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Paper

Ultrasonographic scoring system for superficial digital flexor tendon injuries in horses: Intra- and inter-rater variability

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Superficial digital flexor tendon (SDFT) tendinopathy is an important musculoskeletal problem in horses. The study objective was to validate an ultrasonographic scoring system for SDFT injuries. Ultrasonographic images from fourteen Thoroughbred racehorses with SDFT lesions (seven core; seven diffuse) and two controls were blindly assessed by five clinicians on two occasions. Ultrasonographic parameters evaluated were: type and extent of the injury, location, echogenicity, cross-sectional area and longitudinal fibre pattern of the maximal injury zone (MIZ). Inter-rater variability and intra-rater reliability were assessed using Kendall's coefficient of concordance (KC) and Lin´s concordance correlation coefficient (LC), respectively. Type of injury (core vs. diffuse) had perfect inter/intra-rater agreement. Cases with core lesions had very strong inter-rater agreement (KC ≥0.74, p<0.001) and intra-rater reliability (LC ≥0.73) for all parameters apart from echogenicity. Cases with diffuse lesions, had strong inter-rater agreement (KC ≥0.62) for all parameters, but weak agreement for echogenicity (KC =0.22); intra-rater reliability was excellent for MIZ location and fibre pattern (LC ≥0.82), and moderate (LC ≥0.58) for cross sectional area and number of zones affected. This scoring system was reliable and repeatable for all parameters, except for echogenicity. A validated scoring system will facilitate reliable recording of SDFT injuries, and inter-study meta-analyses.

Introduction

Superficial digital flexor tendinopathy is a common injury in equine athletes; it frequently occurs in racehorses during normal activity, following undefined periods of accumulation of exercise and age-related microdamage without any preceding clinical symptoms. Its prevalence in Thoroughbred racehorses varies significantly between different disciplines ranging from 24% (Avella and others 2009) to 43% (Pickersgill 2000) in National Hunt horses and from 3.4% (Rossdale and others 1985) to 11.1% (Kasashima and others 2004) in Flat-racing Thoroughbred horses. However, there are limited data concerning other disciplines (Palmer and others 1994; van den Belt and others 1994; Dyson 1998). Although complete tendon healing is a long and often frustrating process (Goodship and others 1994; Smith and Schramme 2003) that usually takes between 6-18 months, re-injury rates can be as high as 56% (Marr and others 1993; Dyson 2004). Therefore, tendinopathy remains a significant cause of wastage in Thoroughbred racehorses and a major health and welfare concern, as it is a debilitating and potentially career-ending injury (Dowling and others 2000, Williams and others 2001, Oikawa and Kasashima 2002, Perkins and others 2005).

There are many imaging modalities used to evaluate this condition, including radiography (Verschooten and De Moor 1978), scintigraphy (Martinelli and Chambers 1995), thermography (Denoix and Audigie 2004), ultrasonography (Smith 2008), ultrasound tissue characterisation (UTC) (Van Schie and others 2001) and magnetic resonance imaging (MRI) (Karlin and others 2011). All of these imaging modalities are useful, as each of them assists differently in the diagnosis and differentiation of superficial digital flexor tendinopathy. Objective, accurate and repeatable imaging of the SDFT is difficult, with MRI, UTC and ultrasonography possibly being the most reliable methods. Ultrasonography, as opposed to MRI and UTC, is practical, cost effective and a readily accessible imaging technique that allows real time evaluation of the soft tissues. As a result, it is considered the diagnostic method of choice for assessing equine tendon injuries (Smith 2008) in order to reach a diagnosis or to determine readiness for return to exercise/competition (Palmer and others 1994). In addition, with further assessments, ultrasonography can also be helpful when monitoring recovery and response to treatment. Nevertheless, ultrasonography has a limited field of view and image acquisition depends on the operator, the angle of incidence, the equipment and the physical and physiological status of the tissue (Pickersgill, 2000). Ultrasonographic images have been traditionally assessed using both subjective and objective scales to evaluate the severity of injuries (Genovese and others 1986). Objective measurements are repeatable values which can be measured independently of the operator´s experience, such as percentage of cross-sectional area affected. On the other hand, subjective measurements refer to measures that could vary depending on operator´s experience and opinion, such as echogenicity. Ultrasonographic scoring systems have been described before, but there are currently no published studies which describe repeatability and reliability.

