which sometimes in an indictor of overlying chondral derangement [215].

Advanced osteoarthritic changes such as marginal osteophytes are well delineated with most pulse sequences that are also useful for imaging cartilage. The affected joint and the classic location of osteophytes within it, determines the best slice
orientation. In general, combinations of two planes slicing over the area of interest are necessary for accurate determination of presence or absence of osteophytes [218]. Synovitis and joint effusion, which is commonly found in patients with OA, are easily detected by conventional fat-suppressed T2-weighted FSE sequences [215].

Subchondral and cancellous bone abnormalities associated with OA are most sensitively demonstrated with fat-suppressed T2-weighted FSE and STIR images. Cancellous bone abnormality can also be seen on heavily T1-weighted images, but there are not as sensitive as fat-suppressed T2-weighted images [215]. Gradient echo sequences appear insensitive to abnormalities because the pathology is obscured by susceptible artifacts related to trabecular bone [221]. However, fat-suppressed GE sequences accurately delineate sub-chondral bone cysts [215].

Ligament and tendons are best examined with long-TE MR imaging sequences because of the ‘magic-angle effect’, which on short-TE images can produce foci of high signal intensity within these structures, mimicking inflammation and tears [222]. Additionally, the magic-angle effect has been reported in other collagen-containing structures, such as cartilage, and the menisci [223, 224]. Fast spin echo sequences are usually adequate for ligament and tendon lesions [215].

2.5. TISSUE APPEARANCE WITH DIFFERENT MRI SEQUENCES

MR imaging produces images in which the same tissue may have different signal intensities depending on the sequence used to for image acquisition. MR images are produced in a grey scale with a wide range of contrast, based on the degree of signal intensity. The appearance of the tissue is affected by its nature, the pulse sequence, the
sequence timings, the selected imaging parameters, and the MR system used to acquire the images [210, 225]. When tissue is injured, changes in tissue structure, biochemical composition, or water distribution results in alterations in the image appearance [225].

The image contrast is markedly influenced by the T1, T2 or PD characteristic of the tissue. Based on that, the images are then described as T1-, T2- or PD-weighted images [210]. The mobility and density of the protons in the tissue are important in determining its appearance. In tissues, most MR signal is derived from fat and water where hydrogen nuclei are abundant and freely mobile. Cortical bone or tendon tissue, which has few hydrogen nuclei or where the nuclei are tightly bound, produces very little or no signal (hypointense signal) [225].

Fast spin echo sequences can be PD-, T1- or T2-weighted. The appearance of bone is similar on T1- and PD-weighted images and both images type provide excellent anatomic detail. Cortical bone has low signal intensity and is well differentiated from trabecular bone, which has intermediate to high signal intensity because of the presence of adipose tissue. On T2-weighted images, fluid is hyperintense, while cortical bone and tendons are hypointense. Compared with PD- and T1-weighted images, T2-weighted images have less anatomical detail but greater contrast. The increased signal intensity of fluid on T2-weighted image results in excellent contrast between fluid and that of the surrounding soft tissues, therefore, fluid in the soft tissues are easily identified on T2-weighted images [210].

Gradient echo sequences can be T1- or T2-weighted, which will determine the appearance of the imaged tissue. In general, GE images have less tissue contrast than SE sequences, which is most evident when comparing soft tissue between sequences.
Tendons will have low signal on both SE and GE sequences and have less variability in signal intensity than ligaments. The differences in soft tissue contrast are most evident when comparing ligamentous structures. Normal ligament will vary in signal intensity from light gray to black. The degree of variability depends on the specific ligament, the density of collagen bundles, and the sequence used for imaging. Ligament margins are difficult to visualize in GE sequences because ligaments blend into the grey background of surrounding soft tissue [210].

Inversion recovery sequences used in orthopedic MR imaging protocols produces images in which the adipose tissue signal is suppressed. Suppression of the returning signal from the adipose tissue causes the tissue to appear black on images. Suppression of the signal from the adipose tissue produces images that have hyperintense fluid and hypointense soft tissues and bone [210].

Bone sclerosis is easily detected on T1- and PD-weighted images due to their normal high signal intensity in the trabecular bone caused by the presence of adipose tissue. Trabecular thickening or mineralization results in an area of hypointensity in the medullary cavity as the adipose tissue is replaced by bone. On T1-weighted images, fluid and bone sclerosis show similar signal intensity, therefore these areas must be compared with fat-suppressed images. Areas of sclerotic bone have low signal intensity on both T1-weighted and fat-suppressed sequences, whereas areas of fluid within the bone have low signal intensity on T1-weighted images and high signal intensity on STIR or fat-suppressed images. Soft tissue lesions result in increased fluid in tissue which is most evident on T2-weighted or fat-suppressed images. Fluid has high signal intensity, whereas normal soft tissue structures and bone have lower signal intensity in comparison.
On T2-weighted images, fluid in the trabecular bone may be difficult to appreciate, but fluid in the soft tissues can be identified [210].

HUMAN APPLICATIONS

2.6. DETECTION OF HUMAN ORTHOPEDIC INJURIES WITH MR

MR imaging is the gold standard for diagnosis of many musculoskeletal injuries in human medicine. This imaging modality provides a combination of high resolution, excellent soft tissue contrast, and multiplanar to volumetric imaging capability ideal for demonstrating all the component structures and their possible injuries [226].

2.6.1 Normal Appearance and Injuries of Tendons and Muscles

In general, tendons are relatively avascular structures that are made of dense fascicles of collagen fibers. The fascicles of collagen are composed of smaller units, called microfibrils which interdigitate with one another in a regular and structured fashion to form extremely tight bonds, giving tendons their strength. Because of their tight disposition of collagen fibers, tendinous tissue has so few mobile protons that they are usually low signal intensity on all pulse sequences. However, many tendons may show slightly increased signal intensity near their osseous insertion because tendons may fan out as they come to attach to bone and nontendinous fatty material is interposed between tendon fibers [227, 228]. Another potential reason for a normal tendon having increased signal intensity is the result of the “magic angle phenomenon” or “magic angle effect” [229]. The magic angle effect results because tendons are anisotropic structures; when tendons are oriented at an angle of about 55° to the main magnetic field, there will
be high signal intensity within the tendon on short TE sequences. Determining if high signal on short TE sequences is from the magic angle phenomenon or from pathology is generally completed by (1) using a pulse sequence with a long TE so that the high signal intensity disappears, (2) observing that the tendon is of normal diameter, or (3) repositioning the body part being imaged so that the tendon is imaged at a different angle relative to the main magnetic field [227].

In general, tendons are best imaged in a transverse plane. Occasionally, other planes are helpful to image tendons in their entire length. T1- and T2-weighted images are required for complete evaluation of tendons. The T2-weighted sequences are useful to demonstrate abnormal fluid surrounding the tendon such as in case of tenosynovitis [227].

In humans, several pathologic processes may affect tendons which include myxoid or mucoid degeneration, tenosynovitis, partial or complete tears, and calcific tendonitis. [227, 228, 230, 231] Myxoid or mucoid degeneration of tendons has been proposed to occur with aging or from chronic overuse [227], although there is recent evidence that aging may not be responsible for this change [230]. This is a process that weakens the tendon so that it is predisposed to partial or complete tears with minimal trauma [230]. This pathologic process has been described in the quadriceps tendon which ruptured with no or minimal trauma because of preexisting underlying tendon degeneration [230, 232].

More recently, prospective studies have determined the histopathologic changes of tendinosis demonstrated with ultrasonography and MR imaging. Separation of collagen fibers with gradual increased in mucoid ground substance and fibrinocartilage metaplasia at the level of the tendon insertion were present within affected tendons. Also,
there were central areas of neovascularization and a characteristic abrupt discontinuity of both vascular and myofibroblastic proliferation just before areas of mucoid degeneration. Inflammatory cells were not seen in any of the specimens [230, 231]. Additionally, several studies have not found evidence of an inflammatory response within the affected tendons, so the commonly used term tendonitis should be avoided and tendinopathy or tendinosis used instead [228]. These tendon lesions (except mineralization) have increased signal intensity relative to the tendon on T1-weighted images and they tend to have marked increased signal intensity in T2-weighted and STIR images.

Tenosynovitis is the term used to when there is increased amount of fluid within the tendon sheath indicating an inflammatory process. MR imaging of tenosynovitis demonstrates a rounded collection of fluid that is low signal intensity on T1-weighted and high signal intensity on T2-weighted images, completely surrounding a tendon on images obtained transversely through it. Additionally, the mesotendon may be identified as a thin, low signal intensity line extending from the tendon to the outer layer of the tendon sheath. In case of tendons that do not have a sheath such as the Achilles tendon, they may have inflammatory changes surrounding the tendon, which is called paratendinitis. MR imaging will show abnormal signal intensity typical of edema (low signal intensity on T1-weighted and increased signal intensity on T2-weighted images) in the soft tissues surrounding the tendon [227].

Partial tendon tears represent incomplete disruption of the fibers, whereas complete tendon tears indicate total disruption of the fibers of the tendon so that there are completely separation of the tendon ends. Partial tendon tears can have a variable appearance on MR images. The tendon may be thickened, thinned, or remain of normal
cross sectional area with abnormal signal being the only evidence of partial tear. Usually there is high signal intensity in the tendon on all pulse sequences with partial tendon tears, but with chronic partial tears, there may be low signal intensity because of scarring and fibrosis; an abnormal tendon size or tenosynovitis are the only ways to recognize the tendon as abnormal in this situation [227, 231]. Tenosynovitis often coexists with partial tendon tears. Complete tendon rupture on MR images appears as a focal disruption with absence of the tendon fibers for variable distances [227].

Another pathologic condition in humans is calcific tendonitis from deposition of calcium hydroxyapatite crystals within the tendons. This tendinopathy may be difficult to diagnose with MR imaging because the calcium deposit has low signal intensity on all pulse sequences. Therefore, this abnormal area of calcification is difficult to distinguish from the low signal intensity tendon [227].

Normal skeletal muscle has intermediate signal intensity on all sequences. T1-weighted images demonstrate a marble appearance because of the fat that is interposed between muscle fibers. On T2-weighted images, normal muscle remains intermediate signal intensity and no high signal intensity is evident between the muscle fibers. Several abnormalities of muscle can be detected by MR imaging. In general, these abnormalities include trauma (contusions), inflammation, tumors, and ischemia. MR imaging is highly sensitive for detection of muscle abnormalities but is usually non-specific. Muscle contusions results in interstitial bleeds and hematoma formation, which may show as areas of increased signal intensity in T2-weighted images immediately after the injury due to the blood or edema. On T1-weighted images, hematomas less than 48 hours old usually has the same MR appearance that normal muscle; whereas subacute hematomas
have characteristic increased signal intensity on T1-weighted images. Muscle inflammation results in decreased signal intensity on T1-weighted images and increased signal intensity on T2-weighted images. The MR appearance of muscular tumors depends on the type of tumor. Muscle ischemia is particularly common in patients with diabetes; affected muscles show increased signal intensity on T2-weighted images [227].

2.6.2. Normal Appearance and Injuries of Ligaments

The anterior cruciate ligament (ACL) and collateral ligaments (CL) of the human knee are routinely examined with MR imaging [233]. Assessment of the ACL with MR imaging has proven to be very accurate. When MR imaging was compared with arthroscopy for detection of ACL tears, the sensitivity and specificity of MR imaging was 94% and 100% respectively [234]. The planes selected for evaluation of each ligament depends on the affected joint. For example, the sagittal and dorsal are the most reliable planes used to examine both, the ACL and CL on the knee, whereas the dorsal and transverse are the most reliable planes used to examine the ankle [233, 235].

The normal human ACL has straight taut fibers that run parallel to the roof of the intercondylar notch and it has a striated appearance with some high signal intensity within it, particularly at the level of the insertion on the tibia. T2-weighted sagittal images are recommended for evaluating the ACL. If an abnormal signal is detected within the ACL on sagittal planes images, transverse and dorsal planes should be used to further examine the ACL, but this is hardly necessary. A torn ACL is characterized in MR images by the absence of normal-appearing fibers of the ACL, whereas a sprain or partial
tear of the ACL is characterized by focal or diffuse high signal present within the ACL [233].

The fibers of medial CL of the human knee are interlaced with the joint capsule at the level of the joint (extrasynovial structure) and therefore, the accuracy of MR imaging for detection of tears has not been determined due to the inability to visualize the ligament through arthroscopy [235]. Nonetheless, the three grades of injuries described clinically correspond to three different levels of increased signal intensity in the medial CL seen with T2-weighted coronal images [236].

2.6.3. Normal Appearance and Injuries of Osseous Structures

The cortical bone is smooth with low signal intensity on all MR sequences because protons within the mineralized matrix are unable to resonate and produce signal. The medullary or cancellous bone, which contains adipose tissue, has high signal intensity on most sequences and low signal intensity on fat-suppressed sequences [186]. In humans, MR imaging is currently considered the most sensitive diagnostic technique for detecting bone pathology including, osteonecrosis, osteomyelitis, bone contusions, and stress fractures. Osteonecrosis, or avascular necrosis, of the human knee or femoral head is a rare condition that can be detected by MR imaging, particularly during the early stage. MR imaging shows hypointense signal on T1-weighted images and hyperintense signal on T2-weighted and STIR images. An interesting feature of this condition is the characteristic serpiginous line of signal intensity surrounding areas of “bone edema” [237].
MR imaging is highly sensitive for detection of both acute and chronic osteomyelitis as well as the extent of involvement. A common feature of chronic osteomyelitis in people is the development of sequestrum, which in MR images, can be seen as a low signal intensity area in all pulse sequences. The surrounding granulation tissue is intermediate to low signal intensity on T1-weighted images and high signal intensity on STIR and T2-weighted images [238].

Bone contusions or bone bruises appear to be trabecular injuries that results from impaction forces or ‘non-physiologic’ trauma that results in microtrabecular fractures. Histopathologic studies of these injuries revealed trabecular fractures, edema and hemorrhage in the adjacent marrow. Although most contusions resolve without complications, there is evidence that focal contusions involving the subchondral bone are associated with damage to the overlying cartilage [155]. In MR imaging, bone contusions may appear as diffuse or focal areas of abnormal signal intensity contiguous to the subchondral plate with or without extension to the articular surface. Bone contusions appear as areas of high signal intensity, presumably secondary to the hemorrhage and edema related to the trabecular fracture. Fat-suppressed sequences are the most sensitive for detection of abnormalities of the cortical or marrow bone which results from skeletal trauma. On PD or T1-weighted images, bone contusions have intermediate signal intensity because marrow fat is intermixed with the hemorrhage and edema. Contusions can be missed on non fat-saturated FSE T2-weighted images because the trauma-related edema and surrounding marrow fat display similar signal intensity [221].
2.6.4. Normal Appearance and Injuries of Joints

The articular cartilage is a thin layer of intermediate signal intensity on T1- and T2-weighted images; however, on fat suppressed GE sequences, cartilage has high signal intensity. In high-field MR images, the cartilage can be clearly defined from the adjacent subchondral bone and synovial fluid; the subchondral bone has low signal intensity on all sequences and synovial fluid has low signal intensity on T1-weighted images and high signal intensity on T2-weighted images [186]. Capsular tissue is generally visualized as a thin, smooth band of uniform thickness with a lower signal intensity than the synovial fluid on T2-weighted images, and slightly higher signal intensity than the synovial fluid on T1-weighted images [239].

