CLINICAL SIGNIFICANCE AND PROGNOSIS OF DEEP DIGITAL FLEXOR TENDINOPATHY ASSESSED OVER TIME USING MRI

Maïa Vanel, Julien Olive, Sarah Gold, Richard D. Mitchell, Lea Walker

Deep digital flexor (DDF) tendinopathy is one of the most frequent causes of foot lameness and the prognosis is guarded. The progress of lesion healing may be followed by magnetic resonance (MR) imaging to formulate a prognosis and to adapt the rehabilitation program. We assessed the correlation of outcome with total tendon damage and temporal resolution of MR abnormalities. Images from 34 horses with DDF tendinopathy that had undergone at least two low-field standing MR examinations of the foot (mean 2.5 ± 1.3 times) were reviewed. No horse having a T1-GRE hyperintense lesion over 30 mm in length or over 10% tendon cross-sectional area returned to its previous activity level. Horses with concomitant lesions had worse outcome than horses with DDF tendinopathy only ($P = 0.005$). In all horses including those with excellent outcome, the lesion persisted, even mildly, in T1-GRE and PD images. Horses with tendon lesion resolution on STIR-FSE and T2-FSE images on recheck examination had a better outcome ($P = 0.0004$ and $P = 0.002$, respectively), and all horses that returned to their previous level of performance had complete resolution of signal hyperintensity on the STIR-FSE sequence. Although rehabilitation remains multifactorial, characteristics of DDF tendinopathy and concomitant lesions on first and recheck MR examinations allow refining the prognosis.

Key words: deep digital flexor tendon, lameness, magnetic resonance, prognosis.

Introduction

Magnetic resonance (MR) imaging of the equine foot is used to identify or confirm soft tissue and bone injuries.[1–5] However, the clinical significance and prognosis of these alterations are understood incompletely and occasionally, sound horses or the contralateral limb may have signal modifications that are of uncertain significance.[4,6–8]

Deep digital flexor (DDF) tendinopathy is a common digital injury, with incidence over the range 30–64% in MR examinations.[7,9–11] The prognosis of DDF tendinopathy is often guarded to poor[7,11,12] and presence of concomitant lesions worsens the prognosis.[7,10,12] Recheck MR examinations allow assessment of tendon healing, with possible modification of rehabilitation but, again, the significance of the changes is not understood completely.[13–16]

Most clinical studies have classified equine DDF tendinopathy according to location relative to the distal sesamoid bone and configuration inside a tendon lobe, classically dorsal, core or parasagittal splits.[2,6,9,11,16] However, horses may have a combination of tendon lesion configurations, and the configuration may change with time, complicating accurate classification. Lesion signal intensity, maximum cross-sectional area, length or volume may be a more comprehensive way to assess tendinopathy, as in people.[17–19] Some equine studies have concentrated on these characteristics on MR images over time in natural or artificially created lesions,[13–16,20] but only a few have focused on the relationship between DDF tendinopathy evolution and lameness grade or long-term outcome.[14,16] Recently, resolution of tendon or ligament hyperintensities on STIR sequences was associated with improved lameness at recheck examination but was not associated with long-term outcome.[14]

Our objective was to determine whether the severity of MR-identified DDF tendinopathy and its evolution have an impact on prognosis. We hypothesized that the DDF lesion size would be related to outcome and that resolution of lesions on T2-weighted and STIR sequences would be associated with better outcome.

Materials and Methods

Images from 34 horses with a lesion of the DDF tendon that had undergone at least two MR examinations of the foot at one of three US-based clinics between 2007 and 2010

From the Diagnostic Imaging Department, Faculty of Veterinary Medicine, University of Montreal, Saint-Hyacinthe, QC, Canada (Vanel, Olive), B.W. Furlong and Associates, Oldwick, NJ, USA (Gold), Fairfield Equine Associates, Newtown, CT, USA (Mitchell), California Equine Orthopedics, San Marcos, CA, USA (Walker).

Dr. Maïa Vanel's current address is Diagnostic Imaging Department, National Veterinary School of Alfort, 7 Avenue du Général de Gaulle, 94700 Maisons-Alfort, France.