The objectives of this study were to: 1) develop a robust, reliable and repeatable ultrasonographic scoring system for superficial digital flexor tendinopathy using objective and subjective measurements of ultrasonographic parameters and 2) determine inter-rater variability and intra-rater reliability for a panel of subjectively scored ultrasonographic parameters of SDFT injury in Thoroughbred racehorses.

Materials and Methods

Participants and ultrasonographic data: Five experienced equine orthopaedic clinicians, including three ECVS diplomates and two RCVS certificate holders, working in specialist centres, reviewed and scored the ultrasonographic images using the predefined SDFT scoring system. Fourteen ultrasonographic studies from Thoroughbred racehorses with only forelimb SDFT lesions, including seven cases of SDFT tendonitis with a core lesion and seven cases of diffuse SDFT tendonitis (without a core lesion), were non-randomly selected from a large hospital database. Cases were selected based on having a set of images of diagnostic quality with both transverse and longitudinal views of regions of interest, and were selected to represent a range of lesions with differing severity. In addition, two Thoroughbred racehorses with a complete set of normal ultrasonographic images of the SDFT were also included (control/no-injury cases). Each ultrasonographic study was obtained using a high-frequency linear ultrasonic transducer (5-13MHz), an acoustic stand-off pad and acoustic gel. Transverse (zones 1A - 3C) and longitudinal (L1-L3) images of the SDFT were obtained from the carpal bone down to ergot in the palmar metacarpal region. DICOM (Digital Imaging and Communication in Medicine) data was used to store all the ultrasonographic images in a web-shared folder to allow free access to the participants. All the images were independently reviewed on two occasions, four to six weeks apart using a dedicated DICOM viewer, and scored by completing an online questionnaire (SurveyMonkey; https://www.surveymonkey.co.uk/) with objective and subjective measurements for each case. On each occasion, the ultrasonographic studies were presented to the participant in a computer-generated random order. Throughout the study, participants were blinded to any case information and outcomes.

Predefined scoring system (Fig.1)*:* The ultrasonographic images of each case were initially assessed qualitatively for the presence of an SDFT lesion (scored as 1 = SDFT tendonitis with core lesion, 2 = diffuse SDFT tendonitis without core lesion or 3 = normal SDFT). In cases where lesions were found, two further categories were assessed qualitatively (using case logic on the survey tool to exclude these assessments in cases considered to be normal). These two categories were the number of zones affected (from 1 zone to ≥5 zones), and the location of the maximal injury zone (MIZ; seven different sites on the leg: zones 1A - 3C (Rantanen and others 2011). Three semi-quantitative ultrasonographic criteria were also defined for the MIZ: a) lesion echogenicity (MIZ-echogenicity, scored as 1 = anechoic, 2 = hypoechoic or 3 = hyperechoic compared to normal tendon tissue), b) estimated lesion cross-section area (MIZ-CSA (%), scored as 1 = <25%, 2 = ≥25-50%, 3 = ≥50-75% or 4 = ≥75% of the lesion cross-sectional area affected) and c) estimated lesion longitudinal fibre pattern (MIZ-LFP (%), scored as 0 = normal, 1 = <25%, 2 = ≥25-50%, 3 = ≥50-75% or 4 = ≥75% of the lesion longitudinal fibre pattern affected) *(Fig. 2).* Grey-scale digital images for the different transverse zones (1A-3C) and for the criteria to be used for each category were provided as examples. The scoring system for diffuse SDFT tendonitis without a core lesion was also clarified following initial feedback from the participants. Specifically, scores for the percentage of affected cross sectional area and/or longitudinal fibre pattern of the MIZ related only to the maximum seen in the MIZ image (as opposed to an overall score for the whole injury). Example images and scores were also provided for these parameters in diffuse lesions. This clarification was only provided for injuries without a core lesion and related to the diffuse nature of these injuries.

Statistical analysis: All data was analysed using Genstat v16 (VSNi, Rothampsted, UK). The ability of each rater to reproduce the same score for each category on two occasions (i.e. intra-rater reliability) was evaluated using Lin's Concordance correlation coefficient, which quantifies the agreement between two independent scores of the same parameter (0 = no agreement, 1 = perfect agreement). A value ≥0.75 is considered as very strong agreement and 95% confidence intervals are used to represent the experimental variability around each score. Kendall´s coefficient of concordance was used to measure the degree of agreement/consensus between participants for each SDFT parameter scored (i.e. the inter-rater variability, where a score of 0 = no agreement and 1 = perfect agreement). Statistical significance was considered at $p<0.05$, with $p<0.001$ indicating a highly statistically significant effect.

