Received: 15 August 2019 | Revised: 12 January 2020 | Accepted: 19 January 2020

DOI: 10.1111/vru.12855

WILEY

ORIGINAL INVESTIGATION

Standing MRI lesions of the distal interphalangeal joint and podotrochlear apparatus occur with a high frequency in warmblood horses

Santiago D. Gutierrez-Nibeyro[1] | Natasha M. Werpy[2] | Sarah J. Gold[3] | Silvia Olguin[4] | David J. Schaeffer[1]

[1]Department of Veterinary Clinical Medicine, College of Veterinary Medicine, University of Illinois, Urbana, Illinois

[2]Equine Diagnostic Imaging, Inc., Archer, Florida

[3]B.W. Furlong & Associates, Oldwick, New Jersey

[4]College of Veterinary Medicine, University of La Plata, La Plata, Buenos Aires, Argentina

Correspondence
Santiago D. Gutierrez-Nibeyro, Department of Veterinary Clinical Medicine, College of Veterinary Medicine, University of Illinois, Urbana, IL 61802.
Email: sgn@illinois.edu

Abstract

Foot pain is a common presenting complaint in Warmblood horses. The aim of this retrospective, cross-sectional study was to determine the spectrum of foot lesions detected by magnetic resonance imaging (MRI) in Warmblood horses used for dressage, jumping, and eventing. The medical records of 550 Warmblood horses with foot pain that were scanned using standing MRI were reviewed and the following data were recorded: signalment, occupation, lameness, diagnostic analgesia, imaging results, treatments, and follow-up assessments. Associations between standing MRI lesions and chronic lameness following treatment were tested. Abnormalities of the navicular bone (409 horses, 74%), distal interphalangeal joint (362 horses, 65%), and deep digital flexor (DDF) tendon (260 horses, 47%) occurred with the highest frequency. The following abnormalities were significantly associated ($P < .05$) with chronic lameness following conservative therapy: moderate to severe MRI lesions in the trabecular bone of the navicular bone, mild or severe erosions of the flexor surface of the navicular bone, moderate sagittal/parasagittal DDF tendinopathies, and moderate collateral sesamoidean desmopathies. Also, identification of concurrent lesions of the DDF tendon, navicular bone, navicular bursa, and distal sesamoidean impar ligament was associated with chronic lameness after conservative therapy. Development of effective treatment options for foot lesions that respond poorly to conservative therapy is necessary.

KEYWORDS

equine, foot injuries, outcome, sports medicine

1 | INTRODUCTION

Foot pain is a common source of lameness and poor performance in Warmblood horses,[1,2] and MRI is a standard method used to provide a more definitive diagnosis when the results of traditional diagnostic techniques (radiography, ultrasonography, and scintigraphy) are inconclusive.[3,4] Previous studies describing the foot injuries identified by MRI included horses of different breeds,[5-9] or mainly Quarter Horses used for Western performance activities.[10] Therefore, there have been limited studies of the spectrum of foot injuries identified by MRI that specifically focused solely on Warmblood horses. This information may help elucidate whether Warmblood horses used for dressage, jumping, and eventing activities are predisposed to certain injuries and whether these injuries may negatively impact the prognosis for athletic activity.

Different factors, such as horse occupation, lameness duration, and injury type, among others, have been reported to affect the prognosis for certain foot injuries.[6,8,10-15] A previous study of mainly Warmblood horses found an association between chronic lameness and deep digital flexor (DDF) tendinopathy.[13] However, the association between other foot injuries and chronic lameness could not be determined due to a relatively low number of certain injuries.[13] Aims of the current study were to report the spectrum of foot injuries detected with standing MRI in Warmblood horses presented at a single referral equine hospital. We hypothesized that injuries of the distal interphalangeal

Abbreviations: DDF, deep digital flexor; DIJ, distal interphalangeal joint.

EQUATOR network disclosure: The STROBE-VET checklist was used.

Publication disclosure: None of the study findings were previously presented at a scientific meeting and/or published in abstract form.

joint (DIJ) and/or the podotrochlear apparatus would occur with a high frequency in Warmblood horses. Also, we hypothesized that certain abnormalities of the structures of the podotrochlear apparatus would be associated with an increased likelihood of horses with foot lameness remaining lame after conservative therapy.

2 | MATERIALS AND METHODS

2.1 | Medical records review and case selection criteria

The study was a retrospective cross-sectional study design. Included horses were Warmblood horses used for dressage, jumping, and eventing. The medical records of the B.W. Furlong & Associates Equine Hospital and Advanced Equine Imaging of Wellington were reviewed for Warmblood horses that had been scanned using standing MRI of the distal limb(s) between January 2007 and September 2015. Owners of the horses approved the use of the data for the study. The medical records were reviewed by an American College of Veterinary Surgery-certified equine surgeon (S.D.G.) to ensure that all horses included in the study met each of the following criteria: Warmblood breed, clinical diagnosis of foot pain, and underwent standing MRI. Data retrieved from the medical record entries or calls to owners and/or referring veterinarians included: history, signalment, horse athletic use at the time of MRI, duration and grade (0-5) of lameness,[16] response to diagnostic analgesia, treatments received, and follow-up lameness evaluations. Lameness grades were assigned as follows: 0 = no lameness detected; 1 = lameness difficult to detect and inconsistent while horse trotting in a circle; 2 = lameness difficult to detect while trotting in a straight line but consistent while trotting in a circle; 3 = lameness detected while trotting in a straight line and circles; 4 = lameness detected at a walk; and 5 = minimal weight bearing at rest or a walk.

2.2 | Diagnostic imaging

Lateromedial, dorsal proximal-palmarodistal oblique (at 45° and 60°), dorsal 45° lateral-palmaromedial oblique, dorsal 45° medial-palmarolateral oblique, and palmaroproximal-palmarodistal oblique radiographs were acquired for all lame feet before MRI scanning either by B.W. Furlong & Associates Equine Hospital/Advanced Equine Imaging of Wellington or referring veterinarian. Standing MRI was performed when clinical and radiological abnormalities did not provide a definitive diagnosis for the source of foot pain, or when the severity of the radiological abnormalities were not consistent with the severity of the clinical signs. Standing MRI scans for all horses were acquired using the same 0.27 T MRI system (Hallmarq Veterinary Imaging Ltd, Bridge Park, Merrow Lane, Guildford, Surrey, UK). All MRI images were retrieved and reinterpreted by an American College of Veterinary Radiology-certified veterinary radiologist (N.M.W.) using a commercial DICOM viewer (Asteris Inc, Monument, CO, USA). The same radiologist graded the lesions detected as mild, moderate, or severe at the time of the MRI using a standardized set of scoring criteria (Supporting Information 1).[17] The radiologist was unaware of the horses' outcome at the time of the scoring. For each horse, the radiologist recorded the most clinically relevant imaging finding based on whether the lesion was the most severe (or sometimes the only) lesion detected on MRI and whether there was a lack of other foot lesions.