Address correspondence and reprint requests to Dr. Julien Olive, at the above address. E-mail: julien_olive_veto@hotmail.com

Received September 5, 2011; accepted for publication May 21, 2012.
doi: 10.1111/j.1740-8261.2012.01961.x

Vet Radiol Ultrasound, Vol. 00, No. 00, 2012, pp 1–7.

were reviewed. There were 25 Warmbloods, four Quarter Horses, two Irish Thoroughbreds, one Thoroughbred, one Paint, and one Pony. The median age was 11 years (range 6–17 years). Sixteen horses were used for jumping, six for hunting, four for dressage, three for eventing, one for western performance and four for pleasure. Eleven horses were competing at a high level in their discipline, 18 at an intermediate level and five at a low level or were not competing.

On first examination, the lameness was localized to the right forelimb in 17 horses, to the left forelimb in 13 horses and was bilateral in four horses. In horses with bilateral lesions, data from the lamer limb was considered for analysis. Lameness duration ranged from two weeks to over a year, and lameness grade[21] ranged from 1/5 to 4/5.

Follow-up information was obtained by phone or email interviews with the owner, the trainer or referring veterinarian. They were asked about rest period, shoeing, medical or surgical treatment, whether the horse returned to full work, if the lameness recurred and the reason for having performed a second MR examination. The same questions were asked for the period after the second examination and whether the horse had returned to the previous level of activity. Outcome was defined as excellent if the horse resumed activity at the same or better level, moderate if it performed at an inferior level, and poor if lameness remained unimproved or recurred. Final outcome was assessed between 8 months and 4 years after initial MR diagnosis. Nine horses (26%) had an excellent outcome, seventeen (50%) performed at an inferior level, and eight (24%) had a poor outcome.

The first MR examination was performed because other imaging modalities failed to explain the origin or degree of lameness. The second and further MR examinations were performed either as part of the recheck plan ($n = 22$) or because of persistent lameness ($n = 12$). Timing between both examinations was recorded. MR images were acquired using a standing 0.27T MR unit,* using a dedicated coil. Imaging protocols differed among the three clinics and included a combination of 2D or 3D T1-weighted gradient recalled echo (T1-GRE) ($n = 25$), proton density spin echo ($n = 23$), 2D or 3D T2*-weighted GRE (T2*-GRE) ($n = 13$), T2-weighted fast spin echo (T2-FSE) ($n = 33$) and short tau inversion recovery FSE (STIR-FSE) ($n = 26$) sequences. The number of MR examinations per horse ranged from 2 to 9 (median = 2). However, only the first and the last MR examinations were analyzed in the present study.

Location and length of tendon lesions were assessed on available sequences. Location was defined according to the tendon lobe (medial or lateral) and three areas designated as suprasesamoidean, sesamoidean, infrasesamoidean, or a combination of these. The length of each lesion (mm) in each area was calculated by multiplying the number of slices where the lesion could be observed by the sum of the slice thickness and slice gap on spin echo or 2D GRE sequences. When separate overlapping lesions were present on a tendon, total diseased tendon length was considered rather than individual lesions.

The maximum cross-sectional area (%) of tendon lesions was estimated subjectively for each tendon lobe. In a preliminary study, measurement of the maximum cross-sectional area (%) of tendon lesions in T1-GRE images was performed using DICOM software† in a subset of 24 horses. A linear regression model and a Bland–Altman analysis were performed to assess the agreement between both subjective and objective methods. The determination coefficient was excellent ($R^2 = 0.98$). There was a mean underestimation of −1.4% (95% confidence interval −2.68% to −0.15%) using the subjective method, which was not judged clinically significant. Furthermore, all subjectively determined values were comprised with the agreement limits of the Bland–Altman test (−7.4 to +4.6%), validating the subjective method. To suit future clinical use, each observer was subsequently asked to give a visual estimation of the maximum cross-sectional area, by 10% increments, without measurement. Initial assessment was made per lobe to account for those horses with lesions at different levels in both tendon lobes. The highest value of each lobe was retained; and both lobe values were then added to obtain a total tendon lesion maximum cross-sectional area rated out of 100%. Any other lesions were also recorded.