Abnormalities of the articular cartilage can appear as alterations in signal intensity, or morphology, or both. Any decrease or increase in water content in areas of swollen or fibrillated cartilage influences its signal intensity. With the use of ‘cartilage sensitive sequences’, several layers of different signal intensity may be visible [240]. In human orthopedics several cartilage lesion grading systems are reported; however, a simple one is the use of a simple description of the lesion: focal abnormal signal, surface fibrillation or irregularity, partial thickness defect, full thickness defect with or without abnormal signal of the underlying bone [241].
APPLICATION OF MR TO EQUINE

2.7. DETECTION OF EQUINE ORTHOPEDIC INJURIES WITH MR

The equine digit is the most frequent structure that undergoes MR imaging examination because of the high incidence of foot pain, the difficulty in imaging the soft tissues within the equine foot, and it is technically easier than examining more proximal aspects of the limb [3, 54]. MR imaging has proven to be a valuable diagnostic modality to detect osseous or soft tissue injuries of the equine foot, using sectional images, to visualize bone and the soft tissue structures [210]. The high-resolution images can demonstrate structural and physiologic alterations within the tissues early in the course of the disease before they are detected by other imaging modality. Tissue damage results in changes in biochemical and water content, and therefore signal intensity [198].

2.7.1. Normal Appearance and Injuries of Tendons and Ligaments

Equine tendons, as in humans, are well defined and are normally hypointense on all imaging sequences. In contrast, the MR appearance of ligaments depends on the MR sequence utilized. In general ligaments have intermediate signal intensity on T1-weighted images, and low signal intensity on STIR and T2-weighted images. It is possible to evaluate the size and contour of tendons and ligaments, as well as their origin and insertion sites. In general, injuries of tendons and ligaments are characterized by high signal intensity within and around the hypointense structures [242, 243]. For example, acute tendon and ligament injuries, characterized by edema, hemorrhage and early cellular infiltration, have increased signal intensity on T1- and T2-weighted images, whereas healing tendon and ligament injuries have increased signal intensity on T1-
weighted, but relatively less increased to normal signal on T2-weighted images [244, 245].

**Deep Digital Flexor Tendon**

The DDFT has uniform low signal intensity with tendon fascicles separated by lines of higher signal intensity with two symmetric lobes [243]. DDFT lesions may have different MR appearance depending on the amount of fluid associated with the lesion. Some tendon lesions can have increased signal intensity on T1-weighted and PD images for prolonged periods of time without concurrent increased signal on STIR images [210]. These lesions do not contain fluid, and likely reflect connective tissue or immature scar. Other tendon lesions may be visualized as a focal increase in signal intensity on STIR and T2-weighted which is consistent with increased fluid content. In case of acute injuries, peritendinous fluid can be seen. Chronic degenerative lesions in the tendon have intermediate signal intensity on T1- or PD-weighted images but have normal to slightly increased signal intensity on T2-weighted images [84, 246]. However, if severe tendon degeneration is present, hyperintense signal on STIR images can be seen [50, 230].

A recent histopathologic report of DDFT injuries within the foot showed that focal increased signal remains present on T1-weighted images in spite of histological evidence of mature scar tissue [50, 198, 247]. Swelling of the affected tendon lobe and high signal intensity on T2-weighted and fat-suppressed images are common during the acute stage of tendon injury with associated distension of the DFTS and navicular bursa [198].

Deep digital flexor tendon lesions can be classified as core lesions, parasagittal tear, dorsal abrasion and dorsal border lesions [50, 246]. Lesions of the DDFT occur
most frequently at the level of the CSL and navicular bone according to a recent report [248]. Also, the type of DDFT lesion varies with the level of the DDFT lesion. Core lesions of the DDFT predominate at the level of the proximal phalanx and PIP joint, whereas dorsal abrasions are most common at the level of the CSL, either alone or in combination with other lesions. At the level of the navicular bone dorsal abrasions are most common followed by parasagittal splits and core lesions. Parasagittal tears are less common [248].

**Collateral Ligaments of the Distal Interphalangeal Joint**

Normal CL of the DIP joint are well delineated structures of homogeneous low signal with smooth endosteal and periosteal margins of the middle and distal phalanges at the origin and insertion on high-field MR scans. Medial and lateral CL have similar cross sectional area in normal horses [198, 249]. Lesions are characterized by increased signal intensity in T1-, T2-weighted and STIR images, with or without swelling of the ligament depending on the presence of ligamentous fluid. With severe collateral ligament desmopathies, periligamentous fluid may be evident in T2-weighted and STIR images [250]. Sometimes there is concomitant damage to the bone at the origin or insertion of the ligament which is represents as high signal intensity on STIR and T2-weighted images with low signal intensity on T1-weighted images [65, 251]. Additionally, osseous cyst-like lesions can occur at the ligament insertion in the distal phalanx [69]; these lesions have been recognized with the use of MR imaging [65].
Corroboration with Other Modalities:

Radiography

Unless focal mineralization is present within the DDFT, radiography is an insensitive diagnostic modality for detection of DDFT injuries. Recent reports of horses affected by primarily deep digital flexor tendinitis detected with MR imaging supports the limitations of radiography for detection of these lesions [77, 78].

Ultrasonography

Diagnostic ultrasonography performed via a pastern and transcuneal approaches have been described for identification of DDFT lesions within the foot [26, 83], however, this diagnostic modality is not easy because of the horny hoof capsule and the difficulties in orientating the ultrasound transducer perpendicular to the tendon [79]. Additionally, a high rate of false negatives results for detection of DDFT injuries with the use of ultrasonography are expected according with recent reports in which MR imaging was used a ‘gold standard’ diagnostic technique in clinical cases [77, 78].

The low sensitivity of ultrasound to detect DDFT lesions could be due to the location of the DDFT lesions. Most lesions of the distal or insertional portion of the DDFT identified with MR imaging were located off mid line (medial and lateral lobes of the DDFT) and are difficult to visualize from the transcuneal sagittal approach [78]. Diagnostic ultrasonography has also been used to detect desmopathy of the CL of the DIP joint [65, 67, 68]. Ultrasonography through the coronary band allows visualization of the proximal portion of the CL, therefore more distal lesions, and insertion lesions, can go undetected resulting in false negative results [70, 251].
Another reason for the low sensitivity of ultrasonography could be due to the lesion type. For example, degenerative lesions without fiber disruption or fluid accumulation may not result in a marked change in echogenicity or fiber alignment [230]; so lesions are may not be detectable with ultrasonography in some horses.

**Scintigraphy**

Nuclear scintigraphy has been shown to have low sensitivity for detection of abnormalities of both, DDFT and CL of the DIP joint. In recent reports with the use of MR imaging as a ‘gold standard’, only 40% of horses with DDFT lesions had abnormal increased radiopharmaceutical uptake (IRU) associated with the DDFT [77], whereas 52% of horses with desmopathy of the CL of the DIP joint had abnormal IRU associated with the insertion region of the CL in the distal phalanx [70]. Dyson and coworkers have confirmed previous findings after reviewing a large number of cases that underwent scintigraphy and MR imaging examination [54]. The authors found an even lower sensitivity (<20 % and 15 %) of scintigraphy for detection of injuries of the DDFT and desmopathies of the CL of the DIP joint respectively; however, scintigraphy had a high specificity for detection of such injuries (87% and 99%)[252].

Abnormalities associated with the DDFT lesions include two different IRU patterns; abnormal IRU on the lateral view in a curvilinear pattern following the anatomical path of the tendon as it passes over the navicular bone (soft tissue phase) and abnormal IRU, either dorsal to the navicular bone on the solar view or/and focal abnormal IRU on the center of the distal phalanx on the lateral view [253].
Abnormalities of the CL of the DIP joint follow several different abnormal IRU patterns which may be due to injuries at different levels of the ligament. In the soft tissue phase, abnormal IRU may be noted either from the coronary band down inside of the hoof wall or as a large marked area of IRU at the level of the coronary band. Cases of desmopathy of the collateral ligaments confirmed with the low-field MR systems have revealed that despite positive findings on the soft tissue phase, the bone phase could be negative [253]. On the solar view of the bone phase, desmopathy of the CL may show as mild to intense abnormal IRU outlining the entire palmar process of the distal phalanx or as a focal abnormal IRU on the palmar process near the DIP joint. When these abnormal scintigraphic patterns are observed, a potential stress wing fracture should be ruled out with MR imaging. On the lateral view, the IRU is more difficult to distinguish from some other patterns because it appears as a circular region of IRU in the center of the distal phalanx. For example, the distribution of radiopharmaceutical may be similar to the pattern seen for IRU associated with the insertion of the DDFT, although these conditions should be differentiated with solar view [253].

MR Comparison with Gross Lesions

Recent work from the UK has validated the use of the high-field MR imaging to accurately diagnose injuries of the equine foot in horses with chronic lameness [50, 254]. In general, abnormalities in MR imaging signal intensity and tissue margins of the osseous and soft tissues structures represented macroscopic and microscopic changes in tissue structure. MR imaging examination had fair sensitivity (74%) and excellent specificity (93%) for fibrillation and erosions of the dorsal surface of the DDFT in the
area of the navicular bone when confirmed macroscopically [254]. MR imaging appeared highly effective for detection of severe lesions of the CL of the DIP joint with lesions confirmed macroscopically on necropsy, however, the number of horses examined in the study was low [251].

MR Comparison with Histologic Lesions

Overall, MR imaging examination had an excellent sensitivity (95%) and specificity (100%) for detection of the DDFT lesions. Histologically, irregularities of the dorsal border of the DDFT on MR images were characterized by superficial dorsal fibrillation, crevicing, or splitting which resulted in an excellent specificity of MR imaging for detection of dorsal border lesions. In limbs with more severe lesions on MR images, characterized by high signal intensity in all three sequences used over the affected area, had severe histomorphologic lesions such disruption of superficial layers of the tendon by deep splits extending from the surface. Parasagittal splits on MR images had dorsal crevices, dorsal ridges, and multiple crevices of the appropriate depth with respect to MR images. Also, there was blood vessel occlusion, fibroplasia, and localized fibrocartilagenous metaplasia [50]. Small core lesions detected on MR imaging were represented by focal areas of pale tendon fascicles, increased cellularity, pale septa, and increased blood vessels, whereas large core lesions on MR images were represented by obliteration of the normal tendon fascicle structure, markedly increased vascularization, high cellular matrix, vacuolization, loss of normal septa divisions, and fibrocartilagenous metaplasia [50].
Reports from previous studies indicated good correlation between the MR imaging features and DDFT lesions. Abnormal increased signal intensity on T1- and T2-weighted GE sequences were correlated with collagen necrosis, matrix liquefaction, hemorrhage, edema hyalinization, and chondroid metaplasia [84]. Similar histologic changes correlating with increased signal intensity lesions on MR images were reported at the level of the superficial digital flexor tendon [244, 245].

Busoni and coworkers reported an MR imaging signal pattern that corresponded with histological evidence of tendon degeneration; tendons had edema, hemorrhage, collagen necrosis, and pseudocystic spaces containing eosinophilic plasma like material, but no areas of active inflammation were detected. Degenerative changes in tendons corresponded with intermediate to increased signal intensity on T1 and PD-weighted images but remained normal or became minimally brighter on T2-weighted sequences. A bright signal on T2-weighted sequences was seen with more severe tendon lesions [246].

2.7.2. Normal Appearance and Injuries of the Navicular Apparatus

The navicular apparatus consist of the navicular bone, CSL, DSIL, navicular bursa, and DDFT [90].

Navicular Bone

A normal navicular bone has a clear demarcation between the cortex and the medullary cavity, with a variable number of small symmetrical indentations of the distal articular cortex [102, 247]. Lesions of the navicular bone can be seen alone, in conjunction with lesions of the DDFT, DSIL, or CSL or as a complex of lesions of multiple structures [3, 54]. Dyson and coworkers summarized the abnormalities of the
navicular bone detected with a high-field MR system after reviewing 320 clinical cases (Table 1) [247]. MR imaging findings of horses affected by pathology of the navicular bone were varied. The most common type of lesion found was increased signal intensity on fat-suppressed or T2-weighted images involving the palmar aspect of the navicular bone reflecting fluid accumulation. Some cases had more abnormal generalized increased signal within the cortical bone of the flexor cortex which was best seen on fat-suppressed images. Some horses with the classical “navicular bone edema” had generalized increased fluid signal throughout the navicular bone medulla, with or without a DDFT lesions. Other pathologic changes detected were advanced cystic lesions involving the flexor cortex of the navicular bone, which were highly associated with adhesions to the adjacent DDFT. Lesions included fragments along the distal border of the navicular bone (with or without navicular bone edema), cortical bone irregularity, focal medullary sclerosis and DSIL damage [198].

Navicular bone remodeling, characterized by cortical bone loss, medullary fluid, and mineralization, can be detected by different MR imaging sequences. Trabecular bone changes are visible as a loss in signal homogeneity. Local increase in fluid content in the bone is recognized as local increase in signal intensity on fat-suppressed and T2-weighted images and local decrease in signal intensity on T1-weighted images. This phenomenon has been referred to as bone edema, although it may represent several pathologic processes such as bone necrosis, hemorrhage, trabecular microdamage, or medullary fibrosis, and edema. Areas of sclerosis are characterized by increased bone density and produce low signal intensity on both T2- and T1-weighted images. Adhesions between the flexor cortex of the navicular bone and the DDFT are represented by loss of navicular
bursa fluid signal, navicular bone cortical defect, and apparent continuity of tissue between the DDFT and navicular bone [198].

Table 1. Summary of abnormalities of the navicular bone detected with a high-field MR.