2.3 | Follow-up information

Follow-up information was obtained for 341 horses from the medical records, veterinary recheck evaluations, follow-up MRI evaluations, and telephone interviews with the owners, trainers, or referring veterinarians. This information was recorded by an experienced lameness clinician (S.J.G.) who was aware of radiologist findings at the time of data recording. Data recorded comprised the following: (1) lameness status after treatment and whether the horse returned to previous athletic use at the same or better level and (2) lameness status at the time of follow-up. Long-term outcome established at ≥12 months was considered successful for horses that resumed athletic activity at the same or better level, or unsuccessful for horses that underwent palmar digital neurectomy or failed to return to previous level of exercise due to recurrent or persistent lameness.

2.4 | Data analysis

Statistical tests were selected and performed by a biostatistician (D.J.S.). Data were entered into a spreadsheet (Excel, Microsoft Office Excel, Microsoft Corp., CA), and descriptive information was derived from it. Continuous variables (age, lameness duration, and so on) were evaluated for a normal distribution using normal probability plots and verification that skew ≅ 0 and kurtosis ≅ 3, median ≅ mean, and Anderson-Darling normality tests were not significant ($P > .05$). Horses were assigned to athletic use groups (showjumper, dressage, eventer) or outcome groups (successful, unsuccessful). Kruskal-Wallis nonparametric one-way ANOVA (SYSTAT 13.1; Systat Software Inc., CA) was used to investigate foot injury differences among these groups. Nonrandom associations between different foot injuries in a 2×2 contingency table were identified using Fisher's exact test. When all counts in the table were >0, the exact odds ratio[18] was calculated using StatXact 9 (Cytel Software Corp, MA), otherwise SAS (ver 9.4; SAS Institute Inc., Cary, NC) was used. Lesion profiles for "use" or "outcome" groups were compared using nonparametric discriminant analysis (SAS; SAS Institute Inc., NC). The prevalence of foot injuries among horses with and without follow-up was evaluated for similarity using plots of the percentages of foot injuries for each group. $P < .05$ was considered statistically significant for all the analyses.

3 | RESULTS

3.1 | Signalment and history

A total of 550 horses (425 male and 125 female) met all of the inclusion criteria for the study and their median age was 10 years

(3-20 years). Horses assigned to "use" groups were as follows: showjumping (416 horses, 75.7%), dressage (60 horses, 10.9%), eventing (25 horses, 4.5%), and other disciplines (4 horses, 0.7%). No use information was recorded for 45 (8.2%) horses and these horses were excluded from "use" group comparisons. The median lameness duration at the time of MRI examination was 5 weeks (1-208 weeks).

3.2 | Clinical signs and response to diagnostic analgesia

One hundred thirty-three horses (24.1%) had bilateral forelimb lameness, 379 (68.9%) had unilateral forelimb lameness, 15 (2.7%) had unilateral hind limb lameness, and 23 (4.3%) had no information recorded. The median lameness severity was grade 2 (range, grade 1 to 4) while horses were trotted in a straight line and in circles on a smooth hard surface. The lameness resolved or markedly improved, on the lamest limb with analgesia of the palmar/plantar digital nerves in 367 horses (66.7%), or palmar/plantar nerves in 126 horses (22.9%), or DIJ in 57 horses (10.4%).

3.3 | MRI findings in lame limbs

Standing MRI evaluation was performed in all horses using the protocol described in Table 1; abnormalities identified in the lame or lamest limb are summarized in Table 2. Navicular bone MRI lesions were identified in 409 horses (74.3%) and it was the only lesion identified in 41 horses (7.4%) (Table 3). There were 361 horses (65.6%) that had increased signal intensity on STIR FSE images (without signal alteration on the T2 FSE images) within the trabecular bone of the navicular bone, and it was considered the most relevant imaging finding in only 89 horses (16.1%). One hundred sixty-nine horses (30.7%) had enlarged synovial invaginations in the distal aspect of the navicular bone with increased signal intensity on STIR FSE images in the adjacent trabecular bone. Fifty-one horses (9.3%) had navicular bone flexor surface erosions characterized by a concavity and abnormal signal pattern indicating bone loss on the flexor surface, whereas other 45 horses (8.2%) had distal margin fragmentation of the navicular bone.

Three hundred sixty-two horses (65.8%) had fluid distension and/or osteophytes in the DIJ. Of these, 303 horses (55.1%) had concurrent alterations in the podotrochlear apparatus and nine horses (1.6%) had collateral desmopathy of the DIJ. Of the remaining horses with fluid distension and/or osteophytes in the DIJ, 43 horses (7.8%) had diffuse increased signal intensity on STIR FSE images (without signal alterations on the T2 FSE images) within the trabecular bone of either the dorsodistal aspect of the middle phalanx (26 horses, 4.7%) or the extensor process extending distally into the distal phalanx (17 horses, 3.1%). Interestingly, trabecular bone injuries at the extensor process extending distally into the distal phalanx were only identified in horses used for showjumping. Seven horses (1.3%) had fluid distension in the DIJ and an osseous cyst-like lesion in the middle or distal phalanx seen as defects in the articular surface, subchondral bone, and underlying trabecular bone.

Other distal phalanx MRI lesions were detected in 40 horses (7.2%) and in 30 of these horses the distal phalanx lesion was considered the most relevant imaging finding. Fourteen horses (2.5%) had a fractured palmar/plantar process seen as compact and trabecular bone defects and/or discontinuity bordered by increased signal intensity on STIR FSE images. Twenty-six horses (4.7%) had focal or diffuse trabecular bone lesions seen as either increased signal intensity on STIR FSE images or decreased signal intensity on T2 FSE images.