Images were reviewed by two observers unaware of the lameness status of the horse at the time of reading. Image review was initially independent and a consensus was then reached in instances of disagreement. For quantitative differences ≤5 mm for lesion length or ≤10% for maximum cross-sectional area, mean of values from the two observers was calculated. For differences over these thresholds, measurements were repeated in consensus.

A nonparametric Spearman test was used to compare the lameness grade of each horse at first examination with the length and maximum cross-sectional area of DDF tendinopathy, in T1-GRE, T2-FSE, and STIR FSE sequences. A Cochran–Mantel–Haenszel test was used to evaluate the association between the lameness grade at first and last MR examination with the outcome grades. A nonparametric Spearman test was used to evaluate the association between the total length of the lesion and maximum cross-sectional area on the first MR examination, in respectively T1-GRE, T2-FSE, and STIR-FSE sequences, with the outcome scores. Cochran–Mantel–Haenszel tests were used to evaluate the association between the outcome scores with (a) location of the lesion, (b) presence of any concomitant lesion, and (c) presence of suspected adhesions within the navicular bursa. An exact Chi-squared test was used to

*EQ2, Hallmarq Veterinary Imaging, Guildford, UK.

†OsiriX Imaging Software, Geneva, Switzerland.

compare the outcome scores between horses that were only rested and horses that were rested and received medical treatment. A Cochran–Mantel–Haenszel test was used to evaluate outcome scores relative to persistence or resolution of the DDF lesion in STIR-FSE or in T2-FSE sequences. Cut-off values in terms of lesion size relative to outcome were defined when possible. To account for the low number of horses in each group, a paired Wilcoxon test was used to compare lesion length and maximum cross-sectional area between lameness grade groups, for T1-GRE, T2-FSE, and STIR-FSE sequences. Finally, using a paired Wilcoxon test, lesion length and maximum cross-sectional area from the first and the last MR examinations were compared for the same sequences. Statistical significance was set at $P < 0.05$ for all tests.[‡]

Results

The mean and standard deviation (SD) of tendon lesion length and maximum cross-sectional area at the first MR examination according to the lameness grade are presented in Table 1; and at both the first and the last examinations according to the outcome group in Table 2.

There was a statistically significant positive association, but with only moderate strength, between length and maximum cross-sectional area on first MR examination and lameness grade the same day, on T1-GRE ($r = 0.65$, $P = 0.001$ and $r = 0.41$, $P = 0.04$, respectively), on T2-FSE ($r = 0.52$, $P = 0.002$ and $r = 0.53$, $P = 0.002$, respectively) and on STIR FSE ($r = 0.44$, $P = 0.03$ and $r = 0.55$, $P = 0.005$, respectively).

Outcome was affected negatively by higher lameness grading at the time of the first examination ($P = 0.02$), and of the last MR recheck ($P = 0.0007$). Also no horse with lameness grade higher than 1/5 at recheck examination returned to its previous level of performance, regardless of time between both examinations (range 2–36 months).

A statistically significant negative association, but with only moderate strength, was present between lesion size in T1 GRE, T2-FSE, or STIR-FSE sequences and outcome ($r = -0.54$, $P = 0.009$; $r = -0.51$, $P = 0.003$; $r = -0.53$, $P = 0.007$, respectively for lesion length; and $r = -0.64$, $P = 0.002$; $r = -0.66$, $P = 0.0002$; $r = -0.59$, $P = 0.002$, respectively for maximal cross-sectional area).

No horse with a lesion over 30 mm in length or 10% in maximum cross-sectional area in T1-GRE returned to previous activity. Conversely, all horses with a poor outcome had a lesion length over 35 mm and tendon maximum cross-sectional area over 20%.

Horses with DDF tendinopathy involving multiple areas had a significantly worse outcome than horses with a lesion that involved only one area ($P = 0.007$). The outcome was worse when the suprasesamoidean ($P = 0.02$) or the infrasesamoidean ($P = 0.004$) area was involved.

