ORIGINAL ARTICLE

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Ultrasonographic evaluation of collateral ligaments of the distal interphalangeal joint in Quarter Horse forelimbs

Avaliação ultrassonográfica dos ligamentos colaterais da articulação interfalangeana distal dos membros torácicos de cavalos da raça Quarto de Milha

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ABSTRACT: Thirty non-lame Quarter Horses under athletic exercise training, aged between 2 and 23 years old, both males and females were evaluated in order to find ultrasonographic characteristics of distal interphalangeal joint's (DIPJ) collateral ligaments (CLs) in their forelimbs. The horses were divided into three groups based on age. Group A consisted of horses aged between three and four years old; group B consisted of equines aged between five and ten years old; and group C consisted of animals that were over ten years old. Six parameters were assessed, including increase of the ligament area (LA), hypoechogenicity (HO), collapse of coronal vessels (CV), heterogeneity (HT), hyperechogenicity (HR) and irregularity of ligament borders (IB). Older horses were more prone to displaying ultrasonographic alterations in the CL-DIPJ. The prevalent ultrasonographic findings observed were alterations in the echogenicity of the fibers and ligament thickening, diagnosed in 73,33% (88/120) of the examined ligaments. The medial collateral ligament (MCL) displayed more frequent alterations than the lateral collateral ligament (LCL). In conclusion, this study provided a detailed characterization of the ultrasound examination of the CL-DIPJ in the forelimbs of clinically non-lame Quarter Horses subjected to intensive exercise routines. The findings demonstrate that even in non-lame horses, ultrasonographic alterations can be observed in the CL-DIPJ.

KEYWORDS: athletic horse; equestrian sports; equine musculoskeletal system; equine orthopedics; imaging examination.

RESUMO: Trinta cavalos da raça Quarto de Milha, não claudicantes, em regime de treinamento atlético, com idades entre 2 e 23 anos e de ambos os sexos foram avaliados para determinação das características ultrassonográficas dos ligamentos colaterais (LC) da articulação interfalangeana distal (AIFD) dos membros torácicos. Os equinos foram divididos em três grupos com base na idade. O Grupo A compreendeu cavalos com idade entre três e quatro anos; o Grupo B, equinos com idade entre cinco e dez anos; e o Grupo C, animais com mais de dez anos. Foram avaliados seis parâmetros, incluindo aumento da área do ligamento (AL), hipoecogenicidade (HO), colapso de vasos coronais (CV), heterogeneidade (HT), hiperecogenicidade (HR) e irregularidade das bordas do ligamento (IB). Cavalos mais velhos apresentaram maior tendência a alterações ultrassonográficas no LC-AIFD. As principais alterações ultrassonográficas observadas foram alterações na ecogenicidade das fibras e espessamento ligamentar, diagnosticadas em 73,33% (88/120) dos ligamentos examinados. O ligamento colateral medial (LCM) apresentou alterações mais frequentes do que o ligamento colateral lateral (LCL). Este estudo forneceu uma caracterização detalhada do exame ultrassonográfico do LC-AIFD nos membros torácicos de cavalos Quarto de Milha clinicamente não claudicantes submetidos a intensas rotinas de exercício. Os resultados demonstram que mesmo em cavalos não claudicantes, podem ser observadas alterações ultrassonográficas no LC-AIFD.

PALAVRAS-CHAVE: cavalo atleta; esportes equestres; sistema musculoesquelético equino; ortopedia equina; exame de imagem.

INTRODUCTION

Musculoskeletal injuries are a significant source of economic loss in the horse industry, with most of such injuries affecting the distal limb (Bowers; Weinhandl; Anderson, 2023; Fails, 2020). The distal interphalangeal joint (DIPJ), partially covered by the hoof, is formed by the middle phalanx, distal phalanx, and the navicular bone. This joint is classified as a ginglymus or saddle joint, with articulating surfaces that are reciprocally concavo-convex (Denoix, 2001; Getty, 1986; Köning; Liebich, 2020). The DIPJ can move in three planes: sagittal, frontal,

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and transverse. These multiple directions of movement and the contact of the hoof with the ground make this joint particularly susceptible to injuries (Denoix, 1999, 2001; Johnston; Back, 2006). The main structures that restrict lateral movements and rotation of the DIPJ are the collateral ligaments (CLs) (Johnston; Back, 2006; Parks, 2012). The collateral ligaments of the distal interphalangeal joint (CL-DIPJ) are short and robust structures that are symmetrically located on the dorsolateral and dorsomedial aspects of the joint. They originate from the collateral fossa of the middle phalanx, go into the collateral fossa of the distal phalanx and attach to the joint capsule and radiate to the chondrocoronal ligament (Denoix, 2001; Getty, 1986; Köning; Liebich, 2020). The CL-DIPJ is composed of various fasciculi that are obliquely oriented to the phalangeal axis in a distopalmar/distoplantar direction (Denoix *et al.* 2011a; Denoix *et al.*, 2011b).