Results

All participants successfully (Kendall´s and Lin´s Coefficient = 1) distinguished the type of SDFT injury (core vs. diffuse) for all cases (Table 1).

Reliability of the SDFT scoring system (Intra-rater agreement): For the seven cases of SDFT tendonitis with a core lesion, the intra-rater reliability was very good (Lin´s Coefficient [LC] = ≥0.73; Fig. 3) for the majority of ultrasonographic parameters, including: number of zones (LC = 0.84), maximal injury zone (MIZ) location (LC = 0.93), MIZ-cross-section area (MIZ-CSA (%); LC = 0.77) and MIZ-longitudinal fibre pattern (MIZ-LFP (%); LC = 0.73). For the seven cases with a diffuse SDFT injury (without a core lesion), the intra-rater reliability was excellent (LC ≥0.86) for MIZ-location (LC = 0.82) and MIZ-LFP (%) (LC = 0.85) but only moderate (LC = 0.41-0.60) for the number of zones (LC = 0.62) and MIZ-CSA (%) (LC = 0.58). In contrast, the intra-rater agreement for MIZ-echogenicity for SDFT lesions with a core lesion was weak (LC = 0.31 [-0.05,0.50] 95% confidence interval). Similarly, the Lin´s Coefficient for the cases with diffuse SDFT tendonitis (without a core lesion) was also weak (LC = 0.30 [0.07,0.49] 95% confidence interval).

Variability of the SDFT scoring system (Inter-rater agreement): For cases of SDFT tendonitis with a core lesion, the inter-rater agreement was very strong (Kendall´s Coefficient [KC] ≥0.74, $P<0.001$; Fig. 4) for almost all ultrasonographic parameters including the number of zones (KC = 0.76), MIZ-location (KC = 0.80), MIZ-CSA (%) (KC = 0.84) and MIZ-LFP (%) (KC = 0.74). For cases of diffuse SDFT tendonitis (without a core lesion), the inter-rater agreement was strong (KC = ≥0.62 - <0.69) for the following ultrasonographic parameters: number of zones (KC = 0.64), MIZ-location (KC = 0.62) and MIZ-CSA (%) (KC = 0.69) and very strong for the MIZ-LFP (%) (KC = 0.87). The inter-rater agreement for MIZ-echogenicity for both SDFT lesions with or without core lesions was weak (KC = 0.31, χ^2 26.8, P=0.01) and (KC = 0.30, P=0.36) respectively.

Discussion

At present, MRI is the most sensitive imaging modality for the evaluation of tendon injury (Karlin and others 2011). However, ultrasonography is widely available, portable, cheap and safe and recent improvements in US technology make it the most commonly used imaging modality for equine practitioners to evaluate SDFT injuries. Several ultrasonographic scoring scales to evaluate injured tendons have been developed over the last 30 years in veterinary practice (Genovese and others 1986, Reef and others 1993, Van den Belt and others 1993, Saini and others 2002, Geburek and others 2016), but there is no internationally agreed protocol for reporting SDFT injuries, making it difficult to compare datasets. In an attempt to provide a semi-quantitative evaluation, each of these scoring systems focuses on different parameters: Cross-sectional area and echogenicity (Genovese and others 1986 and Van den Belt and others 1993); length of the lesion and percentage of the cross-sectional area affected (Reef and others 1993) or echogenicity only (Saini and others 2002). A fundamentally more powerful method of ultrasonographic diagnosis is ultrasound tissue characterization (UTC) which quantifies tendon integrity based on a computerized analysis of the stability of echo-patterns in contiguous ultrasound images (Geburek and others 2016). Although this technique has great potential for the future, at present it is mainly being applied in a research environment. With the exception of UTC, the reliability and repeatability of the ultrasonographic parameters included in each system should be investigated. Ideally only parameters with high reliability and repeatability should be included.