Twenty-eight horses (79%) had navicular bursitis and 18 horses (51%) had navicular bone marrow lesions. Excluding navicular bursitis that was present in a large majority of horses, 22 horses (63%) had a concomitant lesion, such as navicular bone marrow lesions or distal interphalangeal collateral, sesamoidian collateral, and impar ligament injuries, and the outcome in these horses was significantly worse than in horses with DDF tendinopathy only ($P = 0.0005$). Suspected adhesions within the navicular bursa were all between the DDF tendon and either the collateral sesamoidean ligaments or the distal impar ligament, none with the navicular bone. Only six horses (17%) had suspected adhesions and these were not significantly related to the outcome ($P = 0.41$), though no horse with a suspected adhesion returned to its previous level of performance.

Treatment varied, but all horses were rested initially for variable time (2–6 months). No horse underwent a surgical procedure; nine horses were rested only; 10 horses were rested and benefited from bursal or intralesional injections of single or combination of either hyaluronic acid, corticosteroid, platelet-rich plasma, or stem cells; four horses were rested and received intraveinous tiludronate[§] perfusion and 11 horses were rested and received both a local injection and tiludronate perfusion. Horses that received any medical treatment in addition to rest did not have a significantly better outcome than horses that were only rested ($P = 0.06$). Outcome was not statistically different between treatment groups ($P = 0.30$).

The outcome was significantly better for horses whose DDF tendinopathy had resolved on STIR-FSE ($P = 0.0004$) or T2-FSE ($P = 0.002$) sequences on recheck examination (Figs. 1 and 2). All horses that returned to their previous level of performance had complete resolution of signal hyperintensity on the STIR-FSE sequence. Only one horse with a resolved lesion on the STIR sequence had a moderate outcome. Among horses with a DDF tendon lesion that resolved on the T2-FSE sequence, three horses did not return to their previous level of performance and conversely, three horses that returned to their previous level of performance had a reduced but persistent lesion on the T2-FSE sequence.

In all horses, including those with excellent outcome, the lesion persisted even mildly, in T1-GRE and PD sequences. DDF lesions resolved on the T2*-GRE sequence in only two horses.

Follow-up information for horses with an excellent outcome ranged from 8 to 24 months.

[‡]SAS, version 9.1, SAS Institute Inc., Cary, NC.

[§]Tildren®, CEVA, France.

TABLE 1. Mean ± SD Tendon Lesion Length and Maximum Cross-Sectional Area at First MR Examination According to Lameness Grade. No Horse Had Grade 5/5 Lameness at Any Time Point

Lameness grade		1/5 ($n = 11$)	2/5 ($n = 13$)	3/5 ($n = 7$)	4/5 ($n = 3$)
T1 GRE	Length (mm)	27.0 ± 13.6^{a}	60.1 ± 29.2^{b}	63.0 ± 16.0^{b}	63.3 ± 40.4^{b}
	Maximum cross-sectional area (%)	20.2 ± 12.1^{a}	23.6 ± 15.7^{a}	24.0 ± 8.8^{a}	40.0 ± 28.4^{a}
T2 FSE	Length (mm)	11.8 ± 12.1^{a}	27.5 ± 17.1^{b}	29.3 ± 12.7^{b}	40.0 ± 31.2^{b}
	Maximum cross-sectional area (%)	10.0 ± 11.8^{a}	20.0 ± 8.5^{b}	24.3 ± 13.0^{b}	41.7 ± 29.3^{b}
STIR FSE	Length (mm)	11.7 ± 7.5^{a}	24.2 ± 16.0^{ab}	26.7 ± 17.5^{b}	30.0
	Maximum cross-sectional area (%)	5.8 ± 3.8^{a}	16.9 ± 9.0^{b}	25.0 ± 16.1^{b}	15.0

Values in the same row having a different superscript letter differ significantly from each other. Number of horses in each lameness grade is indicated in brackets; however, not all horses had all sequences performed. Since only one horse with a 4/5 lameness grade had a STIR-FSE examination, the values could not be compared to the others.