<table>
<thead>
<tr>
<th></th>
<th>Distal Border</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal Border</td>
<td>Smooth extension of the distal border into the DSIL (enthesophyte)</td>
</tr>
<tr>
<td></td>
<td>Irregular thickness of the distal cortex with mineralization extending proximally</td>
</tr>
<tr>
<td></td>
<td>Enlargement of synovial invaginations</td>
</tr>
<tr>
<td></td>
<td>Distal border fragments</td>
</tr>
<tr>
<td>Proximal Border</td>
<td>Enthesophyte formation</td>
</tr>
<tr>
<td></td>
<td>Endosteal mineralization</td>
</tr>
<tr>
<td></td>
<td>Proximal border fragment</td>
</tr>
<tr>
<td>Flexor Border</td>
<td>Endosteal irregularity</td>
</tr>
<tr>
<td></td>
<td>Increased thickness of flexor cortex</td>
</tr>
<tr>
<td></td>
<td>Focal increased signal in flexor cortex in all sequences</td>
</tr>
<tr>
<td></td>
<td>Focal fluid accumulation palmar to bone consistent with fibrocartilage loss</td>
</tr>
<tr>
<td></td>
<td>Linear increase in signal intensity through flexor cortex in STIR sequences</td>
</tr>
<tr>
<td></td>
<td>Disruption of flexor cortex, with reaction (abnormal fluid and mineralization) extending into dorsal aspect of medulla</td>
</tr>
<tr>
<td></td>
<td>Adhesions to the DDFT</td>
</tr>
<tr>
<td>Dorsal Border</td>
<td>Periarticular osteophyte formation</td>
</tr>
<tr>
<td></td>
<td>Endosteal mineralization</td>
</tr>
<tr>
<td>Medulla</td>
<td>Osseous cyst-like lesions in the distal third of the bone</td>
</tr>
<tr>
<td></td>
<td>Diffuse increased signal intensity on STIR images</td>
</tr>
<tr>
<td></td>
<td>Focal increased signal on STIR images at insertion of</td>
</tr>
</tbody>
</table>
Distal Sesamoidean Impar Ligament

A normal DSIL has symmetrical and even low signal intensity on T1- and T2-weighted images mixed with areas of high signal intensity on T2-weighted images [102]. The presence of normal synovial invaginations and small blood vessels make it difficult to interpret DSIL lesions due to the mixed signal on STIR and T2-weighted images (heterogeneous signal). However, clear asymmetry and loss of fiber pattern appears to be associated with pathologic changes. Additional changes include marked thickening, extensive adhesion of the palmar surface of the DSIL to the dorsal surface of the DDFT, cortical irregularity caused by bone proliferation, and lysis at the insertion of this ligament. Impar ligament lesions can also be recognized as a focal increase in signal intensity at its origin on the distal border of the navicular bone and by the presence of distal border fragments or mineralization within the proximal part of the ligament [50].

Collateral Sesamoidean Ligament

A normal CSL has a low to intermediate signal intensity in all sequences and its thickness has lateral to medial symmetry [102]. Its border are clearly demarcated by the high signal intensity of fluid in the palmar recess of the DIP joint and the navicular bursa in SE or FSE and STIR sequences [50, 247]. Lesions of the CSL are represented by thickening and alteration of the normal heterogenic signal in the body of the ligament. Mixed signal intensity is considered a common normal variation due to either differences
in fiber orientation or anatomy. Sometimes, focal intermediate signal intensity in the navicular bone at the ligament’s insertion on STIR images can be seen [247].

**Navicular Bursa**

A normal navicular bursa has homogenous high fluid signal in T2-weighted and STIR images without distension and clearly defined margins. Abnormalities of the navicular bursa are represented by fluid bursal distension on T2-weighted and STIR images, distension of the navicular bursa with low signal tissue (soft tissue), and loss of normal low signal on T1- and T2-weighted and STIR images (replacement of fluid by soft tissue or adhesions) [50]. Thickening and scarring of the synovial membrane is represented by replacement of the normal mixed signal intensity with low signal intensity on STIR and T2-weighted images.

**Corroboration with other modalities:**

**Radiography**

Controversy exits about the interpretation of radiographic changes of the navicular bone. Radiographic changes of the navicular apparatus and their clinical significance have been questioned with the use of scintigraphy, CT and MR imaging [255]. Traditionally, the diagnosis of navicular disease has been based on the radiographic appearance of the synovial invaginations along the distal border of the navicular bone, however, numerous studies have shown that the presence of synovial invaginations are poorly correlated with lameness, rarely progress in time, and are inconclusive for the diagnosis of navicular disease [255]. Additionally, a recent study
comparing MR imaging, radiographic and histologic findings found that widened conical, rounded and mushroom-shaped synovial invaginations were not associated with lameness, but narrow, deeply penetrating synovial invaginations were. Also, MR imaging assessment of the navicular bone correlated well with radiography of the navicular bone despite medullary and flexor surface abnormalities not visible on radiography [254].

Normally, several invaginations arise from the synovial fossa and course proximally into the navicular bone. Each invagination is lined by synovial membrane of the DIP joint and contains a nutrient artery entering the navicular bone is a subsynovial location. Separate osseous fragments are frequently present at the level of the distal border of the navicular bone and these can be difficult to detect on radiographs. The presence of small crescent-shape radiolucent line in the distal border of the navicular bone is an indication that the osseous fragment is present. The crescent-shape radiolucent line is the base of a craterlike defect in the parent bone, adjacent to which the fragment is located. The flexor surface may have a smoothly marginated depression or synovial fossa located in the middle ridge of the sagittal ridge in more than 50% of normal horses. This pattern can be seen on MR scans of the mid-sagittal part of the navicular bone in many horses. These observations are based on clinical and experimental studies with the used of a high-filed MR system [247].

Overall, radiography is limited to assessment of mineralized tissues, and as images are obtained through the entire thickness of the foot, a 40% change in bone and density is required before changes can be identified, therefore small abnormalities are easily missed [42]. In navicular disease, the examination of soft tissues constituting the navicular apparatus would be extremely important for accurate diagnosis; however, the
soft tissue can not be examined by conventional radiography [87], and even with multiple radiographic projections, important degenerative changes can still be missed [256].

**Ultrasonography**

Diagnostic ultrasonography of abnormalities of the navicular apparatus has been described using a pastern and transcuneal approach [83, 87, 257, 258]; however, because of the hoof capsule, even combining these two approaches, some areas of the navicular apparatus are not able to be evaluated in some horses [259]. Recent studies have shown that many lesions diagnosed with MR imaging or bursoscopy are not indentified with ultrasound [54, 78, 89, 108].

**Scintigraphy**

Increased radiopharmaceutical uptake associated with the navicular bone can be seen in both, the lateral and solar images. On the lateral images, it is observed as round to elliptical area of IRU in the middle of the foot, just palmar to the distal phalanx. On the solar images, the IRU can take on several configurations but is most commonly seen as a round focal area of IRU at sagittal midline region of the navicular bone. The solar images appear to be the most sensitive at identifying IRU associated with the navicular bone, however, IRU associated with the navicular bone on both the lateral and solar images is considered to be consistent with navicular bone pathology or injury. When IRU is apparent only in the center of the foot on the solar view, this is more consistent with navicular bone remodeling, which can reflect a physiologic adaptation process [253]. It has been hypothesized that the difference between navicular bone remodeling and disease
is that navicular bone remodeling reverses itself, whereas navicular bone disease progresses [66].

Comparison of the nuclear scintigraphy and MR imaging findings in horses with navicular disease revealed three different patterns of MR signal abnormality in the navicular bone associated with abnormal IRU in the navicular bone. The first pattern was structural osseous changes to the navicular bone on T1-weighted images that were not always evident on radiographs. The second pattern was abnormal increased signal intensity on STIR images in the medullary cavity of the navicular bone; the third was abnormal increased signal intensity on STIR and T1-weighted images in the navicular bone at the level of the origin of the DSIL [253]. These findings highlight the good sensitivity and poor specificity of nuclear scintigraphy for the diagnosis of navicular bone pathology [66].

Historically, nuclear scintigraphy has been considered to be highly sensitive, but not specific, imaging modality [253], however, it appears that the opposite is true for nuclear scintigraphic detection of navicular bone lesions in horses without radiographic abnormalities of the navicular bone. A recent report found a low sensitivity (24%) but a high specificity (97%) of scintigraphy for detection of navicular bone lesions confirmed with MR imaging [252]. These findings are in contrast to previous findings [66], and it could be due to different horse population studied, different criteria selected for MR imaging examination, and the presence or absence of radiographic changes.
MR Comparison with Gross Lesions

MR imaging assessment had a poor sensitivity (36%) but high specificity (100%) for gross evidence of partial or complete loss of fibrocartilage from the flexor surface of the navicular bone, however, the sensitivity (100%) and specificity (97%) for the presence of a synovial fossa on the flexor cortex of the navicular bone was high [254]. The same author reported excellent sensitivity (100%) and specificity (100%) for the presence of macroscopic partial or complete flexor cortex erosions. The sensitivity (92%) and specificity (93%) of MR imaging for gross visible distal border fragments was also high [254]. MR evidence of loss of normal navicular bursa fluid signal, navicular bone defect and apparent continuity of the tissue between the DDFT and navicular bone were associated with macroscopic adhesions between the DDFT and navicular bursa [50]. The sensitivity and specificity of MR imaging for detection of adhesions between the DSIL and the DDFT was fair, however, MR imaging was highly sensitive for identification of periligamentous tissue proliferation, adhesion formation between the DDFT and CSL, and cysts on the CSL [254].

MR Comparison with Histologic Lesions

MR imaging assessment of the flexor cortex of the navicular bone had a good sensitivity (84%), but a fair specificity (65%) for detecting histologic abnormalities of the flexor cortex of the navicular bone. Moderate to severe abnormal MR signal over the flexor surface were associated with thinning of the fibrocartilage and underlying subchondral bone, severe fibrocartilage loss, marked irregularity of the endosteal surface with mineralized extensions into the medulla, fibroplasia over the areas of bone loss,
bone necrosis, and widened intertrabecular spaces [50, 81]. MR imaging assessment of the navicular medulla had excellent sensitivity (94%) and good specificity (85%) for histologic abnormalities. Decreased signal intensity on T1- and T2-weighted images and/or focal or generalized increased signal intensity on fat-suppressed sequences in the medullary navicular bone corresponded with changes including loss of trabecular structure with or without edema, focal to generalized osteonecrosis and fibrosis. In areas of decreased signal intensity in all three sequences, histology confirmed mineralization, sometimes surrounding an area of necrosis which had increased signal intensity on the STIR sequence [50, 81].

MR examination of the distal border of the navicular bone had a good sensitivity (88%) and specificity (71%) for histologic abnormalities of the distal border of the navicular bone. Defects in the cortex surrounded by irregular low signal intensity on T1- and T2-weighted images (consistent with increased mineralization), distal border fragments, and irregularity of the endosteal surface corresponded with histologic changes including entheseophyte formation, enlarged intertrabecular spaces with fibrous tissue, irregular bone metaplasia, enlargement of the distal fossa with synovial invagination into the adjacent cortex or medulla forming a synovial-lined cavity, and synovial hyperplasia [50, 81].

MR examination of the dorsal border of the navicular bone had a low sensitivity (30%) and specificity (63%) for detection of histologic abnormalities of the dorsal border of the navicular bone. Within the group of horses studied, MR imaging abnormalities did not consistently represent histological lesions [81, 254]. For the proximal portion of the navicular bone, MR imaging examination had an excellent sensitivity (100%) and good
specificity (80%) for detection of histologic abnormalities of the proximal navicular bone. Cortical bone irregularity and enthesophyte formation evident on MR images corresponded with enthesophyte formation or bone metaplasia and irregularity of the endosteal surface [50, 81].

MR examination of the navicular bursa had excellent sensitivity (94%) and specificity (91%) for histologic abnormalities. Histologic changes varied from increased vascularization, synovial hyperplasia, fibroplasia of the synovium to organized fibrous tissue on the bursal surface [50, 81]. MR imaging assessment had a good sensitivity (80%), but a poor specificity (50%) for histologic abnormalities of the DSIL. These low percentages are due to the presence of interligamentous synovial spaces which normally produces MR signal alteration. Moderate and severe abnormal signal of the DSIL on MR imaging were characterized by interligamentous synovial pockets, neovascularization, fibrocartilagenous metaplasia and ligament fascicles degeneration [50, 81].

MR imaging assessment had a good sensitivity (73%) and excellent specificity (97%) for histologic abnormalities of the CSL, however, these were rare. Histologically, there was transitional fibrocartilagenous metaplasia and blood vessels occlusion. In horses with thickening of the CSL, the changes on the ligament were due to thickening of the navicular bursal lining covering the ligament or to adhesion formation with the fibrillated dorsal border of the DDFT [50, 81].

Analysis of agreement between MR imaging and histologic grades was good for the navicular bursa, DDFT, navicular bone medulla, and CSL; moderate for distal and palmar aspect of the navicular bone; fair for the DISL, and poor for dorsal and proximal aspect of the navicular bone [254].
2.7.3. Normal Appearance and Injuries of the Hoof Capsule

The hoof capsule is hypointense in all three sequences. Normal laminae are clearly defined with high signal intensity in the deeper layers on T1 and T2-weighted images and there is a well demarcation between the cortex of the distal phalanx and the laminae [247].

Horses with MR imaging evidence of laminitis have focal or diffuse laminar disruption, with increased signal in the dorsa sub-cortical bone of the distal phalanx on STIR images [54]. Equine cadaver limbs affected by chronic laminitis had increased signal intensity, irregularity, and thickening of the lamina on T1- and T2-weighthed images. Additionally, there was increased medullary fluid within the distal phalanx adjacent to the affected laminae [38].

Corroboration with other modalities:

Radiography

Radiography has a low sensitivity for detection of abnormalities of the laminae and hoof capsule in horses with laminitis. Laminar disruption, circumscribed areas of laminar gas, laminar fluid, and distal phalanx medullary fluid were consistently noted with MRI images, but not detected using radiography in cadaver limbs affected by laminitis. Distal phalanx rotation was accurately represented by radiography and MR imaging [38].
Ultrasonography

Diagnostic ultrasonography is not commonly used for assessment of hoof capsule injuries due to the poor penetration of ultrasound through the hoof capsule.

MR Comparison with Gross and Histologic Lesions

Although it is reasonable to believe that MR imaging should be very sensitive for detection of hoof wall abnormalities, such as solar bruises and subsolar abscesses, currently there are no reports assessing this topic. However, it is the clinical impression of some experienced clinicians that MR imaging has a low sensitivity to detect the source of solar pain and palmar heel pain in some cases and that mild solar bruising or laminar tearing might not be detected [198].

2.7.4. Normal Appearance and Injuries of Bones and Joints

As in humans, the equine cortical bone is normally hypointense on all imaging sequences and the medullary bone has hyperintense signal on most sequences because of the high fat content of bone marrow, except in the fat-suppressed or STIR images which have hypointense signal. The articular cartilage is a thin layer of intermediate signal intensity on T1- and T2-weighted images, however, the articular cartilage has high signal intensity with fat-suppressed GE sequences. With high-field MR systems, the subchondral bone plate can be easily defined from the cartilage; the subchondral bone plate has homogenous low signal intensity with a regular osteochondral junction. The synovial fluid has low signal intensity on T1-weighted images, but high signal intensity of T2-weighted and STIR images. Capsular tissue is generally visualized as a thin, smooth band of uniform thickness with a low signal intensity than the synovial fluid on
T2-weighted images, and slightly higher signal intensity than the synovial fluid on T1-weighted images [225, 242].