Over a 10-year period, 148 cases of CL-DIPJ desmopathies were identified in 8.3% of horses with foot pain. These cases were found in showjumpers (75.7%), dressage (7.4%), eventers (5.4%) and pleasure horses (5.4%), with racehorses being less affected. Forelimbs were affected more frequently (93%) than hindlimbs, and the lesion was more frequently medial (54%) than lateral (36.5%). Both sides of the same foot were affected in 9.5% of the cases, and both left and right limbs were affected in 8.1% of the cases (Denoix *et al.*, 2011b).

Ultrasonography is an easy, rewarding, and reliable image technique for evaluating soft tissue abnormalities of the equine foot, including CL-DIPJ desmopathies (Denoix *et al.*, 2011a). Ultrasonographic alterations that can characterize lesions appear as increased ligament volume, presenting focal hypoechoic areas, or heterogeneous echogenicity, with an irregular longitudinal fiber pattern (Denoix *et al.*, 2011b; Dyson; Murray, 2004; Sage; Turner, 2002; Turner; Sage, 2002). Animals affected with DIPJ collateral desmopathy usually have little or no radiographic alterations (Fails, 2020). Therefore, ultrasonography has an essential and complementary diagnostic value. Although magnetic resonance imaging (MRI) is the gold standard for this structure (Mieszkowska *et al.*, 2022), it can generate features that simulate lesions, such as the magic angle artifact, and it is often less accessible, more costly, besides being time consuming, and requires general anesthesia (Barrett *et al.*, 2017; Pauwels *et al.*, 2021; Werpy *et al.*, 2013). In our study, we found that the risk associated with the procedure does not justify investigating the appearance of CL-DIP in horses that show no clinical signs of lesions in these structures. Ultrasonography can even aid in cases of animals that underwent MRI, acting as a screening tool or a guide for sequences and cutting plans in the examination of CLs (Denoix *et al.*, 2011a).

This study outlines the ultrasonographic evaluation of the collateral ligaments in the distal interphalangeal joint (CL-DIP) of the forelimbs of non-lame Quarter Horses undergoing athletic exercise training. It was hypothesized that ultrasonographic alterations of the CL-DIPJ might not always be related to lameness, consequently not resulting in clinical signs.

MATERIAL AND METHODS

The study was approved by the Animal Ethics Committee/CEUA-PRPI-UFG and was registered under protocol number 004/14. A total of 30 purebred Quarter Horses were examined by a single evaluator, (GHC), between January and July, 2015, on farms and training centers in the cities of Goiânia and Nerópolis, Goiás, Brazil. The animals were aged between three and twenty-three (7 ± 3.3) years old and consisted of both males and females (11 males and 19 females). The average weight of the animals was 442.9 ± 40.2 kg, and the body condition score was 3/5. During the study, none of the animals presented complaints of performance drop or lameness. They were all calf roping (13) or barrel racing (17) horses and were under athletic exercise training routines for 5 to 7 days a week, two hours per day, for at least one year. A complete lameness exam was performed, including visual inspection, palpation of the distal portion of the forelimbs, dynamic inspection and flexions tests as needed. All the horses were considered free of lameness.

The animals were divided into three different age groups (A, B, and C). Group A (n = 10) consisted of horses aged between three and four years old, group B (n = 10) consisted of equines aged between five and ten years old, and group C (n = 10) consisted of animals that were over ten years old. The animals were intravenously sedated with 0.005 to 0.015 mg/kg of detomidine hydrochloride (Eqdomin®, Ouro Fino, Brazil) in order to promote safety for the examiner and the animal during the ultrasonographic evaluation (Whitcomb, 2009).

A portable ultrasound device (LOGIQ e Ultrasound®, General Electric, U.S.A.) with a linear multi-frequency transducer (5-13 MHz) set to 10 MHz was used to examine the horses. The horses were clipped three centimeters above the coronary band with a #40 blade, and a silicone pad (stand-off) was attached to the transducer, with conductive gel applied. The ultrasound technique employed was previously described by Denoix *et al.* (2011a). The medial and lateral CL-DIPJ were assessed in both forelimbs, amounting to a total of 120 ligaments. In cross-sectional images, the transducer was positioned on the periople, and the angulation of the probe corresponded to position A. Position A was chosen because there are fewer variations in the ultrasound image in it, which allows for comparison of images between animals, limbs, medial and lateral ligaments, without any interference of the natural variation in the shape of the hoof. It all results in a reliable reference point to examine all the different CLs in the same horse, and in different individuals, at the same level (Denoix *et al.*, 2011a; Denoix *et al.*, 2011b). Longitudinal images were used to confirm alterations observed in cross-sectional images.