TABLE 2. Mean ± SD Tendon Lesion Length and Maximum Cross-Sectional Area at the First and the Last MR Examinations According to the Outcome Group

Outcome group		Excellent		Moderate		Poor	
Examination time		First	Last	First	Last	First	Last
T1-GRE	Length	22.2 ± 9.2	21.2 ± 6.5	46.7 ± 24.3	52.0 ± 22.7	62.5 ± 34.3	75 ± 23.5
	Maximum cross-sectional area	8 ± 2.73	8.0 ± 4.5	23.4 ± 12.6	30 ± 21.2	37.5 ± 23.7	46.3 ± 21.9
T2-FSE	Length	13.4 ± 10.0	11.4 ± 11.2	29.7 ± 18.5	27.7 ± 15.6	37.9 ± 22.3	38.5 ± 23.1
	Maximum cross-sectional area	8.0 ± 5.7	5.0 ± 3.5	22.5 ± 16.0	22.7 ± 13.2	33.2 ± 18.9	39.4 ± 14.3
STIR-FSE	Length	12.6 ± 9.4	0.0 ± 0.0	26.3 ± 18.0	23.1 ± 16.4	33.0 ± 13.3	33.0 ± 12.9
	Maximum cross-sectional area	6.3 ± 4.8	0.0 ± 0.0	16.1 ±11.5	15.4 ± 9.9	24.2 ± 13.2	30.8 ± 9.9

None of the values at the first MR examination differed significantly from values at the last MR examination, probably due to too small numbers in each category.

Discussion

In our study, only 26% of horses had an excellent outcome. This is similar to previously reported results in a larger study (28%);[7] which supports a guarded prognosis for return to previous activity in horses with digital DDF tendinopathy. However, only 24% of horses had a poor outcome, which is less than previously reported (53%).[7] This might be explained by the difference in patient numbers and some horses being lost to follow up in our study. Indeed, six horses had only an 8-month follow-up, which can still correspond to the rehabilitation period. These horses, in light work at that time, were placed in the moderate outcome group, but could have ended up in either the excellent or poor outcome groups.

Usual DDF tendon lesion classification was impractical and therefore not detailed in this study as each tendon commonly had a combination of different lesion configurations that sometimes evolved over time.[22] This might represent a limitation in our study as dorsal lesions reportedly evolve differently from other lesion types.[16] However, lesion configuration has not been related to long-term prognosis.

To assess tendinopathy thoroughly, we recorded DDF tendon lesion length and maximum cross-sectional area. Volume data are likely more accurate and have been used by others[13,16] but our objective was to use a readily available and simple clinical method to assess tendinopathy. Lesion length and maximum cross-sectional area were significantly but only moderately correlated to the outcome. This may be likely explained by the influence of other lesions present in most feet in the study herein. More importantly, some cut off values of tendon lesion size were determined (30 mm in length or 10% in maximum cross-sectional area in T1-GRE), beyond which a long-term excellent outcome seems less likely.

Lesion length and maximum cross-sectional area on T1-GRE, T2-FSE, and STIR-FSE correlated only moderately with lameness grade on first examination, again likely due to the multiple causes of lameness in these horses. For lesion length, this correlation was in fact mainly explained by a significant difference between horses with 1/5 lameness grade and horses with 2/5 to 4/5 lameness grades (Table 1). This remains in agreement with others who proposed that the degree of lameness does usually reflect injury severity.[7] Lameness grade on first and last MR examinations was associated with outcome. This is in contradiction to others who reported that the degree of lameness was not a significant indicator of outcome.[10] However, horses in the previous study were affected by a wide range of etiologies for foot pain, and follow-up duration differed from our study. The degree of lameness might be better correlated to outcome when foot pain is due to distal DDF tendinopathy.