Severe osseous pathologic changes are detectable using either T1 or T2-weighted images. Bone pathology is frequently detected as an increased in signal intensity on T2-weighted sequences, and decreased signal intensity on T1-weighted sequences in the region of bone damage. Additionally, STIR sequences are very useful to identify bone pathology regions because they reduce interference from the fat signal on T2-weighted images [225].

The combination of high signal intensity on STIR and T2-weighted images, and low signal intensity in T1-weighted images is characteristic of bone bruises or contusions. This is a pathologic finding commonly seen in human knees after severe trauma, but it appears to have a low prevalence in horses [52]. Interestingly, similar osseous changes have been found in the navicular bone of horses with clinical sings of navicular disease [3, 84, 108, 260]. Increased bone density is another osseous abnormality commonly seen in horses which is characterized by decreased normal bone signal intensity on T1- and T2-weighted images [225].

Distal Interphalangeal Joint

The distal interphalangeal joint usually has curved cortical surfaces with mild flattening towards the palmar aspect of the joint. The cortical bone has homogenous low signal intensity with a uniform endosteal surface. The articular cartilage has intermediate signal intensity, and in T2-weighted images, is defined by the adjacent high intensity signal of synovial fluid. However, the curved articular surface make this joint prone to
artifacts due to volume averaging, so focal cartilage lesions are usually not evident [225, 247]. Moreover, evaluation of subchondral bone changes is not reliable because articular cartilage lesions in the DIP joint are not associated with subchondral bone signal alteration.

Proximal Interphalangeal (PIP) Joint

The MR appearance of the proximal and distal interphalangeal joint is very similar. Abnormalities of the middle phalanx include irregularity of the cortex/subchondral bone at the level of the articulation with the navicular bone, usually associated with advanced navicular disease, and enthesophyte formation at the level of the origin of the CL of the DIP joint [102].

Distal and Middle Phalanges

The cancellous bone of the middle and distal phalanx usually has uniform high signal intensity on T1- and T2-weighted images, whereas the cancellous bone has hypointense signal on fat-suppressed or STIR images. Bone bruises or osseous trauma to the phalanges is commonly seen as focal increased medullary signal intensity on fat-suppressed and decreased signal intensity on T1-weighted images which represents increased fluid within the affected bone. In chronic cases, sclerosis can be seen [52, 247].

Fractures of the distal phalanx are occasionally seen on MR imaging when are radiographically undetectable due to incomplete fractures or the orientation of the fracture plane. The characteristic of a fracture depends on its chronicity, but in general can be seen as a discontinuity of the homogenous hypointense signal of the cortical bone,
with linear increase signal intensity in T1- and T2-weighted images adjacent to the
trace [198].

Corroboration with other modalities

Radiography

Diagnosis of osteoarthritis of the DIP joint is frequently based on the presence of
osteophytes at the joint margins, most commonly at the level of the extensor process of
the distal phalanx, however, the significance of an isolated osteophyte on the extensor
process can be uncertain and a more accurate diagnosis of osteoarthritis can be made
when additional osteophytes are also present at the dorsodistal and palmarodistal margins
of the middle phalanx and the dorsoproximal margin of the navicular bone [247]. The
first MR imaging study of horses with foot lameness, which was unexplained by other
diagnostic means, revealed the low sensitivity of radiography to detect periarticular
osteophytes of the DIP joint; MR imaging provided clear delineation of bone contour and
detection of osteophytes [108].

Ultrasonography

Ultrasonography provides high contrast resolution and it can be used to image
articular cartilage within joints; however, within the DIP and PIP joints, there are limited
areas that can be visualized with a probe placed on the skin.
Scintigraphy

In cases of hairline fractures of the distal phalanx that remains radiographically invisible, nuclear scintigraphy reveals abnormal focal intense IRU which could be detected over the fractured area of the distal phalanx such as the palmar process or body extending from the solar margin to the DIP joint.

MR Comparison with Gross Lesions

MR imaging has a poor sensitivity for gross evidence of periarticular osteophytes and a fair sensitivity for articular cartilage abnormalities in the DIP joint [254].

MR Comparison with Histologic Lesions

Histopathologic examination of bruised bone areas revealed bone necrosis, inflammation, trabecular microdamage, hemorrhage, fibrosis, and bone edema [50, 261, 262].

3. MR IMAGING DIAGNOSIS OF EQUINE ORTHOPEDIC INJURIES

Diagnostic imaging in equine orthopedics has been limited to radiography, ultrasonography and scintigraphy for the last 20 years. Advance diagnostic modalities, such as CT, have been used in horses under general anesthesia, but the number of computed tomographic scanners used for horses in North America is limited. MR imaging was only used to study cadaver specimens until 2000; in that year, the first antemortem MR imaging study performed in horses became available [64, 84].
3.1. MRI Used in Cadavers Limbs

Several MR imaging anatomic studies on normal and abnormal cadaver’s limbs exit in the equine literature particularly focused on the equine foot [263-265]. An early report correlated the high-field MR images of the equine foot with anatomic and histologic sections validating the use of PD-, T1- and T2-weighted SE sequences to evaluate the osseous and soft tissues of the equine digit [264]. More recent studies have described the normal MR appearance of the palmar navicular apparatus in adult horses and newborn foals utilizing spin echo based-protocols including fat-suppressed FSE sequences [266, 267]. One study included 16 fresh cadaver limbs that were scanned routinely and after imaging, the limbs were dissected and the absence of gross abnormalities of the navicular bone, navicular bursa, DDFT, DSIL, and DDFT confirmed. Interestingly, in 11 normal digits, in SE T1-weighted images, a zone of abnormal increased signal was detected within the thickness of the compact bone of the sagittal ridge [266]. A second study, which included 16 digits preserved at -20° F and subsequently thawed before MR imaging examination, compared the MR appearance of the navicular apparatus of adult horses and newborn foals. No significant differences in the MR appearance were found between images of the adults and newborn foals including a description of the active physis of the distal phalanges [267]. Review of both studies revealed that the MR appearance of the digits was similar, which suggest that freezing and thawing of the digits prior to MR study does not modify the tissue appearance. Another study found no significant differences between antemortem MR images from feet scanned in living horses for clinical reasons and postmortem images from the same feet, scanned after one freeze-thaw cycle [102].
More recent reports have focused on describing the abnormal MR imaging findings in the digit of horses affected by chronic lameness. The first report compared radiography, CT, low-field MR imaging and histopathologic findings in an individual case of navicular disease. MR imaging was highly sensitive to detect pathologic changes of the DDFT, flexor surface of the navicular bone and synovial lining of the DIP joint. Not surprisingly radiography and CT were of limited value to detect pathologic changes of the affected soft tissues of the foot [84]. A second report of a study using cadaver front feet with advanced radiographic changes of navicular disease confirmed the low sensitivity of radiography to detect soft tissue injuries of the navicular apparatus, and the high sensitivity of CT to define navicular bone pathology. MR imaging was the most useful diagnostic imaging modality to identify advanced changes of the DDFT, DISL, and navicular bone degeneration which were confirmed with histology [260].

Busoni and coworkers reported the postmortem MR imaging and histopathologic features of 13 cadaver front feet of horses with advanced radiographic changes of navicular disease and focused on tendinous lesions of the DDFT and navicular bone [246]. The authors found a variety of MR imaging abnormalities of the DDFT and navicular bone medullary cavity in all specimens, and lesion were confirmed at necropsy. These findings confirmed an association between advanced navicular bone and DDFT abnormalities in horses with radiographic evidence of navicular disease [246].

Two studies have been focused on laminitis [37, 38]. In the first report, MR imaging was used to study the laminae of normal feet of cadaver horses using two ultra-high field magnets (4.6 and 7 T) to compare MR and histologic images of healthy laminae. MR images had excellent resolution with clear visualization of the primary and
secondary lamellae confirming that experimental ultra-high field MR imaging could be use to detect early lamellar pathology [37]. The second report compared the MR imaging findings of 10 cadaver feet from horses affected by chronic laminitis and 10 cadaver feet from normal horses. Laminar disruption, circumscribed areas of laminar gas, laminar fluid and bone medullary fluid were consistently noted in horses with chronic laminitis. The authors found that T2* GE and fat-suppressed sequences allowed visualization of the epidermis clearly compared to PD and T2 FSE sequences [38].

3.2. COMMON INJURIES OF THE EQUINE FOOT DETECTED WITH MRI

Dyson and coworkers have recently reported the spectrum of injuries identified in 347 clinical MR imaging examinations of feet of horses affected by chronic foot lameness in the UK [247]. Abnormalities were also detected on the contralateral limb in some horses. Multiple lesions, deep digital flexor tendonitis, and desmopathy of the CL of the DIP joint were the predominant lesion categories. Primary lesions of the DDFT were the most common (75 horses, 21.6%), however the total number of horses with signal abnormalities of the DDFT was greater (127 horses, 37.9%), when horses with combined lesions that included DDFT were considered. The second most common lesion was desmopathy of the CL of the DIP joint (65 horses, 18.7%). The total number of horses with lesions of these ligaments increased (150 horses, 44.7%) when horses with desmopathy of the CL of the DIP joint were added. Forty horses (11.5%) had a combination of DDFT and navicular bone lesions, and only 12 horses (3.5%) had primary lesions of the navicular bone. Horses with multiple lesions (horses which had several lesions that were all thought likely to be contributing to the lameness) represented the
large number of horses (114 horses, 32.9%) that underwent MR imaging examination. The combination of injuries of different structures such as the DDFT, CL of the DIP joint, the navicular bone and its ligaments, and the DIP joint and PIP joint were additional common findings within this group of horses. All other injuries categories had an incidence of less than 10%. They reported between 1 to 6 signal abnormalities in each horse with an average of 3.3 abnormalities per horse [247].

According to the authors, common non-specific MR imaging findings in lame limbs included distension of the DIP joint or the navicular bursa with or without synovial proliferation, mildly increased medullary signal intensity in the navicular bone in fat-suppressed images, minor focal adhesions between the DSIL and the DDFT, focal incomplete sagittal plane split or minor irregularities in the dorsal border of the DDFT, and mineralization of a collateral cartilage of the distal phalanx [247].

Schneider and coworkers have found a much higher incidence of primary navicular bone abnormalities and lower incidence of the DDFT injuries in horses with clinical signs of navicular disease presented for MR imaging examination [3]. It is likely, that these discrepancies are related to different population between these two veterinary hospitals in different parts of North America and Europe. One author proposes that with a high proportion of show jumpers Warmbloods within the patient population, a higher incidence of DDFT lesions might be expected, whereas with a high proportion of Quarterhorses within the patient population, navicular bone abnormalities may be more prevalent [198].

Another study reported the spectrum of injuries detected in jumping and dressage horses in northeastern USA presented for foot related lameness examined with a low-
field MR system. Navicular bone injuries, DDFT injuries, and effusion of the DIP joint were the predominant injuries categories. Lesions of the navicular bone were the most common lesions found (75 horses, 77%) and these lesions were often seen with concurrent DDFT lesions and effusion of the navicular bursa. The second most common lesion category was effusion of the DIP joint (67 horses, 68%). Sixty four horses (64%) had lesions of the DDFT. In contrast to the results of the study performed by Dyson and coworkers, desmopathy of the CL of the DIP joint were only identified on 21 horses (21%).

**Other Abnormalities**

MR imaging has also been useful to evaluate persistent lameness associated with previous penetrating injuries to the foot [24, 27]. MR imaging had excellent diagnostic and prognostic value when evaluating chronic penetrating injuries of the foot even in the absence of an active draining tract. The advantages of MR imaging over other diagnostic modalities were optimal anatomical detail of the affected structures achieving an accurate diagnosis and prognosis [24]. Other application of MR imaging includes identification of suspensory desmitis and adhesion between an axial exostosis of the second metacarpal bone and the suspensory ligament [268].

**3.4. FOLLOW-UP OF HORSES AFTER DIAGNOSTIC MR**

The number of short and long term follow-up studies of horses after MR imaging examination for diagnosis of foot problems is limited, and their results are difficult to compare due to different horse populations studied, different treatment protocols
recommended, and different spectrum of pathologies detected [54, 66, 162, 247]. The largest retrospective study published included 246 horses that had at least 6 months follow-up after diagnostic high-field MR imaging. Nineteen of seventy one horses (27%) with primary DDFT injuries had an excellent outcome, whereas only 5 of 29 horses (17%) had an excellent outcome and were able to return to full athletic function. Horses with primary navicular pathology, characterized by extensive abnormal medullary abnormality increased signal in fat suppressed sequences with variable areas of reduced normal signal in T1- and T2-weighted images, were not able to return to full athletic function. Fourteen of 45 horses (33%) with desmopathy of the CL of the DIP joint and 12 of 29 horses (17%) affected by multiple injuries had an excellent outcome. A higher proportion of horses with an excellent outcome were found for horses with primary impar ligament injuries and primary injuries of the middle and distal phalanx with 5 of 10 horses (50 %) affected by impar ligament injury and 7 of 10 (70%) horses with bone contusions or bruises of the middle or distal phalanx having an excellent outcome [54, 247].

Another retrospective study, which included 66 horses with at least 6 months follow-up after diagnostic low-field MR imaging for foot problems, reported a higher proportion of horses with excellent outcome. Twenty-five of 48 horses (52%) with primary DDFT injuries had an excellent outcome, and 15 of 23 horses (65%) with desmopathy of the DIP joint had an excellent outcome and were able to return to full athletic function. Twenty-nine of 46 horses (63%) affected with navicular bone lesions (which included fluid signal within the medulla, sclerosis, contour defects, cyst-like defects) had an excellent outcome and return to full athletic function [162].
Follow-up MR imaging was performed after 6 to 9 months of rest in 5 horses diagnosed using high-field MR imaging and 14 horses diagnosed using the low-field MR imaging with primary deep digital tendonitis. In all cases, increased signal was still present in the DDFT on the T1- and T2-weighted sequences, even if they showed no lameness. Therefore, it appears difficult to establish the chronicity of a given lesion in the DDFT [198].

In the last 10 years, MR imaging has proven to be a valuable diagnostic tool for making specific diagnosis in horses with pathology in the foot which could not be detected with other imaging modalities before. A specific diagnosis in horses affected by lesions in the foot, allows us to select treatments that specifically target the structure affected. However, the value of these treatments targeting specific structures remains to be proven.

LITERATURE CITED:


203. Kladny, B., et al., Comparison of low-field (0.2 Tesla) and high-field (1.5 Tesla) magnetic resonance imaging of the knee joint. Arch Orthop Trauma Surg, 1995. 114(5): p. 281-6.