One hundred seventy horses (31%) had DIJ collateral desmopathy (133 horses, 24%) and/or collateral enthesopathy (88 horses, 16%), and it was considered to be the most relevant imaging finding in 82 horses (15%). Collateral desmopathies of the DIJ were seen as focal and/or diffuse increased signal intensity on proton density (PD) images with or without a concurrent signal increase on STIR FSE and T2 FSE images, with the extent and variation in the degree of signal increase indicating the severity of the desmopathy. One or both collateral ligaments were affected with or without ligament enlargement and poorly defined margins. Collateral enthesopathies were identified as altered contour of the fossae of the middle and/or distal phalanges and/or an abnormal signal pattern affecting the fossae and/or underlying trabecular bone characterized by increased signal intensity on STIR images and/or decreased signal intensity on T2 FSE images.

Two hundred sixty horses (47.3%) had a DDF tendinopathy that was considered to be the most relevant imaging finding in 96 horses (17.4%) and it was the only lesion identified in 15 horses (2.7%; Table 3). The DDF flexor tendinopathies were seen as increased signal intensity on T1 GE (gradient echo) sequences with or without concurrent increased signal intensity on PD, T2 FSE, and STIR sequences (Supporting Information 1), indicating severity, within the tendon lobes at the level of the navicular bone (67 horses, 12.8%), at the insertion onto the distal phalanx (23 horses, 4.2%), at the level of the middle phalanx to the navicular bone or to insertion on the distal phalanx (95 horses, 17.3%), and at the level of the middle phalanx and collateral sesamoidean ligament (75 horses, 13.6%). Of these 260 horses, 176 had dorsal border DDF tendinopathies, 51 had core lesion DDF tendinopathies, and 33 had sagittal/parasagittal splits DDF tendinopathies. Core lesion DDF tendinopathies extending from the middle phalanx to the insertion on the distal phalanx were more common (22/51, 43%), whereas sagittal/parasagittal splits DDF tendinopathies at the level of the insertion on the distal phalanx were less common (2/33, 6%).

Two hundred fifty-two horses (45.8%) had lesions involving the navicular bursa and 179 of these horses (71%) had concurrent DDF tendinopathies (Table 3). Ninety horses (16.3%) had fluid distension of the proximal recess of the navicular bursa, and 163 (29.4%) had synovial proliferation/probable adhesion formation within the proximal recess of the bursa seen as areas of intermediate signal intensity tissue within synovial fluid of high signal intensity on STIR FSE and T2 FSE sequences. Also, 19 horses (3.4%) had lesions interpreted to be probable adhesions within the navicular bursa seen as linear or spherical regions of low to intermediate signal intensity on all MRI sequences between the DDF tendon and erosion on navicular bone flexor surface.

TABLE 1 Pulse sequence parameters used for evaluation of the lame or lamest limb of 550 Warmblood horses

Sequence	Repetition time (ms)	Echo time (ms)	Flip angle (degrees)	Field of view (cm)	Matrix size	Slice thickness (mm)	Gap (mm)
T1 GE	50	8	55	170 x 170	256 x 256	5	NA
T2*GE	65	12	26	170 x 170	256 x 256	5	NA
Proton density	1,200	24	90	170 x 170	256 x 256	5	NA
STIR FSE	2,300	22	90	192 x 192	256 x 256	5	0.5
T2 FSE	1,800	84	90	170 x 170	256 x 256	5	0.5

Abbreviations: FSE, fast spin echo; GE, gradient echo; NA, not available; STIR, short tau inversion recovery.
T1 GE and STIR FSE were obtained in all imaging planes, T2 FSE sequences were obtained in dorsal and transverse planes, and T2*GE sequences were obtained in a sagittal plane. In some horses, proton density sequences were obtained in sagittal and transverse planes.

Seven horses (1.2%) had collateral sesamoidean enthesopathy at the navicular bone attachment and 86 horses (15.6%) had collateral sesamoidean desmopathy seen as alteration of the normal signal pattern, size, and loss of distinct dorsal and palmar/plantar ligament margins; collateral sesamoidean desmopathy was the most relevant imaging finding in only four horses. One hundred thirty-four horses (24.3%) had lesions involving the distal sesamoidean impar ligament; 104 of these horses (77.6%) had also concurrent navicular bone lesions (Table 3). One hundred seventeen horses (21.3%) had distal sesamoidean impar ligament lesions characterized by alterations in the size, shape, and margins with loss of the increased signal intensity on STIR and T2 FSE images indicating the presence of DIJ synovial invaginations, interpreted to be a normal anatomic feature of this ligament. Longitudinal fiber disruption characterized by increased signal intensity on STIR FSE and T2 FSE sequences was identified in the distal sesamoidean impar ligament in 31 of 117 horses (26.5%). The other 86 horses (73.5%) with distal sesamoidean impar enthesopathies had altered contour of the distal phalanx margin at the ligament distal attachment indicating resorption, osseous proliferation, vascular channel enlargement, and/or osseous cyst-like lesion with an abnormal signal pattern in the adjacent trabecular bone characterized by increased signal intensity on STIR images and/or decreased ST on T2 FSE images. Distal sesamoidean impar enthesopathies had a higher prevalence in horses used for eventing (29%) than in horses used for dressage (13%; $P \leq .05$).

Eighty-eight horses (16%) had lesions interpreted to represent ossification of the collateral cartilages of the foot. Of these, 44 horses (50%) also had increased signal intensity on STIR FSE sequence and/or decreased signal intensity on T2 FSE sequences extending into the palmar/plantar process of the distal phalanx; 13 horses had a fracture line at the base of the ossified cartilage extending into the distal phalanx that was considered to be the most relevant imaging finding in five horses. Lastly, 30 horses (5.4%) had fluid distension and/or osteophytes and subchondral bone abnormalities in the proximal interphalangeal joint. Only two of 550 horses (0.4%) had no osseous or soft tissue lesions identified.

3.4 | Treatments

For the 249 horses (45.3%) that had treatment information available, the most frequently recorded treatment consisted of athletic rest, intrasynovial anti-inflammatory medication, and corrective shoeing. These treatments were always elected following MRI. Stall rest duration was determined by the clinician on the case based on clinical signs and the type and severity of the abnormalities diagnosed. Horses with mild to moderate MRI abnormalities had 4-8 weeks of stall rest combined with 5-10 minutes of hand-walking twice daily, followed by 4-12 weeks of stall rest combined with 15-20 min of hand-walking twice daily. Horses with severe MRI abnormalities had 12-52 weeks of rest. If horses were sound at follow-up, they were started to trot and resumed full work gradually.