Suprasesamoidean and infrasesamoidean locations were associated with a worse outcome. However, these results should be interpreted carefully since overall few severe lesions were identified in the sesamoidean area in this group of horses. It is likely that horses with a severe DDF tendon lesion, often associated with suspected adhesion to the

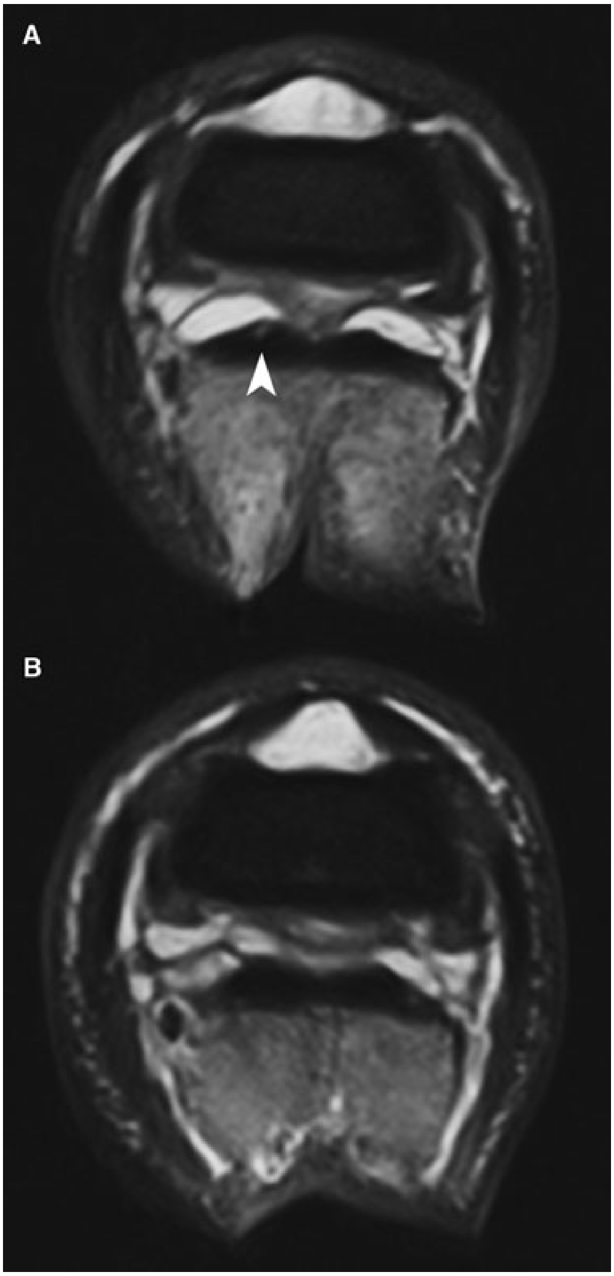

FIG. 1. Corresponding transverse STIR-FSE images (slice thickness/gap 5.0/0.6 mm, TI/TE/TR 85/27/2840 ms, FoV 180 mm, matrix 168 × 165, NEX 2) at the level of proximal recesses of the navicular bursa, at initial diagnosis (A) and 5 months later (B). Note resolution of signal hyperintensity in the lateral lobe (left of each image, arrowhead) of the DDF tendon, initially occupying 10% of total tendon maximum cross-sectional area and 17 mm in length. Notice the marked navicular bursa distension by fluid in A, and more synovial proliferations and/or fibrillation in the navicular recesses at recheck. This horse had an excellent outcome.

navicular bone,[4] are considered catastrophic injuries and rarely evaluated subsequently. Therefore none of these horses were included in our study due to the inclusion criteria.

FIG. 2. Corresponding parasagittal (A, dorsal to the left), transverse (B, medial to the left) 3D T1-GRE (slice thickness/gap 3.0/0.0 mm, TE/TR 7/23 ms, flip 40°, FoV 180 mm, matrix 170 × 170, NEX 1), and dorsal STIR-FSE (C, medial to the left) (slice thickness/gap 5.0/0.6 mm, TI/TE/TR 85/27/2840 ms, FoV 180 mm, matrix 168 × 165, NEX 2) images. There is extensive DDF tendinopathy of the medial lobe. Image B is at the tendon lesion maximum cross-sectional area (25%) in the suprasesamoidean area, but the lesion continued in the sesamoidean and infrasesamoidean areas for a total of 100 mm as depicted in A (black arrowheads delimit the lesion). There was no hyperintensity in STIR images in the suprasesamoidean area, but in the infrasesamoidean area a hyperintense lesion was visible on STIR images at initial diagnosis (white arrowhead in C) and was unchanged on recheck 6 months later (not shown). This horse had a moderate outcome.