OUTCOMES OF MEDICAL TREATMENT FOR PATHOLOGIES OF THE EQUINE FOOT DIAGNOSED WITH MAGNETIC RESONANCE IMAGING

Santiago D. Gutierrez-Nibeyro, MV, Nathaniel A. White II, DVM MS DACVS, Natasha Werpy*, DVM DACVR, Kenneth E. Sullins, DVM MS DACVS, Jill McCutcheon DVM PhD

From the Marion duPont Scott Equine Medical Center (Leesburg, Virginia) Virginia-Maryland Regional College of Veterinary Medicine, Virginia Polytechnic and *Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University.

INTRODUCTION

Lameness caused by lesions of the foot have a high prevalence in horses. According to a recent national study, caudal heel pain, laminitis, sole bruises and abscesses account for approximately 75% of the foot problems [1]. Conventional diagnostic imaging modalities are useful to detect the source of foot lameness in most cases, however they have limitations in some horses [2]. Advanced imaging modalities, such as Computed Tomography (CT) and Magnetic Resonance (MR) imaging have been increasingly used to diagnose equine foot pathologies. Computed tomography provides an excellent axial representation of the distal phalanges and navicular bone, however the need for general anesthesia and the lack of precise definition and adequate detail of the soft tissues remain the major disadvantages of this imaging modality [3, 4]. MR imaging
provides excellent soft tissue detail and allows identification of both soft tissues and osseous lesions contained within the equine foot [2, 5, 6]. Therefore MR imaging has become the gold standard imaging modality of the equine foot [7].

With MR examination providing an accurate diagnosis and characterization of equine foot pathologies treatment can be directed to the structures with abnormal MR appearance [5, 8]. Moreover, with the increasing use of MR imaging applied to the equine foot, clinicians are asked to identify horses with lesions that may interfere with future athletic performance and to establish an effective course of therapy. However current treatment recommendations for lesions detected with MR rely on clinician’s personal experience due to the limited published reports [9-12].

Lesions of soft tissue structures (deep digital flexor tendon, collateral ligaments of the distal interphalangeal joint, distal sesamoidean impar ligament and collateral sesamoidean ligament), synovial structures (navicular bursa, digital flexor tendon sheath and distal and proximal interphalangeal joints) and fibrocartilaginous-osseous structures (distal phalanges, navicular bone and collateral cartilages of the distal phalanx) are common findings in horses subjected to high-field MR examination of the foot [5, 7, 13]. However, the spectrum of abnormalities detected with low-field MR imaging has not been adequately reported.

Horses with foot pain have several treatment options, such as corrective shoeing, rest, injection of anti-inflammatory drugs into the synovial structures of the foot, extracorporeal shock wave therapy and tiludronate [12, 14-18]. Prior to MR imaging of the equine foot, the effectiveness of these treatments could not be determined because of the lack of a definitive diagnosis. With MR imaging the long term response to treatments
for lesions encountered in horses can be determined [5, 15, 19, 20]; however there are no reports with a follow up period longer than 12 months.

Since installation at of a low-field MR system to examine horses with foot lameness Marion duPont Scott Equine Medical Center in April 2004, treatment of the distal interphalangeal (DIP) joint, the navicular bursa and the digital flexor tendon sheath (DFTS) with sodium hyaluronan and corticosteroids has been used to target structures with abnormal MR signal. These treatments have been combined with corrective shoeing, a variable period of rest, extracorporeal shock wave therapy and administration of non-steroidal anti-inflammatory drugs. However, horses received different treatments due to several factors such as clinician’s preference, lack of time for rehabilitation program, uncertain prognosis and risks of intrasynovial medication with corticoidsteroids [16, 25]. Though some horses successfully returned to performance, the rate of recurrent lameness in individual cases suggested that many horses did not return to a previous level of work.

The objective of the study was 1) to report the spectrum of lesions detected with a low-field MR system in horses affected by foot pain; 2) to evaluate two different therapeutic protocols for horses affected by injuries of the foot, and 3) to determine if any of the lesions detected was associated with a poor outcome. We hypothesize that 1) the proportion of horses treated successfully between treatment protocols was similar; 2) there was no difference between outcomes of horses with different periods of lameness; and 3) there was no difference between outcomes of horses with unilateral or bilateral lameness.
MATERIALS AND METHODS

Medical records from all horses admitted to Marion duPont Scott Equine Medical Center from April 2004 through December 2006 for MR examination of the distal limb if the lameness resolved, or significantly improved (≥ 75% improvement), by a palmar or plantar digital nerve block were reviewed. Horses were subjected to MR examination if clinical and radiographic findings did not provide a definitive diagnosis. Some horses underwent ultrasonography and scintigraphy prior to MR imaging. Horses were included in the study only if a complete MR examination of one or both front feet was available for retrospective review and if a minimum follow up of 12 months had been obtained from owner/trainer or referring veterinarian. MR examination was considered complete if T1-, T2-weighted and STIR images in at least a transverse and sagittal imaging planes were available for review.

Procedures

Data collected from medical records, owners or referring veterinarians included history, duration and grade of lameness (0-5) prior to MR examination [26], signalment, occupation at the time of MR imaging, clinical findings, response to diagnostic analgesia, and radiographic abnormalities. Horse occupations were categorized as jumping, eventing, dressage, hunting, pleasure ridding (hacking, pony lessons, etc) or other (barrel racing and racing). If available, scintigraphic and ultrasonographic findings were also included.

At a minimum, lateromedial, dorsal 60 degree proximal-palmarodistal views of the distal phalanx and navicular bone and a palmaroproximal-palmarodistal view of the
navicular bone were acquired in all horses, however radiographs were available for review in only 64 cases.

Horses were sedated and MR examination of the affected distal limb performed using an open 0.3 Tesla permanent magnet (Hallmarq Equine Limb MRI scanner, Hallmarq Veterinary Imaging Ltd, Surrey, United Kingdom). A radiofrequency receiving coil was placed on the foot to be imaged and the lower limb centrally positioned within the magnetic field. The contralateral limb was examined in 76 out of 95 horses (80%).

For 35 horses examined during the first year (until June 2005), the standard protocol for foot imaging included 3D GE T1-weighted, 3D GE T2*-weighted, and STIR 2D pulse sequences in a sagittal, transverse, and dorsal plane (Table 1). Transverse images were obtained perpendicular to the deep digital flexor tendon (DDFT) at the level of the middle phalanx, whereas dorsal images were obtained perpendicular to the dorsal border of the DDFT distal to the navicular bone. After the first year, the standard protocol was modified. Subsequently 60 horses were examined with 3D GE T1-weighted, 3D GE T2*-weighted, FSE STIR and FSE T2-weighted images. FSE STIR and 3D GE T1-weighted images were obtained in all three planes as described previously. FSE T2-weighted images were obtained in dorsal and transverse planes and 3D GE T2*-weighted images were obtained in a sagittal plane. Additional FSE T2-weighted images were obtained in a transverse plane, aligned parallel to the sole of the foot, to specifically assess the collateral ligaments (CL) of the DIP joint [27].

MR images had been examined at the time of presentation by the clinician of the case and recorded findings and treatments recommended based on the initial evaluations of the MR images, however for this study a boarded certified radiologist re-evaluated the
MR images retrospectively and the results were entered into a database (Microsoft ® Access 2002, Microsoft Corporation, Redmond, WA). The radiologist was aware of patients’ signalment, duration of lameness, occupation, abnormal clinical findings and results of diagnostic tests performed prior to MR examination but unaware of patient’s treatment or long term outcome. All MR images were evaluated in regards to the presence and location of abnormal MR signal in T1-, T2-weighted and STIR sequences in the DDFT between the proximal interphalangeal joint and the insertion on the distal phalanx, the collateral sesamoidean ligament (CSL), the distal digital annular ligament (DDAL), the navicular bone, the navicular bursa, the proximal and distal interphalangeal joints, the middle and distal phalanges, the CL of the DIP joint, the collateral cartilages of the distal phalanx, laminae and hoof capsule. The MR findings of 95 horses affected by foot lameness used to establish the presence of lesions in each anatomic structure are summarized in Table 2. In the present study only MR abnormalities detected in the lame foot, or lamest foot (for bilateral lameness), were included and considered for statistical analysis.

Horses were categorized by the first author (SGN) based on the location of the most significant abnormalities that were detected on MR images by a board certified radiologist (NMW). Category 1 included horses with MR abnormalities in at least 4 different structures, including the DDFT, navicular bone, CSL, CL of the DIP joint, navicular bursa, DDAL, collateral cartilages of the distal phalanx and the palmar/plantar processes of the distal phalanx. Few horses had DIP joint or DFTS effusion. Category 2 included horses with MR abnormalities in the navicular bone, navicular bursa and/or the CSL. Few horses also had DIP joint effusion. Category 3 included horses with MR
abnormalities in a CL of the DIP joint and navicular bone. Few horses had concomitant MR abnormalities of the CSL or/and navicular bursa. Category 4 included horses with MR abnormalities of the DDFT and other structures including the CSL, navicular bursa and DDAL. Category 5 included horses with MR abnormalities in the middle or distal phalanges. Few horses also had evidence of partial or complete ossification of the collateral cartilages of the distal phalanx and/or DIP joint effusion. Category 6 included horses with MR abnormalities in a CL of the DIP joint. Few horses had DIP joint effusion and/or ossification of the collateral cartilages of the DIP joint. Category 7 included horses with moderate to severe DIP joint effusion and osteophyte formation. Few horses also had osteochondral fragmentation of the extensor process of the distal phalanx or subchondral bone cysts. Category 8 included horses with MR abnormalities in the solar corium.

Abnormalities of the navicular bone, navicular bursa and DDFT were graded by the first author (SGN) based on evaluation of MR images using a modified grading system previously reported (Tables 3-5) [28, 29]. The DDFT and navicular bone were graded based on the location of altered MR signal within the tendon or navicular bone respectively. The navicular bursa was graded based on the MR signal pattern of its content.

Treatments and long term follow up information was obtained by detailed telephone questionnaires of owners, trainers and referring veterinarians in all horses. After MR imaging, treatment 1 or 2 was recommended in each particular case by the attending clinician, however the owner or trainer elected the treatment protocol. Treatment 1 consisted of 1) corrective shoeing, 2) a variable period rest and 3)
medication of the DIP joint and/or navicular bursa and/or the DFTS with 20 mg of sodium hyaluronan and a corticosteroid (3-6 mg of triamcinolone or 40 mg of methylprednisolone sodium). Treatment 2 consisted in corrective shoeing and a variable period of rest. Additional treatments in few horses of each treatment group were extracorporeal shock wave therapy and non-steroidal anti-inflammatory drugs.

The duration of stall rest was determined based on the severity of clinical signs, but horses received at least 4 to 8 weeks of strict stall rest, followed by 4 to 8 weeks of stall rest combined with 10 minutes of hand walking twice a day. If lameness persisted beyond this period, horses were turned out in a small paddock until resolution of the lameness was observed. Alternatively, horses with mild lameness on initial presentation were turned out in a small paddock for a minimum of 12 weeks followed by gradual return to their previous level of activity.

In general corrective shoeing was directed to achieve a proper hoof balance and a straight hoof-pastern axis by shortening the toes and using a wedge full pad. Shoes used included egg bar, heart bar, open wide webbed or natural balance shoes.

Long term outcome was arbitrarily established at 12 months. Outcome was defined as successful if the horse was able to return to a previous level of exercise and maintained this level for at least 3 months without receiving oral non steroidal anti-inflammatory drugs or unsuccessful when a horse failed to return to previous level of exercise due to persistent lameness or owners’ decision. Also a horse was considered to have an unsuccessful outcome if a palmar digital neurectomy was required to resume exercise.
Statistical Methods

Logistic regression (univariable and multivariable analyses) and Fisher’s exact tests were used to investigate potential association of MR imaging data and clinical parameters with horses’ outcome (successful versus unsuccessful) using P < 0.05 as the cut off criterion. MR imaging data consisted of abnormal MR signal in the DDFT, CSL, DDAL, navicular bone, navicular bursa, and DIP joint, middle and distal phalanges, CL of the DIP joint, collateral cartilages of the distal phalanx, laminae, corium and evidence of adhesions. Abnormalities of the navicular bone and DDFT were evaluated on an integer scale from 0-3, whereas abnormalities of the navicular bursa were evaluated on an integer scale from 0-2. Clinical parameters included duration of lameness (< 6 months vs > 6 months) and affected limbs (unilateral or bilateral lameness). Fisher’s exact test was also used to investigate an association between horses with ≥ 4 structures affected (including the DDFT and navicular bone) and unsuccessful outcome.

Logistic regression analysis was performed to compare the outcome between horses that received treatment 1 and horses that received treatment 2. Correlations between DDFT, navicular bone and bursa grades were evaluated using the Pearson’s correlation coefficient. The standard Z-test for non-zero correlation was used. Comparisons of the mean DDFT, navicular bone and bursa grades among different activities were made with a Mantel-Haenzel test. The Wilcoxon test was used to compare the mean number of MR abnormalities of horses used for eventing with horses used for other activities. ANOVA was used to investigate whether the mean duration of lameness was different among athletic activities. All statistical analyses were done using SAS (ver. 9.1, SAS Institute Inc. Cary, NC 27513). All P-values are two-sided. In terms of post hoc
power, there were 57 horses in treatment 1 and 38 horses in treatment 2. Using a two sided 0.05 level test, if the true proportion of excellent response after receiving treatment 2 is between 0.3-0.6, then the power of the study is approximately 80% to statistically detect an odds ratio of 3.7.

RESULTS

Long term follow-up was obtained for 123 horses admitted for MR imaging between April 2004 and December 2006. However, 28 horses were not included in the study either because of incomplete MR exams or poor diagnostic quality of the MR images (23) or because the horses were not subjected to treatment after diagnostic MR imaging (5). Of the remaining 95 horses in the study, there were 74 males and 21 females. The mean age was 9.9 years (median 9 years; range, 1 to 24 years). Breeds included Thoroughbred (22), Thoroughbred cross (8), Warmbloods (30), Warmblood crosses (5), Irish crosses (5), Quarter horses (12), Quarter horse crosses (2), Welsh ponies (2), pony crosses (3), Appaloosa (1), Arabian (1), Draft crosses (2), Connemara (1), and Saddlebred (1). Forty-one horses were used for jumping, 15 for eventing, 20 for dressage, 2 for hunting, 1 for flat racing, 14 were used for general purpose riding, 1 was used for barrel racing, and 1 horse was unbroken at the time of MR imaging.

Duration of lameness prior to MR imaging ranged from 1 to 60 months (mean 9 months; median 4 months). Information about previous treatments could not be obtained accurately because it was not recorded in the medical record or the owner, trainer or referring veterinarian could not remember at the time of follow-up. However most horses
had been rested and received non-steroidal anti-inflammatory drugs prior to referral for diagnostic MR imaging.