In addition to correction of hoof imbalance and corrective shoeing, 97 horses (39%) had the DIJ medicated, 73 horses (29.3%) had the navicular bursa medicated, 10 horses (4%) had the proximal interphalangeal joint medicated, and five horses (2%) had the digital flexor tendon sheath medicated. Intrasynovial anti-inflammatory consisted of a combination of hyaluronan (Hyvisc, Anika Therapeutics Inc., MA) and triamcinolone (Vetalog, Fort Dodge Animal Health Division, IA) or methylprednisolone (Depomedrol, Pfizer Animal Health, NY), autologous conditions serum (IRAP, Arthrex Vet Systems, FL) or autologous protein solution (Pro-Stride APS, Owl Manor Veterinary, IN) per manufacturer's instructions. Seventy-six horses with navicular bone injuries received tiludronate disodium (Tildren, Ceva Sante Animale, Libourne, France) or clodronate disodium (Osphos, Dechra Veterinary Products, KS). Sixty-eight horses diagnosed with injuries of the DDF tendon and/or collateral ligaments of the DIJ received intralesional injection of platelet rich-plasma (Arteriocyte Magellan PRP, Isto Biologics, MA), autologous protein solution (Pro-Stride APS, Owl Manor Veterinary, IN), or autogenous mesenchymal stem cells cultured at Cornell University (New York, USA). Twenty-nine horses that failed to respond to conservative therapy underwent unilateral or bilateral palmar digital neurectomy.

3.5 | Recheck MRI findings in lame limbs

The median time for a recheck MRI examination of 120 horses (21.8%) was 24 weeks (range, 3-281 weeks). Eighteen of 80 horses (22.5%) with increased signal intensity on STIR FSE images without concurrent signal alterations on T2 FSE images within the trabecular bone of the navicular bone, 15 of 76 horses (19.8%) with DIJ fluid distention, and 20 of 73 horses (27.4%) with DIJ collateral desmopathy were considered improved or resolved at the time of follow-up MRI. How-

TABLE 2 Magnetic resonance imaging abnormalities identified in the lame or lamest limb of 550 Warmblood horses and distribution of long-term outcomes by specific diagnosis by MRI

	Horses included in the study			Horses with follow-up and successful outcome			Horses with follow-up and unsuccessful outcome		
Abnormality identified	Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
Altered SI in the trabecular bone of the navicular bone	179	155	27	53	33	2	46	61	21
Enlarged synovial invaginations in the navicular bone	86	78	5	25	12	2	31	37	2
Fragments in the distal border of the navicular bone	12	21	12	4	4	3	7	8	3
Navicular bone flexor surface erosion	20	17	14	1	1	0	10	15	12
DIJ effusion and synovitis	134	206	9	43	53	3	40	75	5
DIJ osteoarthritis	38	55	9	12	14	0	13	22	4
PIJ osteoarthritis	10	15	5	2	3	0	2	7	1
DDF tendinopathy (core)	12	24	15	2	5	1	3	12	9
DDF tendinopathy (sagittal/parasagittal)	11	21	1	1	2	0	4	14	1
DDF tendinopathy (dorsal border)	113	56	7	32	12	1	40	25	3
Navicular bursa effusion and synovitis	56	28	6	20	8	0	11	10	5
Navicular bursa synovial proliferation and synovial membrane thickening	37	117	8	7	17	0	16	62	7
Collateral desmopathy of the DIJ	35	82	16	5	27	2	11	28	10
DIJ collateral enthesopathy	52	29	7	15	7	0	15	8	6
Distal sesamoidean impar desmopathy	18	11	2	1	1	0	10	5	0
Distal sesamoidean impar enthesopathy	70	33	0	20	10	0	28	12	1
Collateral sesamoidean desmopathy	35	50	1	9	6	0	12	28	0
Collateral sesamoidean enthesopathy at the navicular bone attachment	3	4	0	0	0	0	3	3	0
Ossification of the collateral cartilage(s) of the foot	31	44	13	15	14	3	7	12	3
Altered SI in the dorsodistal aspect of the middle phalanx	10	14	2	3	4	0	3	7	1
Altered SI (with or without fractures) at the extensor process, or dorsodistal or palmar/plantar process(es) of the distal phalanx	10	33	14	4	12	6	2	9	3

Abbreviations: DDF, digital flexor tendon; DIJ, Distal interphalangeal joint; PIJ, proximal interphalangeal joint; SI, signal intensity.

ever, five of eight horses with navicular bone flexor surface erosions and four of seven horses with DDF sagittal/parasagittal tendinopathies were considered worse at the time of follow-up MRI. Fourteen of 120 horses (11.7%) had developed additional abnormalities, such as navicular bone flexor surface erosion (1 horse), DDF tendinopathies (9 horses), and collateral sesamoidean desmopathy (4 horses). In the remaining horses, the abnormalities were largely unchanged at the time of follow-up MRI.

3.6 | Outcomes

Follow-up information was obtained from 341 (62%) horses at a median time of 43 months (12-102 months) of which 120 had also recheck MRI examination. Overall, 183 (53.7%) horses had an unsuccessful outcome and 152 (44.6%) had a successful outcome; six (1.7%) horses were not treated or died within 12 months of the MRI diagnosis and they were excluded from the statistical analysis. Of 170

TABLE 3 MRI abnormalities identified in the lame or lamest limb of 550 Warmblood horses

MRI abnormality/ies identified	Horses included in the study
Only DDF tendon injury	15
Concurrent injuries of the DDF tendon and navicular bone	207
Concurrent injuries of the DDF tendon and navicular bursa	179
Concurrent injuries of the DDF tendon, navicular bone and navicular bursa	143
Concurrent injuries of the DDF tendon, navicular bone, navicular bursa and distal sesamoidean impar ligament	47
Only navicular bone injury	41
Concurrent navicular bone injury and distal sesamoidean impar desmopathy/enthesopathy	104
Concurrent navicular bone injury and collateral sesamoidean desmopathy/enthesopathy at the navicular bone attachment	74
Concurrent injuries of the navicular bone and DIJ	258
Only distal sesamoidean impar desmopathy/enthesopathy	2
Only collateral sesamoidean desmopathy/enthesopathy at the navicular bone attachment	4
Concurrent injuries of the DIJ, DDF tendon, navicular bone, and navicular bursa	86

Abbreviations: DDF, digital flexor tendon; DIJ, Distal interphalangeal joint.

horses with a recent history (≤12 weeks) of lameness, 102 (60%) became sound after treatment whereas only 31 of 110 (28.1%) horses with a history of chronic (>12 weeks) lameness became sound after treatment. Thus, horses with recent lameness were more likely to become sound than were chronically lame horses (odds ratio: 4; 95% confidence interval, 1.6-10.2; $P = .007$).