This is the first study which describes the reliability and repeatability of an ultrasound scoring system for SDFT injuries. Scoring systems (i.e. qualitative, semi-quantitative and quantitative) are widely used in human medicine to provide a framework for standardization of clinical management, benchmarking outcomes and planning or analysing research. The ultrasonographic scoring system developed in this study, obtained by categorizing type and extent of SDFT injury together with location and ultrasonographic characteristics of the maximal injury zone (MIZ), will allow equine practitioners to apply these criteria in veterinary medicine. In comparison with previously described scoring systems, we have included more ultrasonographic parameters with higher reliability and repeatability which allow for a more detailed characterization of the injury. Two of the previously proposed ultrasonographic systems (Genovese and others 1986 and Van den Belt and others 1993, Saini and others 2002) rely heavily on echogenicity which in our study had weak intra/inter rater agreement. Contrary to the scoring system proposed by Reef and others (1993), this ultrasonographic scoring system also required subjective visual assessment of the area of tendon damaged to assess the echogenicity.

This study presents a simple, repeatable and thus reliable scoring system for tendon injury evaluation using ultrasonographic features of the MIZ as a representative part of the injury. Contrary to previously described ultrasonographic scoring scales (Genovese and others 1986), our system described here is quick (taking on average 5 to 10 minutes) and simple to complete, requiring only minimal training which will facilitate its incorporation into routine practice. However, it still relies on subjective ultrasonographic parameters, some of which have poor reliability and repeatability. This scoring system could allow standardization of the SDFT evaluations in clinical practice allowing comparison of clinical findings when cases are reassessed by colleagues, and enabling practices to monitor and audit clinical cases by comparing and contrasting findings and responses to treatment between different cases. We acknowledge that scoring diffuse SDF tendonitis without a core lesion is more subjective and difficult than SDF tendonitis with a core lesion. In this study both Kendall´s and Lins coefficients were lower for the majority of the categories without a core lesion (with wider confidence intervals as expected), but the tendency was similar in both groups (see Fig. 4). This fact was also highlighted by our study: in order to significantly improve the initial inter-rater agreement of clinicians assessing tendonitis without a core lesion, a detailed explanation and images of all the categories had to be provided to each of the participants prior to assessment.

Limitations of the study: The main limitation of this study is that ultrasound images were retrospectively reviewed. The images were also obtained by multiple clinicians with different ultrasonographic equipment which could alter image quality. Although all the images were of diagnostic quality, no attempt was made to assess or compare the quality of the images which could have affected some categories of the scoring system. In addition, lack of ultrasonographic images of the contralateral limb for comparison is a weakness. However, in our study images of two control horses with no-injury were reliably interpreted by all practitioners. Nevertheless, we acknowledge that having images of the contralateral limb could have significantly improved our scores.

With regard to echogenicity, which showed poor reliability and agreement, the test conditions could have influenced results to some extent; for example, the brightness in the room, the type of screen or the dedicated DICOM viewer used by the participants were not recorded but could have influenced echogenicity score of the cases. Some of the participants changed the test conditions between part one and two of the study, by using different screens and DICOM viewers to score the cases. Echogenicity is highly dependent on the positioning of the probe and angle of the ultrasound beam in comparison with the longitudinal axis of the tendon fibres. Assessment of the echogenicity in real time by the operator would have led to a better evaluation of the echogenicity score. Nevertheless, echogenicity is an ultrasonographic parameter commonly used to characterize tendon injury in horses and whilst this study highlighted low intra- and inter-rater agreement, all cases were acute injuries that were either scored hypoechoic or anechoic by all participants.

In summary, this study describes a scoring system which uses both qualitative and semi-quantitative measures that can be simply and consistently applied by equine practitioners and researchers. The development of a validated scoring system is important to enable standardised clinical recording of SDTF injuries for equine practitioners both for repeated assessments within the same patient, and also for comparison of lesions between different patients. It will also enable inter-study comparisons and meta-analysis of future SDFT research projects by minimizing variation between different operators and/or different studies.

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Ethics statement*:* This study was reviewed and approved by the ethical committee of the School of Veterinary Medicine and Science, University of Nottingham.

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Figure 1: Flowchart summarising the predefined scoring system used in this study.