Thirty-nine horses (41%) had bilateral lameness, whereas 56 horses (59%) had unilateral lameness (20 right forelimbs, 36 left forelimbs, 1 left hind limb and 1 right hind limb). The degree of lameness while trotting in a straight line on a hard surface varied from grades 1/5 to 5/5 (mean 2.6; median 3). According to medical records, features observed during physical exam included increased digital pulse amplitudes (7 horses), DIP joint effusion (11 horses), swelling of the coronary band over the CL of the DIP joint (3 horses), positive response to hoof testers (22 horses), and DFTS effusion (3 horses).

Radiographic, ultrasonographic and scintigraphic results recorded in 95 horses are summarized in Table 6. No radiographic abnormalities were reported in 47 horses. Prior to MR imaging, ultrasonographic and nuclear scintigraphic examination were performed in 25 horses (23 were negative or inconclusive) and in 12 horses (3 were negative) respectively.

Navicular bone abnormalities were the most common lesion detected within this group of horses (74%) followed by the navicular bursa (50%), the DDFT (42%) and the CL of the DIP joint (34%). DIP joint effusion was found in 42 horses (44%). The location of abnormalities detected on MR images are presented in Graph 1.

The majority of horses (72%) examined had between 2 to 4 structures with MR abnormalities (mean 3.4; median and mode 3, range 1-8) in the lame limb, or lamer limb if there was a history of bilateral lameness. In general, abnormalities were also detected in the contralateral limb of horses with a history of bilateral limb lameness. Comparison between horses’ occupation and structures and mean number of structures affected is
summarized in Table 7. Analysis of the mean number of structures with MR abnormalities in horses used for eventing (2.7) revealed that it was lower than the one of the rest of horses, but the difference was not statistically significant. However, when the mean number of structures with MR abnormalities detected in horses used for eventing (2.7) was compared to the one detected in horses used for other activities combined (3.5), there was a statistically significant difference (P=0.04).

When horses were categorized based on the location of the most significant MR abnormality, horses included in diagnostic category 1 predominated (Table 8); there were 28 horses (29.5%) which had significant MR abnormalities of the DDFT and navicular bone (100%). Twenty-five horses (89%) had abnormalities in the navicular bursa, 11 horses (44%) had DIP joint effusion, 10 horses (35%) had abnormalities in the CSL and 9 horses (32%) had adhesions.

Eighteen out of 95 horses (18.9%) were included in diagnostic category 2 (Figure 1). Other abnormalities detected within this diagnostic category included altered synovial fluid volume (decreased or reduced) in the navicular bursa in 10 horses (55%) (Figure 2) and DIP joint effusion in 9 horses (50%). Seventeen horses (17.8%) were included in diagnostic category 3 (Figures 3-4). Of these horses, 8 had DIP joint effusion and 6 had collateral ligament enthesopathy. Six horses (6%) were included in diagnostic category 6 (Figure 5). In addition to a desmopathy of the collateral ligament, 4 horses had DIP joint effusion.

Eleven horses (11.5 %) were included in diagnostic category 4. In addition to DDFT abnormalities, 9 horses had MR abnormalities in the navicular bursa (Figure 6), 2
horses had DFTS effusion and 1 horse had marked thickening of the DDAL. Adhesions were detected in 1 horse.

Of the 9 horses (9.4%) included in diagnostic category 5, 2 horses had MR abnormalities in the middle phalanx and 7 horses had MR abnormalities in the distal phalanx. Abnormalities included a medial palmar process fracture (type 1) [30] in 2 horses, an intra-articular distal phalangeal fracture (type 2) [30] in 2 horses (Figures 7-8), a medial palmar process bruise (which was also detected by scintigraphy) in 1 horse, moderate fluid signal on STIR images at the level of the toe of the distal phalanx extending towards the terminal arch in 2 horses. One horse had evidence of moderate to severe fluid signal extending from the toe proximad to the DIP joint and partial ossification of the collateral cartilages. Another horse had diffuse increased signal intensity of the subchondral bone in the dorsodistal region of the middle phalanx consistent with a subchondral bone bruise (Figure 9).

Four horses (4.2%) included in diagnostic category 7 had marked DIP joint effusion and osteophyte formation (Figures 10-11). Osteochondral fragmentation of the extensor process (1 horse) and a subchondral bone cyst-like lesion (1 horse) were also detected (Figure 12). Two horses (2.2%) were included in diagnostic category 8 since they had abnormal MR signal at the level of the subsolar and heel bulb which was consistent with a subsolar abscess (Figure 13).
Response to Treatments and Outcomes

The mean follow up was 17.7 months (median 13 months, range 12-36 months). Overall, 43 horses (45%) responded to either of the treatments and returned to their intended used for at least 3 months, whereas the remaining 52 horses (54%) did not respond to the treatments and had recurrent lameness (Table 11).

Seventy-five horses received at least 1 to 2 months of strict stall rest, followed by 1 to 2 months of stall rest combined with 10 minutes of hand walking twice a day. Of these horses, 33 were turned out in a small paddock until the lameness resolved (21 horses that received treatment 1 and 11 horses that received treatment 2). Twenty horses with mild lameness on initial presentation were turned in a small paddock for a minimum of 1 to 2 months followed by gradual return to their previous level of activity; 16 received treatment 1 and 4 received treatment 2. Extracorporeal shock wave therapy over the affected structure and non steroidal anti-inflammatory drugs administration were added to 16 horses that received treatment 1 and 6 horses that received treatment 2.

Diagnostic category 1: 5 out of 28 horses (18%) responded to either of the treatments and had a successful long-term outcome. Generally, horses were subjected to an additional period of rest beyond the initial 4 months due to low grade lameness. Only 2 horses were sound at 4 months but exhibited low grade lameness when returned to a previous level of athletic activity.

Diagnostic category 2: 12 out of 18 horses (67%) (Figure 14) became sound and were performing at a previous level of exercise at the time of follow up. Significant
lameness improvement at 2-3 months following MR imaging was a common feature within this category.

**Diagnostic category 3:** 8 out of 17 horses (47%) had a successful long-term outcome. Three horses that had a successful outcome were subjected to a longer period of rest (8-12 months) due to low grade lameness at 4-6 months. Three horses that had an unsuccessful outcome responded temporarily to treatment 1 but were maintained in a lower level of work (2 horses) or were retired (1 horse) due to low grade lameness at the time of follow-up.

**Diagnostic category 4:** 5 out of 11 horses (45%) responded to treatment and had a successful outcome. Two horses that received treatment 1 and failed to respond underwent a unilateral palmar digital neurectomy, however both horses failed to return to full work.

**Diagnostic category 5:** 6 out of 9 horses (67%) had a successful outcome. In this category, horses were subjected to an additional 2-3 months of rest beyond the initial recommended program, however horses with a distal phalanx type 2 fracture required 12 months to heal.

**Diagnostic category 6:** 3 out of 6 horses (50%) responded to treatment and had a successful outcome. Two horses were being used at a lower level and 1 horse had undergone a bilateral palmar digital neurectomy and was performing at a higher level compared to the previous level of exercise.

**Diagnostic category 7:** 1 out of 4 horses (25%) had a successful outcome. Horse with an unsuccessful outcome developed osteoarthritis of the DIP joint within 3-4 months after MR examination.
Diagnostic category 8: Two horses had MR evidence of a subsolar abscess. Both horses responded to treatment and were sound and in full work at the time of follow up.

Analysis of prognostic factors and treatment effects

Contrary to expected, the proportion of poor outcomes between horses with a shorter (< 6 months) and longer (>6 months) duration of lameness was not significantly different (P= 0.16). Also, there was no significant difference in the proportion of poor outcomes in horses with unilateral lameness compared to horses with bilateral lameness (P= 0.13) (Table 9).

Association of abnormal MR findings with poor outcome was examined. Adhesions and DDAL lesions were evaluated using Fisher’s exact test. All horses with adhesions (10 out of 10 affected horses) had a poor outcome (P= 0.002). As far as the DDAL, the proportion of horses that had a poor outcome was not significantly greater for horses with DDLA lesions than horses without DDAL lesions (P=0.07).

Horses affected by ≥ 4 structures including the DDFT and navicular bone and other structures of the foot were significantly more likely to have a poor outcome (P= < 0.01). Horses with higher grades of lesions in the DDFT, navicular bursa and navicular bone were significantly more likely to have a poor outcome (Table 11). No lesion in the remaining structures demonstrated evidence of association with outcome. Univariable logistic regression analysis produced model coefficients relating the probability of poor outcome with DDFT, navicular bone, and navicular bursa grades (Table 11). The greater coefficient estimate for the navicular bone grade (-1.09, P=.004) was the strongest predictor of poor outcome among the graded structures. Horses with navicular bone
grade of 2 or 3 had a significantly greater chance of poor outcome than those with 0 or 1 (21/22 vs 31/73) (P= <0.001).

There was a higher percentage of poor outcomes in horses subjected to treatment 1 compared to those subjected to treatment 2 (60 % vs 47 %). This could be due to an imbalanced in the number of structures with MR abnormalities between treatment groups. However, analysis of the proportions of structures affected in both treatments groups revealed no imbalance in the number of anatomic structures affected between the two treatment groups as showed in Table 10.

There was a significant correlation between DDFT and navicular bursa grades (r= 0.64, P= < 0.0001), DDFT and navicular bone grades (r= 0.28, P= 0.007), and navicular bursa and navicular bone grades (r= 0.40, P= < .0001). When adjusted for DDFT grade, navicular bursa grade, and navicular bone grade, there was no significant difference between of treatment 1 and treatment 2 (P=0.31). The result was the same when all prognostic factors, clinical and structural, were included in the model.

**DISCUSSION**

MR imaging identifies the cause of pain in horses with foot lameness and its use has become particularly important in horses with navicular syndrome because detection and treatment of lesions at specific anatomic sites of the navicular apparatus is now possible [31]. It has been proposed that antiinflammatory drugs injected into the synovial compartments of the foot may be absorbed by the soft tissues or osseous structures decreasing inflammation and pain in horses with foot lameness [5]. However, in the present study there was no significant difference in the long term outcome between
horses that received intrasynovial antiinflammatory medication targeting the structures with abnormal MR signal and horses that were managed without intrasynovial antiinflammatory medication. Moreover, recent studies have revealed little evidence of acute inflammatory changes within the structures of the navicular apparatus in horses with navicular syndrome [8, 32-34]. Considering these findings, the use of corticosteroids and sodium hyaluronan for treatment of lesions of the navicular apparatus is most likely ineffective in the absence of active inflammation.

Previous studies suggest that intrasynovial antiinflammatory medication provide temporary improvement in horses with navicular syndrome, but are ineffective in resolving lameness in the long term [15, 16, 18, 25]. The short term effect of intrasynovial antiinflammatory drugs was not determined in our study, however the lack of effectiveness in providing long term resolution of lameness agrees with previous studies.

Corrective trimming, shoeing and controlled exercise is extremely important in the treatment of foot injuries, particularly navicular disease [18, 44-46]. For this reason all horses included in the present study had recommendations made in terms of hoof balance and shoeing. Corrective trimming and shoeing variables, such as the type of shoe, the frequency of shoeing, and their association with outcome could not be assessed due to the low number of horses with each type of shoe and variable frequency of shoeing. Larger numbers of horses with consistent shoeing for particular problems are needed to assess particular types of shoeing formulae.

Contrary to expectations, whether horses had unilateral or bilateral limb lameness did not influence long term outcome. This is not surprising as a recent study found
pathological changes in the navicular apparatus of similar severity are sometimes seen in both limbs of unilaterally lame horses suggesting that lesion development may precede the onset of pain and lameness [28]. Horses in the present study may have had similar pathologic changes in the navicular apparatus in the lame and contralateral limb, therefore horses with unilateral limb lameness had a similar outcome when compared to horses with a bilateral limb lameness. In addition, duration of lameness prior to MR imaging did not influence long term outcome. This result supports previous evidence that horses with advanced pathological changes in the navicular apparatus may be present relatively soon (6-8 weeks) after recognition of lameness, indicating preexisting abnormalities [7, 8]. Advanced pathological changes may have been present in horses with a shorter duration of lameness as well as in horses with a longer duration of lameness precluding identification of differences in long term outcomes between groups.

Magnetic resonance imaging was able to identify abnormalities in horses with unexplained foot lameness as determined by conventional imaging modalities. The location and appearance of the majority of the lesions indentified were similar to those reported by others [2, 9, 15, 17, 20], however the presence of certain lesions could not be identified because of the imaging limitations of the low-field MR system used. The low resolution of the MR system used in the study did not allow characterization of lesions of the DSIL, navicular bone fibrocartilage, and articular cartilage of the DIP joint [35]. Therefore, the prevalence of these lesions cannot be ruled out and could be under represented as a cause of lameness in this study.

In the present study, the high prevalence of navicular bone MR abnormalities was similar to the one reported in previous studies conducted in North America [5, 17].
Despite the high percentage of navicular bone MR abnormalities detected, only 14% of horses had radiographic abnormalities of the navicular bone prior to MR imaging. One of the advantages of MR imaging is detection of osseous physiologic and structural changes of the navicular bone that are not detected by radiography as found in the present study [5].

There was also a high prevalence (50%) of navicular bursal and DDFT (42%) MR abnormalities, but these were always identified with concomitant abnormalities of the navicular apparatus as previously reported [15]. In addition, a significant association was found between DDFT and navicular bursa grade, DDFT and navicular bone grade, and navicular bursa and navicular bone grade. These findings support the presence of pathologic changes of closely related structures of the navicular apparatus in horses with foot pain. Most likely these abnormalities are degenerative pathologic changes in the DDFT, navicular bone and navicular bursa typically found in horses with navicular syndrome [8, 34].

The third most common MR finding was DIP joint effusion which was evident in 42 horses (44%). This is a consistent finding in horses subjected to MR imaging for diagnosis of foot pain [5, 12, 15, 17]. The source of distention of the DIP joint in these horses may be due to degeneration of the articular cartilage or due to lesions in the navicular apparatus based on observations from clinical cases [5]. Moreover, distention of the DIP joint appears to be a sign of DIP joint arthritis or navicular syndrome [5]. In the present study, given the high prevalence of abnormalities in the navicular bone and supportive structures, it is possible an association exists between distention of the DIP joint and lesions in the navicular apparatus. However, degeneration of the articular
cartilage of the DIP joint may be undetected at the time of MR examination in our study due to the limitations of the low-field system used [36].