The foot injuries that were significantly associated with a decreased likelihood of horses having a successful outcome are summarized in Table 4. Horses with moderate or severe altered signal intensity on STIR FSE images within the trabecular bone of the navicular bone (Figure 1), mild or severe erosions of the flexor surface of the navicular bone (Figure 2), moderate sagittal/parasagittal DDF tendinopathies (Figure 3), or moderate collateral sesamoidean desmopathies were less likely to return to their previous level of performance due to recurrent or persistent lameness than horses without these abnormalities. Also, horses with concurrent injuries of the DDF tendon, navicular bone, navicular bursa, and distal sesamoidean impar ligament were less likely to return to their previous level of performance than horses without these abnormalities.

4 | DISCUSSION

Our first hypothesis was supported in which a high frequency of Warmblood horses with foot lameness had MRI lesions involving the DIJ and/or the podotrochlear apparatus. Our second hypothesis was also supported in which moderate to severe MRI lesions within the trabecular bone of the navicular bone, mild or severe erosions of the flexor surface of the navicular bone, moderate sagittal/parasagittal DDF tendinopathies, and moderate collateral sesamoidean desmopathies were significantly associated with chronic lameness following treatment. The prevalence of MRI lesions involving the DIJ and/or the podotrochlear apparatus was similar to those previously reported in Warmblood horses used for showjumping and dressage.[2,19] However, the clinical significance of some of the lesions reported in our study could not be established as we did not study control limbs of sound horses to compare with this population of Warmblood horses. It has been suggested that repeated strain in the DIJ and podotrochlear apparatus associated with showjumping or dressage might predispose to these injuries.[20] Effusion of the DIJ was common in the horses included, however the clinical significance of this finding is always difficult to determine because DIJ effusion can be identified asymptomatic horses,[21,22] or may be associated with superficial articular cartilage defects which cannot be reliably identified in horses using standing MRI due to its low resolution.[23,24]

In contrast to a previous report,[2] the median lameness duration prior to MRI was only 5 weeks in our study. This may have been influenced by the current trend among clinicians to recommend advanced diagnostic imaging sooner after lameness development, and the need of an expediated definitive diagnosis and proper management plan during the showing season. Interestingly, horses with >12 weeks history of lameness were four times more likely to remain lame after treatment than horses with ≤12 weeks history of lameness. This would suggest that foot injuries are likely to worsen over time without appropriate treatment. The results support our clinical impression and that of others,[25] that horses with chronic foot injuries treated without an accurate diagnosis of the source of foot pain or proper management plan have guarded prognosis for soundness, likely due to the presence of advanced pathological changes at the time of MRI.

It has been reported that core or sagittal/parasagittal DDF tendinopathies within the hoof carry a guarded prognosis for long-term soundness.[14] However, the prognosis seems to be affected by the severity of the DDF tendinopathy because in this study horses with mild DDF tendinopathies had similar outcomes. Contrary to that, moderate sagittal/parasagittal DDF tendinopathies were associated with recurrent or persistent lameness. Also, nine of 10 horses with severe core DDF tendinopathies had recurrent or persistent lameness; we suggest that moderate to severe sagittal/parasagittal or severe core

TABLE 4 Standing MRI lesions and associations with unsuccessful outcome at least 1 year after MRI evaluation in 335 Warmblood horses with foot pain.[a]

Variable and category	Number of horses	OR	95% CI		*P*-value
			lower	upper	
Horses with moderate altered SI in the trabecular bone of the NB and successful outcome	33/152 (22%)	Referent	1.07	3.06	.02
Horses with moderate altered SI in the trabecular bone of the NB and unsuccessful outcome	61/183 (33%)	1.80			
Horses with severe altered SI in the trabecular bone of the NB and successful outcome	2/152 (1%)	Referent	2.24	42.17	>.001
Horses with severe altered SI in the trabecular bone of the NB and unsuccessful outcome	21/183(11%)	9.72			
Horses with mild NB flexor surface erosion and successful outcome	1/152 (1%)	Referent	1.21	38.20	.02
Horses with mild NB flexor surface erosion and unsuccessful outcome	10/183 (5%)	8.72			
Horses with severe NB flexor surface erosion and successful outcome	0/152 (0%)	Referent	4.44	51.11	>.001
Horses with severe NB flexor surface erosion and unsuccessful outcome	12/183 (7%)	31.17			
Horses with moderate DDF tendinopathy (sagittal/parasagittal) and successful outcome	2/152 (1%)	Referent	1.39	56.97	.010
Horses with moderate DDF tendinopathy (sagittal/parasagittal) and unsuccessful outcome	14/183 (8%)	6.21			
Horses with moderate CSD and successful outcome	6/152 (4%)	Referent	1.71	13.31	
Horses with moderate CSD and unsuccessful outcome	28/183 (15%)	4.39			>.001
Horses with concurrent injuries of the DDF tendon, NB, navicular bursa and distal sesamoidean impar ligament and successful outcome	5/152 (3%)	Referent	1.5	15.56	>.001
Horses with concurrent injuries of the DDF tendon, NB, navicular bursa, and distal sesamoidean impar ligament and unsuccessful outcome	26/183 (14%)	5.2			

The exact odds ratios (OR) represents the odds that a horse in that category would be lame 1 year after MRI evaluation compared with a horse in the referent category.

Abbreviations: CI, confident intervals; CSD, collateral sesamoid desmopathy; DDF, deep digital flexor; NB, navicular bone; SI, signal intensity.

[a]Six horses were not treated or died within 12 months of the MRI diagnosis thus were excluded from the analysis.

DDF tendinopathies represent advanced intratendinous pathologic abnormalities in Warmblood horses. Moderate or severe core or sagittal/parasagittal DDF tendinopathies had intermediate to high signal intensity on T2 and fat-suppressed sequences, which has been found to be correlated with severe degeneration, edema, and necrosis of the collagen bundles.[26-28] In agreement to a previous study,[14] moderate or severe core or sagittal/parasagittal DDF tendinopathies tended to persist over time on follow-up MRI evaluations (intermediate to high signal intensity on T2 and fat-suppressed sequences) thereby contributing to the reduced likelihood of return to previous levels of athletic activity due to recurrent or persistent lameness.