Table 1: Summary of Kendalls and Lin's coefficients of concordance

	SDFT tendonitis with core lesion			Diffuse SDFT tendonitis without core lesion		
Parameter assessed	**Lin's coeff.**	**Kendal's coeff.**	**P-value**	**Lin's coeff.**	**Kendal's coeff.**	**P-value**
Type of Injury (Core vs. Diffuse)	1	1	<0.001	1	1	<0.001
Nº of zones	0.84 (0.72-0.91)	0.76	<0.001	0.62 (0.37-0.79)	0.64	<0.001
MIZ: Location	0.93 (0.88-0.96)	0.80	<0.001	0.82 (0.67-0.90)	0.62	<0.001
MIZ: CSA (%)	0.77 (0.60-0.87)	0.84	<0.001	0.58 (0.31-0.76)	0.69	<0.001
MIZ: Echogenicity	**0.31*** (-0.05-0.50)	**0.34***	0.013	**0.30*** (0.07-0.49)	**0.22***	0.36
MIZ: LFP (%)	0.73 (0.54-0.85)	0.74	<0.001	0.85 (0.72-0.92)	0.87	<0.001

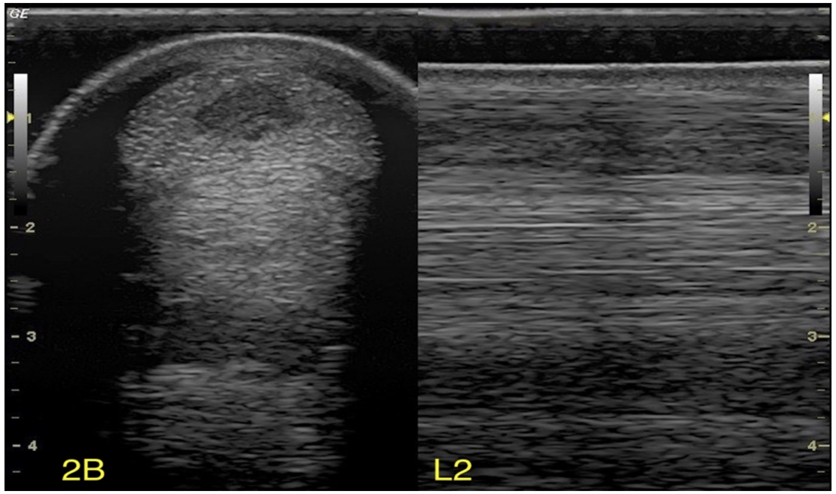
* Weak agreement

Figure 2: Example of the semi-quantitative ultrasonographic criteria (echogenicity, cross-section area and longitudinal fibre pattern) used to score the lesion at the maximal injury zone (MIZ) in equine cases with superficial digital flexor tendon injuries. Transverse and longitudinal ultrasonographic images of the MIZ of SDFT injury:

a) SDFT tendonitis with a core lesion; lesion echogenicity (MIZ-echogenicity) scored as 1 = anechoic, lesion cross-section area (MIZ-CSA (%) scored as 1 = < 25% and lesion longitudinal fibre pattern (MIZ-LFP (%) scored as 3 = 50-75%.

b) SDFT tendonitis without a core lesion; lesion echogenicity (MIZ-echogenicity) scored as 2 = hypoechoic, lesion cross-section area (MIZ-CSA (%) scored as 4 = ≥75% and lesion longitudinal fibre pattern (MIZ-LFP (%) scored as 3 = 50-75%.

a)



b)