The prevalence of deep digital flexor tendinopathy (42%) was lower than that reported by Dyson et al.[13] (82%) using a high-field MR system, however the prevalence of MR of desmopathy of the CL of the DIP joint (34%) was similar to that reported by the same group of investigators [13]. The higher prevalence of deep digital flexor tendinopathy reported by Dyson probably reflects a different selection criterion for MR examination, different horse population examined at the two hospitals and a different sensitivity and specificity between the low- and high-field MRI systems. DDFT lesions that predominated were core and dorsal border lesions which were identified at different levels between the PIP joint and insertion of the DDFT to the distal phalanx. However it was not uncommon to find different types of lesions at different levels of the tendon in the same foot. Para-sagittal lesions were under represented in our study.

The mean number of structures with MR abnormalities in the lame limb, or lamest limb if there was a history of bilateral lameness, was 3.4 which is similar to the one previously reported (3.3)[7]. Interestingly, the mean number of structures with abnormal MR signal was significantly lower in horses used for eventing (2.7) compared to horses used for other activities combined (3.5). Although it is logical that horses with a history of chronic lameness would have a higher number of abnormalities than horses with a more recent history of lameness [28], in this study the mean duration of lameness between different horses activities was not significantly different. We speculate that potential reasons for the lower mean number of structures affected in horses used for
eventing may be due the selection criterion for MR examination, level of exigency and ability of riders to perceive low grade lameness.

Horses used for jumping had a significantly higher mean navicular bone grade when compared to horses used for eventing and dressage, supporting the presence of more advanced pathologic navicular bone changes in the former group. The aetiopathogenesis of navicular disease is multifactorial but excessive biomechanical stress over the navicular apparatus appears to play a significant role [37, 38]. Biomechanical stresses linked to navicular disease include non-physiologic forces exerted on the navicular bone and supporting soft tissue structures that result in degeneration of the navicular apparatus [37, 38]. Results of the present study suggest that that horses used for jumping are subjected to more non-physiologic forces and stress of the navicular bone resulting in more advanced pathologic changes as detected with MR.

Overall, 45% of horses responded to the treatments and returned to their intended used for at least 3 months. The percentage of horses returning to full work decreased significantly as the DDFT, navicular bone and navicular bursa grades increased supporting an association between the outcome and the severity lesions in these structures. Thereby, horses with more advanced pathologic changes are less likely to become sound and maintain the same level of exercise. Moreover, among the anatomic structures graded, navicular bone grade was the strongest predictor of poor outcome which could be due to the presence of adhesions between the flexor cortex of the navicular bone and the adjacent dorsal border of the DDFT detected in horses with advanced navicular bone changes [8].
The long term outcome of horses with lesions of the foot is influenced by the anatomic structure injured and number of structures affected [15]. Horses with MR abnormalities of the navicular bone or DDFT generally have a poor prognosis for soundness beyond 6 months [15]. In our study, adhesions of the dorsal border of the DDFT to the flexor surface of the navicular bone, CSL, or navicular bursa were associated with a poor outcome (P= 0.002). This agrees with descriptions of adhesions associated advanced stage of navicular disease [34]. Thickening and scarring of the DDAL was not significantly associated with poor outcome, however there was a trend toward an association with poor outcome (P=0.07). Horses with thickening of the DDAL also had multiple injuries of the palmar/plantar structures of the foot as previously reported [15]. In the present study horses affected by a combination of abnormalities of the DDFT, navicular bone and other anatomic structures had a poor prognosis for long term soundness.

Because intrasynovial antiinflammatory drugs in horses with navicular syndrome appear ineffective to resolve lameness in the long term, alternative treatments have been developed and are under investigation. Tiludonate, a bisphosphonate that reduces bone resorption in humans, was beneficial as a therapeutic agent in the treatment of navicular disease in a double-blind placebo-controlled clinical trial [39]. More recently, decompressive drilling of the navicular bone to decrease the intraosseous hypertension and allow neovascularization of the bone medulla was used experimentally [24, 40]. Despite these alternative therapies, palmar/plantar digital neurectomy is still the most common surgical technique used for treatment of refractory navicular disease, but careful patient selection is necessary to achieve a favorable outcome [41].
Alternative treatments have also been developed for treatment of deep digital flexor tendinopathy because of the poor outcome after conservative therapy [12, 15]. CT guided intra-lesional injections with mesenchymal stem cells or platelet-rich plasma and dorsal fibrillation debridement of the DDFT using tenoscopy or navicular bursoscopy are currently under investigation [10, 22, 23]. However, it is not clear yet if in fact they do significantly improve the outcome over the reported studies.

MR imaging allows us to identify areas of subchondral bone damage that are not detectable by any other diagnostic imaging modality; these injuries have been observed in the proximal, middle and distal phalanges associated with each joint [42]. In humans, the prognosis for subchondral bone injuries without articular cartilage damage is excellent [43], however the prognosis for horses has not been reported yet. Based on the limited number of horses with such abnormalities in the present study, it appears that 2-3 months of rest combined with gradual return to exercise is effective, but long-term follow-up of many horses is required.

One of the limitations of the study was the lack of random allocation. Random allocation avoids subjective influence of treatment selection and ensures that the groups are comparable. Although not statistically significant, there was a higher percentage of horses subjected to treatment 1 that had a poor outcome when compared to the percentage of horses subjected to treatment 2. This difference could be the result of chance; however the lack of randomization may have been influenced objective allocation of treatments so the causes of any subsequent differences in performance between the treatment groups were not apparent. Horses were subjected to a different treatment protocol (treatment 1 or 2) based on clinician’s opinion at the time of MR examination. In the present study,
treatment groups were comparable based on analysis of the proportions of anatomic structures with abnormal MR signal in both treatments groups, which indicated no substantial bias.

Several different questions formed the basis of the telephone questionnaire in the present study. Whether horses achieved soundness and returned to full work was used to assess long term outcome. The advantage of using soundness and return to previous level of exercise is that this approach may be less subject to the owner influence. Horses may be sound after treatment according to the owner, however we can speculate that if a horses did not return to a previous level of exercise was due to recurrent or persistent lameness. Failure to return to previous level of exercise may be due to owner decision. In our study, some horses were sound according to the horses’ owner, but they were not put in full work to prevent potential recurrence of foot injuries. Consequently this study may have underestimated the potential beneficial effects of treatment 1 because horses that did not return to full work were considered to have a poor outcome independently of whether horses were sound according to the owners.
REFERENCES:


151


Figure 1: Sagittal GE T1-weighted image from a horse with enlarged synovial invaginations in the distal border of the navicular bone. There is a large cystic-like lesion characterized by abnormal intermediate signal intensity at the distal half of the navicular bone outlined by a rim of decreased signal intensity (arrow). This is consistent with enlarged synovial invaginations and/or trabecular bone resorption surrounded by sclerotic bone just proximal to the attachment of the origin of the distal sesamoidean impar ligament.
Figure 2: Transverse FSE T2-weighted image obtained from same horse of figure 1. The image was obtained at the level of the middle phalanx. Medial is to the right. There is marked effusion of the navicular bursa (arrows).

Figure 3
Figure 3: Transverse FSE T2-weighted image obtained at the level of the middle phalanx. Medial is to the left. Although the image was obtained with a mild degree of obliquity which can cause distortion in size and signal intensity, there is enlargement and generalized increased signal intensity of the medial collateral ligament of the distal interphalangeal joint (arrow).

Figure 4

Figure 4: Sagittal FSE STIR image obtained from same horse of figure 3. There is diffuse hyperintense signal in the navicular bone medulla (arrow). The horse was turned out in a small paddock for 8 months and returned to full work.
Figure 5: Transverse FSE STIR image of horse with a 2 week history of severe right forelimb lameness obtained at the level of the middle phalanx. Medial is to the left. There is marked enlargement and generalized increased signal intensity of the medial collateral ligament of the distal interphalangeal joint (arrow). The periligamentous tissues are thickened with diffuse increased signal intensity and loss of definition of the tissue planes. The increased signal intensity is more prominent along the palmar margin of the medial collateral ligament indicating periligamentous edema and swelling (arrowhead). The horse had stall rest and was treated with extracorporeal shock wave therapy and maintained on a wide webbed shoe. However radiographic changes of osteoarthritis of the distal interphalangeal joint were detected 3 months after MR examination. The treatment was unsuccessful.
Figure 6: Transverse FSE T2-weighted image obtained at the level of the middle phalanx. Medial is to the right. The image was obtained with a slight degree of obliquity. The medial lobe of the deep digital flexor tendon is markedly enlarged and has a combination of lesions. There is a linear area of abnormal intermediate to high signal intensity on the axial portion of the medial lobe (parasagittal lesion). Also, there is an area of abnormal intermediate to high signal intensity on the center of the medial lobe that extends through the dorsal margin of the medial lobe (core lesion and dorsal border lesions respectively) (arrowhead). The normal fluid signal within the navicular bursa at the level of the tendon lesions has been replaced by an area of intermediate signal intensity which is compatible with synovial proliferation or focal adhesions. There is also effusion in the proximal lateral recess of the navicular bursa (arrow). Although the medial collateral ligament of the distal interphalangeal joint has normal signal intensity, it appears moderately enlarged, likely due to slight obliquity of the image and wide base stance. The horse was subjected to treatment 1 with an extensive period of rehabilitation, but it was still lame 24 months after MR examination.
Figure 7: Sagittal GE T1-weighted image obtained from a horse with a 3 week-old history of severe lameness. The distal phalanx has a linear area of increased signal intensity compatible with a distal phalangeal fracture (arrow). This linear defect has a contiguous area of marked low signal intensity which is compatible with fluid accumulation or sclerosis of the adjacent bone; however comparison with FSE T2-weighted images is necessary to fully characterize this lesion.
Figure 8: Transverse FSE T2-weighted image obtained from the same horse in figure 7 at the level of the distal phalanx. Medial is to the right. As in the previous figure, the distal phalanx has a linear area of increased signal intensity (arrow). This linear defect has a contiguous area of diffuse low signal intensity which is compatible with bone mineralization or sclerosis (arrowhead). The horse returned to full work after 14 months of rest and rehabilitation.
Figure 9: Sagittal FSE STIR image obtained from a horse with a chronic forelimb lameness. There is an extensive hyperintense signal area in the dorsodistal aspect of the middle phalanx which is indicative of fluid accumulation within the cancellous and subchondral bone. This finding is consistent with bone bruising or bone contusion (arrow). The horse returned to full work and remained sound after to 3 months of stall rest with increasing periods of handwalking.
Figure 10: Sagittal FSE STIR image obtained from a horse with a chronic forelimb lameness. There is marked effusion of the distal interphalangeal joint characterized by severe fluid distension of the dorsal pouch of the joint.

Figure 11: Sagittal GE T1-weighted image obtained from the same horse in figure 10. There is an irregular area of intermediate signal intensity at the dorsodistal aspect of the middle phalanx (arrow). This abnormal signal intensity area is at the level of the distal...
interphalangeal joint capsule attachment on the middle phalanx. This finding is consistent with osteophyte formation. Abnormalities of the articular cartilage of subchondral bone are not visible. The horse developed radiographic evidence of osteoarthritis of the distal interphalangeal joint 3 months after MR examination.

Figure 12

Figure 12: Sagittal GE T1-weighted image obtained from a horse with bilateral forelimb radiographic evidence of subchondral bone cyst in the distal phalanx. There is an elliptical focal area of intermediate signal intensity within the subchondral bone of the distal phalanx (arrow). The cyst is surrounded by a diffuse area of decreased signal intensity consistent with bone sclerosis. This horse developed osteoarthritis of both forelimb distal interphalangeal joints.
Figure 13: Transverse FSE T2-weighted image obtained from a horse with an acute and severe fore limb lameness. The image was obtained at the level of the distal phalanx with a mild degree of obliquity. Medial is to the left. There is an extensive area of intermediate to high signal intensity along the medial sulcus of the frog consistent with fluid accumulation between the cuneal corium and the sole. A subsolar abscess was found and drained after MR examination.
Figure 14: Sagittal GE T2*-weighted image obtained from a horse with a history of bilateral chronic forelimb lameness. There is an area of intermediate to low signal intensity outlined by a rim of decreased signal intensity in the level of the distal border of the navicular bone (arrow). This is consistent with enlarged synovial invaginations in the distal border of the navicular bone. In addition, there is moderate effusion of the dorsal and palmar pouches of the distal interphalangeal joint.
TABLES

Table 2: Pulse sequence parameters

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>Flip Angle (Deg.)</th>
<th>FOV (cm)</th>
<th>Matrix size</th>
<th>Slice Thickness (mm)</th>
<th>Gap (mm)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D GE T1</td>
<td>23</td>
<td>7</td>
<td>60</td>
<td>170 x 170</td>
<td>256 X 256</td>
<td>2.5</td>
<td>NA</td>
<td>3:12</td>
</tr>
<tr>
<td>3D GE T2*</td>
<td>40</td>
<td>20</td>
<td>40</td>
<td>170 x 170</td>
<td>256 X 256</td>
<td>2.5</td>
<td>NA</td>
<td>3:33</td>
</tr>
<tr>
<td>STIR 2D</td>
<td>1500</td>
<td>20</td>
<td>90</td>
<td>192 x 192</td>
<td>256 X 256</td>
<td>5</td>
<td>0.5</td>
<td>4:52</td>
</tr>
<tr>
<td>FSE STIR</td>
<td>1800</td>
<td>28</td>
<td>90</td>
<td>192 x 192</td>
<td>256 X 256</td>
<td>5</td>
<td>0.5</td>
<td>4:04</td>
</tr>
<tr>
<td>FSE T2</td>
<td>1800</td>
<td>30</td>
<td>90</td>
<td>170 x 170</td>
<td>256 X 256</td>
<td>5</td>
<td>0.5</td>
<td>3:34</td>
</tr>
</tbody>
</table>

TR= time of repetition, TE= time of echo, FOV= field of view, 3 D GE T1= 3 D gradient echo T1, 3 D GE T2*= 3 D gradient echo T2*, STIR= short tau inversion recovery, FSE STIR= fast spin echo short tau inversion recovery, FSE T2= fast spin echo T2 and NA= not applicable.
Table 3: Summary of MR findings of 95 horses affected by foot lameness used to establish the presence of lesions in each anatomic structure