Alterations in the navicular bone were identified in 409 horses (74.3%), and increased signal intensity on STIR FSE sequence within the trabecular bone was the most common finding. This abnormality may reflect edema, hemorrhage, necrosis, fibrosis, degeneration, or bone modeling due to physiologic stress.[29-31] Therefore, degenerative injury of the navicular bone is indistinguishable from contusion or physiologic stress remodeling of the navicular bone when there is no compact or trabecular bone damage, such as an erosion on the palmar aspect of the bone. Consequently, the most reliable method for differentiating these causes is clinical reassessment of the lameness and recheck MRI to asses if the trabecular bone injury persists or

FIGURE 1 Sagittal STIR FSE image (slice thickness: 5 mm) obtained from a horse with a severe injury of the navicular bone. There is generalized increased signal intensity within the medullary cavity of the navicular bone (arrowhead)

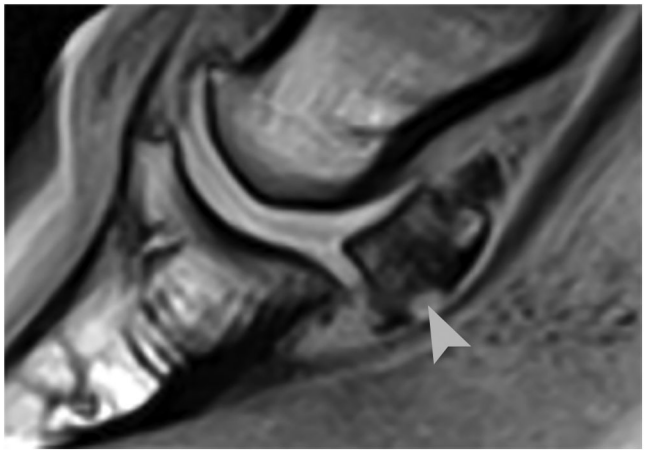

FIGURE 2 Sagittal T1 GE weighted image (slice thickness: 5 mm) obtained from horse with a severe erosion of the flexor surface of the navicular bone. There is a large defect of increased signal intensity (arrowhead) on the sagittal ridge of the navicular bone. Adjacent to the erosion there is decreased density in the compact and trabecular bone of the navicular bone on all sequences (only T1 GE weighted image shown), which is consistent with sclerosis. There is also diffuse intermediate signal intensity within the deep digital flexor tendon extending from the navicular bone to the tendon attachment to the distal phalanx

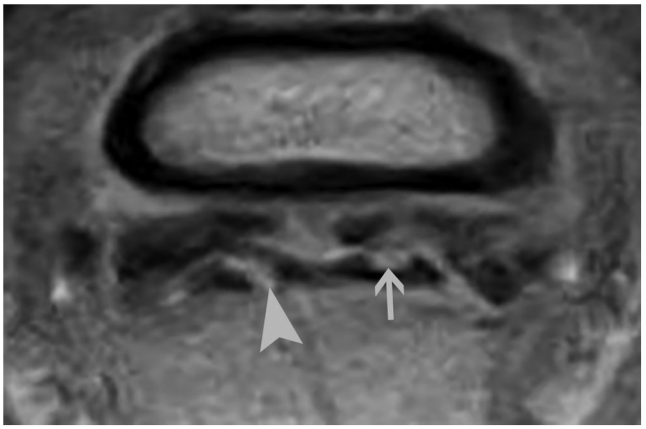

FIGURE 3 Transverse T1 GE weighted image (slice thickness: 5 mm) obtained from a horse with moderate parasagittal deep digital flexor tendinopathy. Medial is to the left. The medial lobe of the deep digital flexor tendon is enlarged with a focal area of high signal intensity extending through the whole lobe of the tendon (arrowhead). The lateral lobe of the deep digital flexor tendon is also enlarged and has a large defect along its dorsal margin (arrow)

if additional abnormalities develop.[32] Recognition of altered signal intensity in the trabecular bone consistent with degenerative injury of the navicular bone is clinically important as horses with moderate to severe of altered signal intensity in the navicular bone trabecular bone were two to 10 times more likely to remain lame after treatment than horses with other injuries.

Of 39 horses diagnosed with a navicular bone flexor surface erosion, 37 (95%) remained lame following conservative therapy. Others have reported that horses with large navicular bone flexor surface erosions respond poorly to conservative therapy.[6,13,30] Histologically, erosions represent degeneration of the navicular bone flexor surface's fibrocartilage with adjacent osteonecrosis and fibroplasia of the subchondral compact bone and medulla.[28-30] The poor clinical response to conservative therapy of the horses in our study supports previous reports that navicular bone erosions reflect advanced degenerative injury of the navicular bone, which explains why affected horses are unlikely to heal or improve with conservative therapy.[30] In fact, our follow-up MRI evaluations showed that these abnormalities did not improve after treatment as previously reported[30]; therefore, these navicular bone erosions in Warmblood horses used for dressage, jumping, and eventing are an important predictor of poor prognosis for athletic use.

Only distal sesamoidean impar enthesopathies and trabecular bone injuries at the extensor process extending distodorsally into the distal phalanx were overrepresented in certain athletic uses. Trabecular bone injuries at the extensor process extending distodorsally into the distal phalanx were only identified in showjumpers; however, we are aware that these injuries may occur in Warmblood horses used for dressage. These imaging abnormalities in horses with osseous injuries at the extensor process extending distodorsally into the distal phalanx may reflect bone hemorrhage, necrosis, fibrosis, degeneration, or bone modeling as in on other osseous structures of the foot.[8,28] We speculate that these osseous injuries are traumatic in horses used for jumping due to repeated jumping activity. It is plausible that repeated stress on the distal phalanx due to jumping, particularly on hard footing, may be a predisposing factor. In addition, palmar foot pain could alter weight bearing and more pronounced dorsal loading, and an additional cause of dorsal distal phalanx fluid. Pathologic changes and altered magnetic resonance appearance associated with trauma typically resolve with rest and can be evaluated with follow-up MRI to assess this injury over time. Only two of 17 horses with these injuries underwent follow-up MRI thus we cannot infer the pathologic changes associated with these MRI abnormalities. Histologic studies in horses with increased signal intensity on STIR FSE sequences at the extensor

process extending distodorsally into the distal phalanx are necessary to clarify this.