In a large study, 95% of horses with combined navicular bone and DDF tendon injuries had a poor outcome.[7] In our study, horses with concomitant lesions had a worse outcome. This is in agreement with other studies stating that prognosis is worsened when other lesions are associated with a DDF tendinopathy.[7,12]

No significant correlation was evident between suspected adhesions within the navicular bursa and outcome. This might be explained by the low number of horses presenting suspected adhesions. This may also indicate that MR imaging without bursography is inaccurate to distinguish true adhesions from synovial proliferations or tendon dorsal fibrillation.[23] However, as no horse with this suspicion returned to the previous level of performance, this may either indicate a type-2 statistical error or that adhesions, severe fibrillation or severe bursitis have a similarly poor prognosis.

Horses that were rested only did not have a significantly worse outcome than horses receiving additional treatments. Resting period and injected drugs were highly variable among horses, due to the retrospective nature of this study.

In spite of the wide range of duration between subsequent MR examinations, no horse had lesion resolution on the T1-GRE sequence. This supports the hypothesis that a lesion present on T1-GRE only is probably more representative of a chronic injury, namely fibroplasia.[7,11,14] However, it remains unknown whether naturally developing tendon lesions begin with T2 hyperintensities, as proven experimentally,[13,15] or whether they may initially be visible only in T1-weighted sequences. There was indeed a non-significant trend for lesion size in the T1-GRE sequence to remain stable in the excellent outcome group and to increase with time in the poor and moderate outcome groups (Table 2). The leading hypothesis is degenerative rather than traumatic DDF tendinopathy,[6] with minimal inflammation. If this is true, then the risk might be to misinterpret a developing lesion as a chronic lesion. Time to recheck and time to return to work were not evaluated as they were too dependent on the clinician and/or the trainer decision about the horse.

Our results emphasize the importance of follow up imaging to obtain prognostic information especially based on lesion signal evolution, and provides guidelines for sequence selection. Based on our results and those of others,[7,14] and despite contradiction coming from an experimental study,[15] it seems that the STIR-FSE sequence offers the most reliable indication of outcome. In previous studies, resolution of DDF tendon lesion on STIR-FSE was associated with improved lameness,[7,14] but not with a return to previous level of performance.[14] The difference may be explained mainly by the strict focus of the present study on the DDF tendon while others have assessed other soft tissues as well or even bone lesions.

Based on experiments in a limited number of horses, T2-FSE hyperintensity in artificial tendon lesions is supposed to resolve before hyperintensity on STIR.[13] However, based on naturally occurring lesions, T2-FSE hyperintensity resolution seems more variable and yet is unexplained as histologic assessment was not available from this clinical study. STIR sequences with shorter TE and fat signal inversion may be more sensitive than T2-weighted spin-echo sequences to depict some matrix changes or to better distinguish core necrosis from fibrocartilaginous metaplasia.[6] T2*-GRE sequences were performed in a limited number of horses and as expected, the signal pattern was very different from that obtained with T2-FSE weighting. Furthermore, T2* hyperintensities in DDF tendons did not have signal alterations over the course of a few months, with the exception of dorsal lesions, contrary to what we and others commonly observed on FSE-based sequences[16]. Therefore, and based on fundamental MR physics, T2*-weighting gives information close to T1-GRE weighting and may have more limited value in a clinical protocol for DDF tendon assessment. Further investigations are required to better understand its significance.

Images for this study were obtained using a standing low-field system, which may have led to some measurement imprecision due to inherently limited spatial resolution. It is possible that lesion size might have been underestimated due to volume averaging that is inversely related to spatial resolution. Therefore, our results may not be directly applicable using higher resolution images obtained at higher field strength.

It must be acknowledged that lameness originating in the foot is probably multifactorial in many horses, leading others to state that comparing prognostic data to lesion characteristics may be erroneous.[14] However, our good correlation results mainly focusing on DDF lesions may at least indicate that these lesions contribute significantly to the lameness.