<table>
<thead>
<tr>
<th>Anatomic Structure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collateral ligaments of the distal interphalangeal joint</td>
<td>Focal or generalized lesions at the origin, body or insertion with or without swelling. Sometimes lesions were accompanied by an enthesopathy in the middle and/or distal phalanx. Desmopathy was characterized by hyperintense signal within the CL in T2-weighted and STIR images visible in more than one plane. Areas of hyperintense signal around the affected CL were also seen.</td>
</tr>
<tr>
<td>Deep digital flexor tendon</td>
<td>Core, parasagittal, dorsal and palmar border lesion extending a variable distance along the tendon anywhere from the PIP joint to the tendon’s insertion on the distal phalanx. Affected tendons had a variable increase in size and signal intensity in T1-, T2-weighted and sometimes on STIR images.</td>
</tr>
<tr>
<td>Distal interphalangeal joint</td>
<td>Joint effusion, subchondral bone cyst-like lesions, osteochondral fragmentation and osteophyte formation. Effusion was characterized by ↑ volume of hyperintense signal articular fluid in T2-weighted and STIR images. Synovial proliferation within the dorsal pouch of the DIP joint appeared hypointense signal in all three pulse sequences. Subchondral bone cyst-like lesion was characterized by discrete elliptical area of high to intermediate signal within the subchondral bone in all three sequences. Osteochondral fragments appeared hypointense in all three sequences.</td>
</tr>
<tr>
<td>Middle and distal phalanges and collateral cartilage of the distal phalanx.</td>
<td>Focal or generalized distal phalangeal bruise, subchondral bone bruise of the middle phalanx, distal phalangeal fracture, mineralization of the palmar process, and partial or complete ossification of the collateral cartilages. Bone bruise of the phalanges was characterized as focal or generalized increased signal intensity on STIR and T2-weighted images and decreased signal intensity on T1-weighted images. A mineralized palmar process appeared as a diffuse area of hypointense signal in T1- and T2-weighted images. Fractures were characterized by discontinuity of the homogenous hypointense signal of the cortical bone, with linear increase signal intensity in T1- and T2-weighted images adjacent to the fracture. Ossification of the collateral cartilages was characterized by loss of normal intermediate signal intensity on T1- and T2-weighted images.</td>
</tr>
<tr>
<td>Dermis of the sole and heel bulbs</td>
<td>A foot abscess was characterized by a focal area of ↑ signal intensity in T2-weighted and STIR images contained in the subsolar space at the level of the heel bulbs and caudal sole.</td>
</tr>
<tr>
<td>Navicular bone</td>
<td>Enlarged synovial invaginations evident on T1-T2*-weighted sequences and hyperintense signal of the navicular bone medulla on STIR images, smooth extension of the distal border into the DSIL (enthesophyte), cystic-like lesion evident on T1-T2*-weighted and STIR sequences with diffuse high signal intensity within the navicular bone medulla on the STIR, diffuse increased signal intensity of the navicular bone medulla on STIR images with or without diffuse decreased signal intensity of the medulla on T1 and T2-weighted images, focal hyperintense signal on STIR images at insertion of CSL or origin of DSIL, cystic-like lesion communicating with the flexor border visible on T1-T2 and STIR images, endosteal irregularity and thickness of the flexor cortex, focal increased signal in flexor cortex in all sequences, focal hyperintense signal on T2*-weighted and STIR images palmar to bone consistent with fibrocartilage loss, adhesions characterized by focal hyperintense signal between the flexor cortex of the navicular bone and dorsal border of the DDFT.</td>
</tr>
</tbody>
</table>
Navicular bursa

Fluid bursal distension or replacement of synovial fluid by soft tissue or adhesions. Navicular bursal effusion was characterized by ↑ volume of hyperintense synovial fluid in T2-weighted and STIR images. Distension by soft tissue proliferation within the navicular bursa had a low to intermediate signal intensity (soft tissue), and replacement of fluid by soft tissue or adhesions was characterized by loss of normal low signal on T1- and T2-weighted and STIR images.

Multiple Abnormalities

Combination of deep digital flexor, navicular bone and other soft tissue lesions of the navicular apparatus.

Navicular bone and collateral ligaments of the distal interphalangeal joint

Lesions of the navicular bone and collateral ligament of the distal interphalangeal joint.

Digital flexor tendon sheath

Effusion was characterized by ↑ volume of hyperintense articular fluid in T2-weighted and STIR images.

Distal digital annular ligament

Generalized or focal thickening with associated low signal intensity in T1- and T2-weighted images

Table 4: Criteria used for classification of deep digital flexor tendinopathies based on its location (adapted from Murray et al. 2004)

<table>
<thead>
<tr>
<th>Location</th>
<th>MR findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>Uniform low signal intensity in all sequences with two symmetric lobes</td>
</tr>
<tr>
<td>Grade 1 (Parasagittal lesion)</td>
<td>Linear area of high signal intensity in T1- and T2-weighted images in the medial and/or lateral lobe. Abnormal tendons maintained their lateromedial symmetry</td>
</tr>
<tr>
<td>Grade 2 (Dorsal border lesion)</td>
<td>Irregularity and high signal intensity in T1-and T2-weighted images in the dorsal border of the medial or/lateral lobe. Lesion did not extent more than 1/3 of the tendon area in transverse section. Some lesions were visible on STIR images. Abnormal tendons maintained their lateromedial symmetry</td>
</tr>
<tr>
<td>Grade 3 (Core lesion)</td>
<td>High signal intensity in T1- and T2-weighted images in the center of the medial and/or lateral lobe. Some lesions were visible on STIR images. Lesions tended to extend towards the dorsal and/or palmar border in some cases. Abnormal tendons tended to loss their lateromedial symmetry</td>
</tr>
</tbody>
</table>
Table 5: Criteria used for grading the navicular bone

| Grade 0 | NB distal: Smooth indentations into cortical surface and uniform cortical thickness  
|         | NB flexor: Smooth fibrocartilage layer and uniform cortical thickness  
|         | NB medulla: Uniform high signal intensity in T1-and T2-weighted images, with low signal intensity on STIR images  
|         | NB proximal: Smooth proximal cortical surface |
| Grade 1 | NB distal: Irregular indentations into the cortical surface and trabecular bone (defects did not extend more than 1/3 into the navicular medulla), variable cortical thickness, smooth extension of the distal border into the DSIL  
|         | NB flexor: Smooth fibrocartilage layer and uniform cortical thickness  
|         | NB medulla: Generalized uniform increased signal intensity on STIR images but with normal high signal intensity in T1-and T2-weighted images.  
|         | NB proximal: Mild irregular indentation into the cortical surface adjacent to the CSL insertion. |
| Grade 2 | NB distal: Irregular indentations into the cortical surface and trabecular bone (defects did extend more than 1/3 into the navicular medulla)-variable cortical thickness-Irregular extension of the distal border into the DSIL, distal border fragments  
|         | NB flexor: Smooth to irregular fibrocartilage layer and uniform cortical thickness  
|         | NB medulla: Generalized or focal increased signal intensity on STIR images, and low to intermediate signal intensity in T1- and T2-weighted images.  
|         | NB proximal: Superficial irregular indentation into the cortical-enthesophyte formation |
| Grade 3 | NB distal: Irregular indentations into the cortical surface and trabecular bone extending a variable distance into the navicular medulla  
|         | NB flexor: Fibrocartilage and flexor cortex defect extending a variable distance into the medulla sometimes communicating with distal border indentations or cyst-like lesions  
|         | NB medulla: Generalized increased signal intensity signal STIR images and decreased signal intensity in T1- and T2-weighted images  
|         | NB proximal: Deep irregular indentation into the cortical surface adjacent to the CSL insertion with altered signal intensity of the adjacent trabecular bone |
Table 6: Criteria used for grading the navicular bursa

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>Homogenous high signal in T2-weighted and STIR images without distension and clearly defined margins</td>
</tr>
<tr>
<td>Grade 1</td>
<td>Fluid bursal distension in T2-weighted and STIR images and clearly defined margins</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Distension of the navicular bursa with low signal tissue (soft tissue), and loss of normal low signal on T1- and T2-weighted and STIR images (replacement of fluid by soft tissue or adhesions)</td>
</tr>
</tbody>
</table>

Table 7: Radiographic, ultrasonographic and scintigraphic abnormalities detected in 95 horses prior to MR imaging examination

<table>
<thead>
<tr>
<th>Structure</th>
<th>Number of horses affected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiography</strong></td>
<td></td>
</tr>
<tr>
<td>Middle phalanx:</td>
<td></td>
</tr>
<tr>
<td>- Enthesophyte formation on the dorsomedial or dorsolateral aspect</td>
<td>5</td>
</tr>
<tr>
<td>Distal phalanx:</td>
<td></td>
</tr>
<tr>
<td>- Subchondral bone cyst</td>
<td>1</td>
</tr>
<tr>
<td>- Collateral cartilage ossification</td>
<td>3</td>
</tr>
<tr>
<td>- Osteophyte at the extensor process</td>
<td>2</td>
</tr>
<tr>
<td>Navicular bone:</td>
<td></td>
</tr>
<tr>
<td>- ( \uparrow ) Number of synovial invaginations</td>
<td>9</td>
</tr>
<tr>
<td>- Flexor cortex changes</td>
<td>2</td>
</tr>
<tr>
<td>- Abaxial enthesophyte formation at the attachment of the CSL.</td>
<td>3</td>
</tr>
<tr>
<td>- Medullary cyst formation</td>
<td>2</td>
</tr>
<tr>
<td><strong>Ultrasonography</strong></td>
<td></td>
</tr>
<tr>
<td>CL of the DIP joint:</td>
<td></td>
</tr>
<tr>
<td>- Enlarged and diffusely hypoechoic</td>
<td>1</td>
</tr>
<tr>
<td>DDFT:</td>
<td></td>
</tr>
<tr>
<td>- Hypoechoic area of short irregular fibers abaxially at the level of the navicular bone associated with a sole puncture tract</td>
<td>1</td>
</tr>
</tbody>
</table>
Scintigraphy

Navicular bone:
- Moderate focal IRU bilaterally - region of the navicular bone

Distal phalanx:
- Moderate focal IRU in the medial palmar process
- Moderate focal IRU - region of DDFT and
- Intense focal IRU - region of CL of the DIP joint

Table 8: Horse’s occupation, structures affected and mean number of structures with MR abnormalities detected in 95 horses

<table>
<thead>
<tr>
<th>Occu.</th>
<th>DDF T</th>
<th>CSL</th>
<th>NBu</th>
<th>DDA</th>
<th>CL DIP</th>
<th>DIP joint Eff</th>
<th>CC</th>
<th>M&amp;D PP</th>
<th>DFT Eff</th>
<th>NBo</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP</td>
<td>19</td>
<td>5</td>
<td>21</td>
<td>4</td>
<td>13</td>
<td>21</td>
<td>6</td>
<td>11</td>
<td>5</td>
<td>34</td>
<td>3.6</td>
</tr>
<tr>
<td>EVT</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>DS</td>
<td>9</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>14</td>
<td>3.3</td>
</tr>
<tr>
<td>PR</td>
<td>8</td>
<td>1</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td></td>
<td>3</td>
<td></td>
<td>5</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

included horses used for activities other the one of above. Mean: mean number of structures with MR abnormalities.

Table 9: Results of logistic regression analysis.

<table>
<thead>
<tr>
<th>Variable and category</th>
<th>No. of horses w/ excellent outcome</th>
<th>No. of horses w/ poor outcome</th>
<th>Odds ratio</th>
<th>95 % Confidence interval</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration of clinical signs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 6 months</td>
<td>33 (48 %)</td>
<td>35 (52 %)</td>
<td>1.59&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.64-4.0</td>
<td>0.16</td>
</tr>
<tr>
<td>&gt; 6 months</td>
<td>10 (37 %)</td>
<td>17 (63 %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limbs Affected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One</td>
<td>29 (52% )</td>
<td>27 (48 %)</td>
<td>1.92&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.83-4.3</td>
<td>0.13</td>
</tr>
<tr>
<td>Both</td>
<td>14 (35 %)</td>
<td>25 (65 %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment received</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment 1</td>
<td>23 (40 %)</td>
<td>34 (60 %)</td>
<td>0.61&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.27-1.39</td>
<td>0.24</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>20 (53 %)</td>
<td>18 (47 %)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> The odds ratio represents the odds that a horse with duration of lameness of > 6 months would have an excellent outcome, compared with the odds for a horse with duration of lameness of < 6 months.

<sup>2</sup> The odds ratio represents the odds that a horse with a unilateral lameness would have an excellent outcome, compared with the odds for a horse with a bilateral lameness.

<sup>3</sup> The odds ratio represents the odds that a horse subjected to treatment 1 would have an excellent outcome, compared with the odds for a horse subjected to treatment 2.
Table 10: Proportions of foot structures with abnormalities per each treatment group (percentages).

<table>
<thead>
<tr>
<th>Structure</th>
<th>TR 1</th>
<th>TR 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDFT</td>
<td>47</td>
<td>34</td>
</tr>
<tr>
<td>CSL</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>N Bursa</td>
<td>56</td>
<td>42</td>
</tr>
<tr>
<td>DDAL</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>MCL</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td>DIP effusion</td>
<td>49</td>
<td>37</td>
</tr>
<tr>
<td>TI P2</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>CC</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>TI P3</td>
<td>19</td>
<td>34</td>
</tr>
<tr>
<td>Adhesions</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>DFTS</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>N Bone</td>
<td>77</td>
<td>75</td>
</tr>
</tbody>
</table>
Table 11: results of univariable regression model of association of abnormal MR findings with poor outcome.

<table>
<thead>
<tr>
<th>Variable and category</th>
<th>No. of Horses w/ excellent outcome</th>
<th>No. of Horses w/ poor outcome</th>
<th>Coefficient estimate- (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDFT grade:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>32 (74)</td>
<td>23 (45)</td>
<td>-0.44 (0.008)</td>
</tr>
<tr>
<td>1</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3 (8)</td>
<td>12 (23)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8 (18)</td>
<td>17 (32)</td>
<td></td>
</tr>
<tr>
<td>Navicular bursa grade:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>29 (67)</td>
<td>21 (40)</td>
<td>-0.80 (0.004)</td>
</tr>
<tr>
<td>1</td>
<td>9 (22)</td>
<td>12 (24)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5 (11)</td>
<td>19 (36)</td>
<td></td>
</tr>
<tr>
<td>Navicular bone grade:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>15 (35)</td>
<td>11 (21)</td>
<td>-1.09 (0.006)</td>
</tr>
<tr>
<td>1</td>
<td>27 (63)</td>
<td>20 (39)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 (2)</td>
<td>14 (27)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0 (0)</td>
<td>7 (13)</td>
<td></td>
</tr>
</tbody>
</table>

Number in parenthesis in column 2 and 3 are percentages.
Graph 1

Location of abnormalities detected on MRI in 95 horses

CONCLUSIONS

In addition to corrective shoeing, systemic anti-inflammatories and controlled exercise, intrasynovial corticosteroid treatment has been widely used for horses with navicular disease. However, recent experimental and clinical evidence suggest that intrasynovial corticosteroids does not provide additional benefit over corrective shoeing and controlled exercise in horses with navicular disease or a positive response to intra-articular anesthesia of the distal interphalangeal joint. The results of the present study support these previous findings and our clinical impression that horses affected by soft tissues and osseous lesions treated with a combination of intrasynovial medication, corrective shoeing, a variable period rest and additional therapy have a similar long term outcome to horses affected by the same spectrum of lesions and treated with a combination of corrective shoeing, a variable period of rest and additional therapy.