Follow-up lameness and MRI evaluations revealed that most horses with collateral sesamoidean desmopathy did not improve after treatment. In our clinical experience, moderate to severe collateral sesamoidean desmopathies are rare but they can be problematic to treat successfully in Warmblood horses used for jumping or dressage. Collateral sesamoidean desmopathy may be due to chronic supraphysiologic loading of the digit before limb break-over, leading to repetitive tearing of fibers and associated inflammation and fibrosis.[7,25] Arthroscopic collateral sesamoidean desmotomy has been proposed as a potential treatment option for horses with chronic foot pain due to fibrosis of the collateral sesamoidean ligament.[33] However, we are not aware if this procedure is beneficial in horses with primary pathologic abnormality of the collateral sesamoidean ligament.

Trabecular bone injuries in the dorsodistal aspect of the middle phalanx were relatively infrequent in this study. Moreover, trabecular bone injuries in the dorsodistal aspect of the middle phalanx do not always cause lameness,[34-36] which may be related to the severity or timing of the injury. It has been proposed that most of these injuries are bone contusions or bruises,[8] but trauma resulting in contusion can also cause injury to the adjacent articular surfaces.[35] The prognosis for trabecular bone injuries of the middle phalanx is generally good[8,36] as long as there is not associated osteoarthritis of the DIJ or proximal interphalangeal joint[36] or persistent bone injury. We currently recommend for horses with trabecular bone injuries in the dorsodistal aspect of the middle phalanx athletic rest for 2-3 months in mild cases, 3-5 months for moderate cases, and 4-6 months for severe cases following treatment, at which time recheck MRI may be performed.[36]

One of the limitations of the current study was that articular cartilage abnormalities were likely underdiagnosed in some horses. Distal interphalangeal joint articular cartilage loss is a distinct short coming of standing low-field MRI because high-field studies demonstrate articular cartilage loss in the DIJ without any trabecular bone abnormalities to indicate a problem. This is different to other joints that have marked trabecular bone abnormalities when articular cartilage loss is present. An additional limitation of the study was the lack of distinction between the transient and permanent abnormalities within the trabecular bone of the navicular bone due to the overlap MRI signal pattern of these osseous abnormalities. Cases that did not have a recheck MRI examination could not be further distinguished as transient or permanent bone injury. Other limitations included the fact that review and grading of the MRI scans were performed by a single individual, there was inconsistency in the lameness workups performed by the primary clinician, there was a lack of review of the pre-MRI radiographs for some horses, and there was a lack of follow-up information for 209 of the 550 horses. Lastly, we did not investigate the potential relationship between the type of treatment instituted following MRI and outcome.

In conclusion, the most prevalent standing MRI foot lesions detected in Warmblood horses used for jumping, dressage, or eventing involved the DIJ and/or the podotrochlear apparatus. Current study findings suggested that the chronicity and severity of injury and the intended use of the horse play a major role in the response to conservative therapy. The authors propose that poor outcomes associated with certain foot injuries in this sample of Warmblood horses used for jumping or dressage activities could be due to the different athletic demands as compared to those previously reported for western performance horses. Future research should be aimed to the development of effective treatment options for foot injuries in Warmblood horses that respond poorly to conservative or traditional therapies.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Gold, Werpy, Gutierrez-Nibeyro, Olguin, Schaeffer

(b) Acquisition of Data: Gold, Olguin, Gutierrez-Nibeyro.

(c) Analysis and Interpretation of Data: Gold, Werpy, Gutierrez-Nibeyro, Olguin, Schaeffer

Category 2

(a) Drafting the Article: Gold, Werpy, Gutierrez-Nibeyro, Olguin, Schaeffer

(b) Revising Article for Intellectual Content: Gold, Werpy, Gutierrez-Nibeyro, Olguin, Schaeffer

Category 3

(a) Final Approval of the Completed Article: Gold, Werpy, Gutierrez-Nibeyro, Olguin, Schaeffer

ACKNOWLEDGEMENTS

The authors acknowledge the referring veterinarians for their assistance in providing data for this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest. None of the authors have any financial affiliation with the manufacturer of the MRI scanner used in this study.

ORCID

Santiago D. Gutierrez-Nibeyro
https://orcid.org/0000-0002-1982-3520

REFERENCES

1. Egenvall A, Bonnett B, Wattle O, et al. Veterinary-care events and costs over a 5-year follow-up period for warm blooded riding horses with or without previously recorded locomotor problems in Sweden. *Prev Vet Med*. 2008;83:130-143.
2. Mitchell RD, Edwards III RB, Makkreel LD, et al. Standing MRI lesions identified in jumping and dressage horses with lameness isolated to the