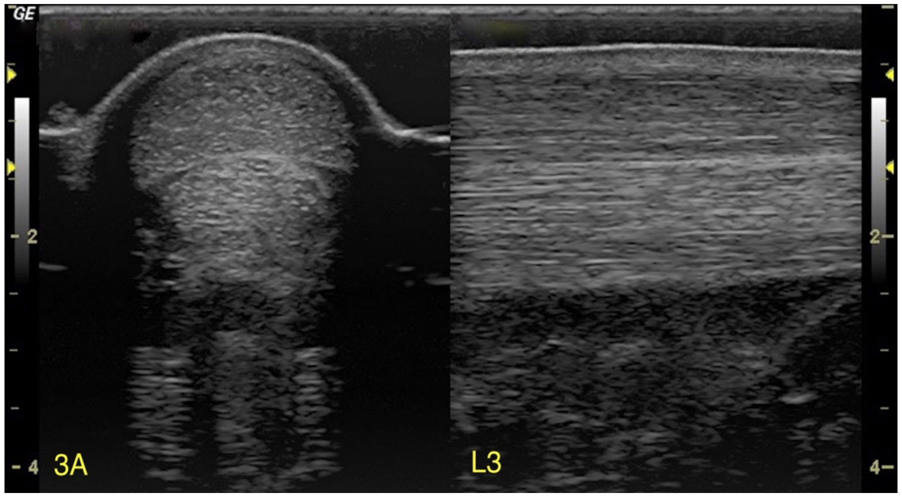


Figure 3: Lin's concordance coefficient (LC) for ultrasonographic parameters

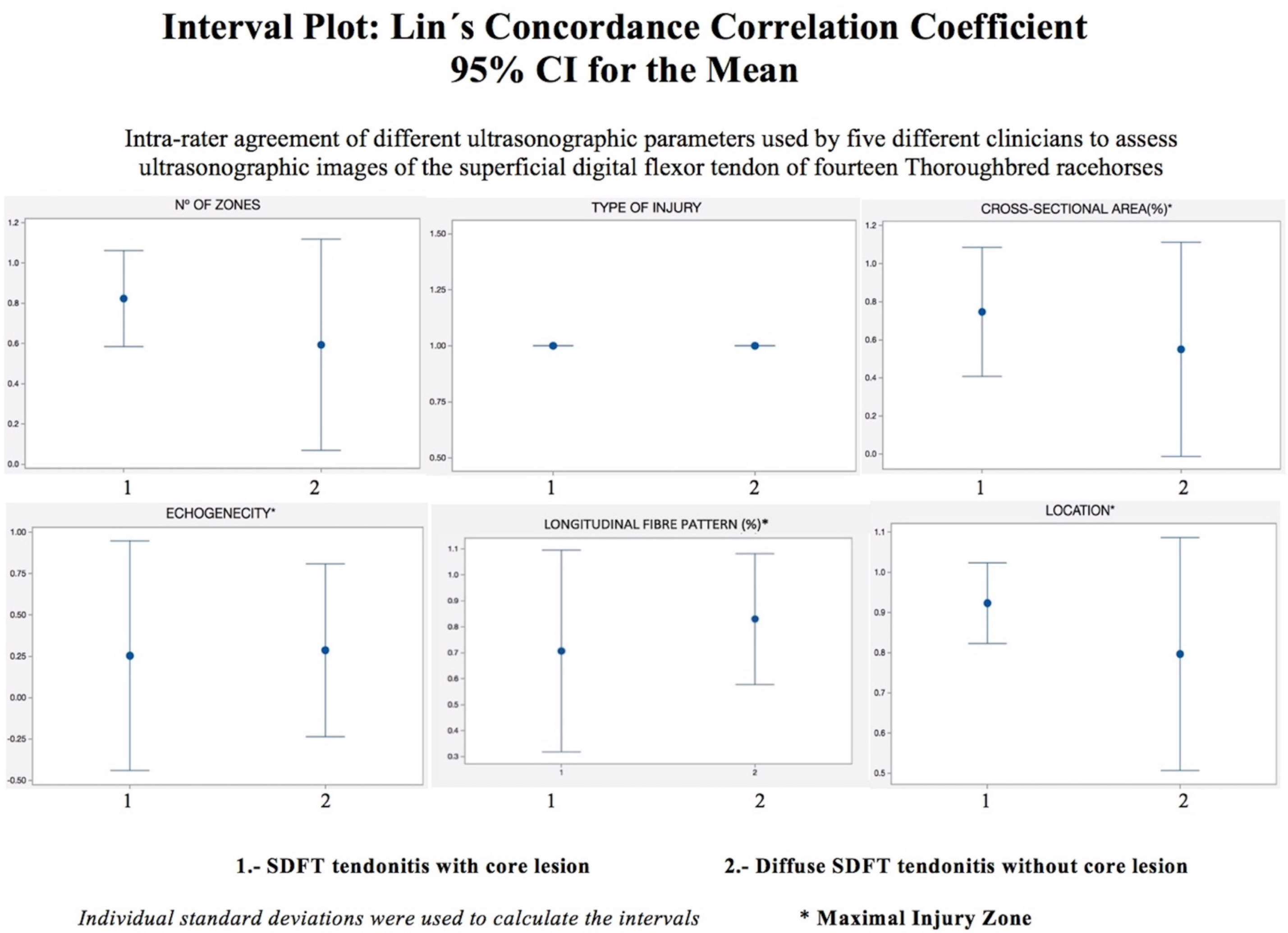


Figure 4: Kendalls coefficient of concordance (KC) for ultrasonographic parameters