Valuable prognostic information can be obtained clinically from low-field MR imaging in horses with DDF tendinopathy. The assessment of total tendon damage seems a valid alternative, or may be complementary to more descriptive ways of tendon lesion evaluation. T1-GRE and STIR-FSE sequences provided the most meaningful information to evaluate prognosis and should be included in standard protocols. Follow-up MR examinations are recommended to provide prognosis based on evolution of lesion signal.

ACKNOWLEDGMENTS

The authors thank all clinics for their active collaboration, Guy Beauchamp for statistical analysis, and Nick Bolas from Hallmarq Vet Imaging, Guildford, UK, for support and partial funding of this study.

REFERENCES

1. Dyson S, Murray R. Use of concurrent scintigraphic and magnetic resonance imaging evaluation to improve understanding of the pathogenesis of injury of the podotrochlear apparatus. Equine Vet J 2007;39:365–369.

2. Dyson S, 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.

3. Sampson SN, Schneider RK, Gavin PR, Ho CP, Tucker RL, Charles EM. Magnetic resonance imaging findings in horses with recent onset navicular syndrome but without radiographic abnormalities. Vet Radiol Ultrasound 2009;50:339–346.

4. 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.

5. Gutierrez-Nibeyro SD, White NA 2nd, 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.

6. 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.

7. 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.

8. 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.

9. Dyson S, Murray R, Schramme M, Branch M. Lameness in 46 horses associated with deep digital flexor tendonitis in the digit: diagnosis confirmed with magnetic resonance imaging. Equine Vet J 2003;35:681–690.

10. Bell CD, Howard RD, Taylor DS, Voss ED, Werpy NM. 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.

11. Schramme MC. Deep digital flexor tendonopathy in the foot. Equine Vet Educ 2011;23:403–415.

12. 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.

13. Schramme M, Kerekes Z, Hunter S, Labens R. MR imaging features of surgically induced core lesions in the equine superficial digital flexor tendon. Vet Radiol Ultrasound 2010;51:280–287.

14. Holowinski M, Judy C, Saveraid T, Maranda L. Resolution of lesions on STIR images is associated with improved lameness status in horses. Vet Radiol Ultrasound 2010;51:479–484.

15. Karlin WM, Stewart AA, Durgam SS, Naughton JF, O'Dell-Anderson KJ, Stewart MC. Evaluation of experimentally induced injury to the superficial digital flexor tendon in horses by use of low-field magnetic resonance imaging and ultrasonography. Am J Vet Res 2011;72:791–798.

16. Milner PI, Sidwell S, Talbot AM, Clegg PD. Short-term temporal alterations in magnetic resonance signal occur in primary lesions identified in the deep digital flexor tendon of the equine digit. Equine Vet J 2012;44:157–162.

17. Cross TM, Gibbs N, Houang MT, Cameron M. Acute quadriceps muscle strains: magnetic resonance imaging features and prognosis. Am J Sports Med 2004;32:710–719.

18. Gärdin A, Bruno J, Movin T, Kristoffersen-Wiberg M, Shalabi A. Magnetic resonance signal, rather than tendon volume, correlates to pain and functional impairment in chronic Achilles tendinopathy. Acta Radiol 2006;47:718–724.

19. Fujikawa A, Kyoto Y, Kawaguchi M, Naoi Y, Ukegawa Y. Achilles tendon after percutaneous surgical repair: serial MRI observation of uncomplicated healing. AJR 2007;189:1169–1174.

20. Crass JR, Genovese RL, Render JA, Bellon EM. Magnetic resonance, ultrasound and histopathologic correlation of acute and healing equine tendon injuries. Vet Radiol Ultrasound 1992;33:206–216.

21. American Association of Equine Practitioners. Definition and classification of lameness. Guide for veterinary service and judging of equestrian events. Lexington, KY: AAEP, 1991.

22. Mair TS, Kinns J. Deep digital flexor tendonitis in the equine foot diagnosed by low-field magnetic resonance imaging in the standing patient: 18 cases. Vet Radiol Ultrasound 2005;46:458–466.

23. Maher MC, Werpy NM, Goodrich LR, McIlwraith CW. Positive contrast magnetic resonance bursography for assessment of the navicular bursa and surrounding soft tissues. Vet Radiol Ultrasound 2011;52:385–393.