foot. In: Proceedings 52th Annual Meeting of American Association of Equine Practitioners, San Antonio, TX 2006:422-426.
3. Dyson SJ, Murray R, Schramme MC, et al. Magnetic resonance imaging of the equine foot: 15 horses. *Equine Vet J*. 2003;35:18-26.
4. Dyson SJ, Murray R. Magnetic resonance imaging evaluation of 264 horses with foot pain: The podotrochlear apparatus, deep digital flexor tendon and collateral ligaments of the distal interphalangeal joint. *Equine Vet J*. 2007;39:340-343.
5. Gutierrez-Nibeyro SD, Werpy NM, White II NA. Standing low-field magnetic resonance imaging in horses with chronic foot pain. *Aust Vet J*. 2012;90:75-83.
6. Bell CD, Howard RD, Taylor DS, et al. Outcomes of podotrochlear (navicular) bursa injections for signs of foot pain in horses evaluated via magnetic resonance imaging: 23 cases (2005-2007). *J Am Vet Med Assoc*. 2009;234:920-925.
7. Sampson SN, Schneider RK, Gavin PR, et al. Magnetic resonance imaging findings in horses with recent onset of navicular syndrome but without radiographic abnormalities. *Vet Radiol Ultrasound*. 2009;50:339-346.
8. Dyson SJ, Murray R, Schramme MC. Lameness associated with foot pain: Results of magnetic resonance imaging in 199 horses (January 2001-December 2003) and response to treatment. *Equine Vet J*. 2005;37:113-121.
9. Parkes R, Newton R, Dyson S. Is there an association between clinical features, response to diagnostic analgesia and radiological findings in horses with a magnetic resonance imaging diagnosis of navicular disease or other injuries of the podotrochlear apparatus?. *Vet J*. 2015;204:40-46.
10. Marsh CA, Schneider RK, Sampson SN, et al. Response to injection of the navicular bursa with corticosteroid and hyaluronan following high-field magnetic resonance imaging in horses with signs of navicular syndrome: 101 cases (2000-2008). *J Am Vet Med Assoc*. 2012;241:1353-1364.
11. Gutierrez-Nibeyro SD, Werpy NM, White II NA, et al. Outcome of palmar/plantar digital neurectomy in horses with foot pain evaluated with magnetic resonance imaging: 50 cases (2005-2011). *Equine Vet J*. 2015;47:160-164.
12. Dakin SG, Dyson SJ, Murray RC, et al. Osseous abnormalities associated with collateral desmopathy of the distal interphalangeal joint. Part 2: treatment and outcome. *Equine Vet J*. 2009;41:794-799.
13. Gutierrez-Nibeyro SD, White II NA, Werpy NM. Outcome of medical treatment for horses with foot pain: 56 cases. *Equine Vet J*. 2010;42:680-685.
14. Cillan-Garcia E, Milner PI, Talbot A, et al. Deep digital flexor tendon injury within the hoof capsule; does lesion type or location predict prognosis?. *Vet Rec*. 2013;173:70-75.
15. Lutter JD, Schneider RK, Sampson SN, et al. Medical treatment of horses with deep digital flexor tendon injuries diagnosed with high-field-strength magnetic resonance imaging: 118 cases (2000-2010). *J Am Vet Med Assoc*. 2015;247:1309-1318.
16. Kester W. Definition and classification of lameness. *Guide for Veterinary Services and Judging Veterinary Events*. 4th ed. Lexington, KY: American Association of Equine Practitioners; 1991.
17. Vanel M, Olive J, Gold SJ, et al. Clinical significance and prognosis of deep digital flexor tendinopathy assessed over time using MRI. *Vet Radiol Ultrasound*. 2012;53:621-627.
18. Parzen M, Lipsitz S, Ibrahim J, et al. An estimate of the odds ratio that always exists. *J Comput Graph Stat*. 2002;11:420-436.
19. Kristiansen KK, Kold SE. Multivariable analysis of factors influencing outcome of 2 treatment protocols in 128 cases of horses responding positively to intra-articular analgesia of the distal interphalangeal joint. *Equine Vet J*. 2007;39:150-156.
20. Kaneps AJ. Diseases of the foot. In: Hinchcliff KW, Kaneps AJ, Geor RJ, eds. *Equine Sports Medicine and Surgery*. 2nd ed. St. Louis, MO: Saunders; 2014:253-274.
21. Sherlock CE, Kinns J, Mair TS. Evaluation of foot pain in the standing horse by magnetic resonance imaging. *Vet Rec*. 2007;161:739-744.
22. Dyson S, Murray R. Magnetic resonance imaging of the equine foot. *Clin Tech Equine Pract*. 2007;6:46-61.
23. Olive J. Distal interphalangeal articular cartilage assessment using low-field magnetic resonance imaging. *Vet Radiol Ultrasound*. 2010;51:259-266.
24. Smith MA, Dyson SJ, Murray RC. Reliability of high- and low-field magnetic resonance imaging systems for detection of cartilage and bone lesions in the equine cadaver fetlock. *Equine Vet J*. 2012;44:684-691.
25. Sampson SN, Schneider RK, Gavin PR. Magnetic resonance imaging findings in horses with recent and chronic bilateral forelimb lameness diagnosed as navicular syndrome. In: Proceedings *of the* 54th Annual Meeting of the American Association of Equine Practitioners. 2008:419-434.
26. Busoni V, Heimann M, Trenteseaux J, et al. Magnetic resonance imaging findings in the equine deep digital flexor tendon and distal sesamoid bone in advanced navicular disease-an ex vivo study. *Vet Radiol Ultrasound*. 2005;46:279-286.
27. Blunden A, Murray R, Dyson S. Lesions of the deep digital flexor tendon in the digit: A correlative MRI and post-mortem study in control and lame horses. *Equine Vet J*. 2009;41:25-33.
28. Murray RC, Blunden TS, Schramme MC, et al. How does magnetic resonance imaging represent histologic findings in the equine digit? *Vet Radiol Ultrasound*. 2006;47:17-31.
29. Dyson S, Blunden T, Murray R. Comparison between magnetic resonance imaging and histological findings in the navicular bone of horses with foot pain. *Equine Vet J*. 2012;44:692-698.
30. Sherlock C, Mair T, Blunden T. Deep erosions of the palmar aspect of the navicular bone diagnosed by standing magnetic resonance imaging. *Equine Vet J*. 2008;40:684-692.
31. Murray RC, Schramme MC, Dyson SJ, et al. Magnetic resonance imaging characteristics of the foot in horses with palmar foot pain and control horses. *Vet Radiol Ultrasound*. 2006;47:1-16.
32. Werpy NM. Recheck magnetic resonance imaging examinations for evaluation of musculoskeletal injury. *Vet Clin North Am Equine Pract*. 2012;28:659-680.
33. Sampson SN, Schneider RK, Gavin PR, et al. Evaluation of an arthroscopic approach for transection of the equine collateral sesamoidean ligament. *Vet Surg*. 2010;39:1011-1020.
34. Gutierrez-Nibeyro SD, White II NA, Werpy NM, et al. Magnetic resonance imaging findings of desmopathy of the collateral ligaments of the equine distal interphalangeal joint. *Vet Radiol Ultrasound*. 2009;50:21-31.
35. Olive J, Mair TS, Charles B. Use of standing low-field magnetic resonance imaging to diagnose middle phalanx bone marrow lesions in horses. *Equine Vet Educ*. 2009;21:116-123.
36. Werpy NM. Diagnosis of middle phalanx bone marrow lesions in horses using magnetic resonance imaging and identification of phase effect cancellation for proper image interpretation. *Equine Vet Educ*. 2009;21:125-130.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Gutierrez-Nibeyro SD, Werpy NM, Gold SJ, Olguin S, Schaeffer DJ. Standing MRI lesions of the distal interphalangeal joint and podotrochlear apparatus occur with a high frequency in warmblood horses. *Vet Radiol Ultrasound*. 2020;1-10. https://doi.org/10.1111/vru.12855