To interpret and measure the CLs, a Picture Archiving and Communication System (PACS) viewer for medical images Onis 2.5.1.6 Free Edition (2009-2013 Digital Co. LTD) for the Windows 10 operating system was used to obtain the ligament cross-sectional area. The tests were repeated three times in each ligament to precisely determine the extent of the ligament's cross-sectional area and to avoid the presence of peri ligamentous structures that could be mistakenly incorporated in the ligament area. Five other parameters were subjectively evaluated according to the presence or absence of each one, including hypoechogenicity (HO), the collapse of coronal vessels (CV), heterogeneity (HT), hyperechogenicity (HR), and irregularity of ligament borders (IB). The total area of the CL was divided by the lesion area to establish the proportion of the ligament that was altered.

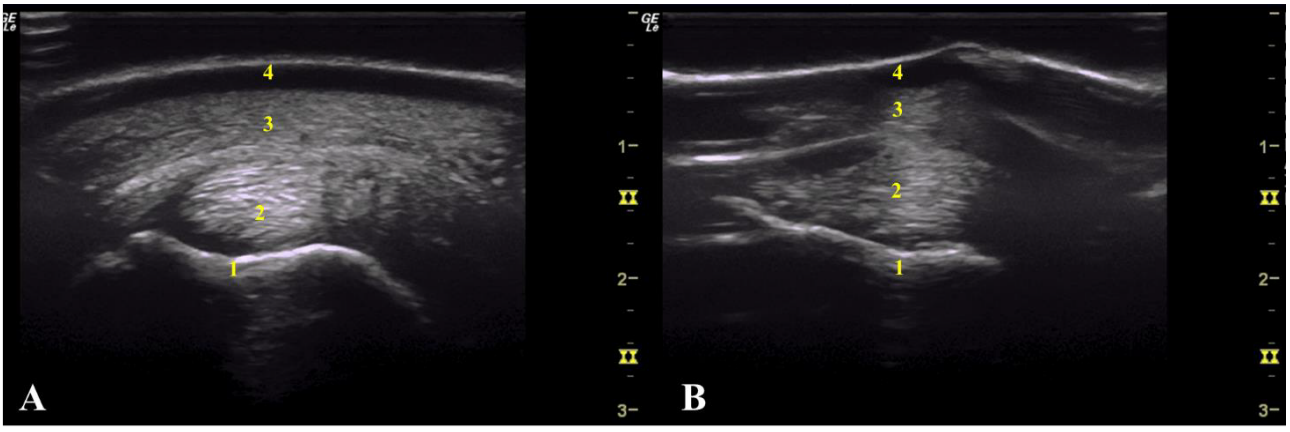
The variables were analyzed according to descriptive statistics and frequency distribution (%), using R software (version 3.2.1, R Core Team). The parametric assumptions were tested by the Shapiro–Wilk (normality) and Levene (homoscedasticity) tests. To compare the averages (± SD) of thickness, width, and cross-sectional areas of medial and lateral CL-DIPJ, a t-test for independent samples at a 5% significance level was performed. To compare the frequency of alterations on the left versus right limbs, lateral versus medial ligaments, calf roping versus barrel racing horses, and among the groups the percentage data were transformed into the square root of arc sin (arcsin $\sqrt{x}$). Then, the variance analysis (ANOVA) was applied, followed by the Tukey test at a 5% significance level.

RESULTS AND DISCUSSIONS

In this study, the CL-DIPJ was identified in position A, inside the collateral fossa of the middle phalanx, and appeared as an oval and echogenic structure in the transverse section, as described by some authors (Evrard *et al.*, 2012; Whitcomb, 2009) (Figure 1-A). In the longitudinal image, the proximal half of the CL-DIPJ is imaged down to the distal aspect of the collateral fossa of the middle phalanx showing a regular pattern of parallel echogenic fibers, as described by Denoix *et al.* (2011a) (Figure 1-B). The region where the collateral fossa of the middle phalanx was concave and aligned with the middle of the image was used as the reference point to obtain suitable images for further comparison, as previously reported (Denoix *et al.*, 2011a) (Figure 1-A). This position was considered optimal, and the ligament showed minimal variations, providing good image quality, which allowed examination and comparison of all CL-DIPJ in the same horse at the same level, as previously described (Denoix *et al.*, 2011a; Evrard *et al.*, 2012). On average, only 57% of the CL-DIPJ can be assessed by ultrasound, even when probe positions are switched while seeking the most distal portion (Evrard *et al.*, 2012). Therefore, in this study, a smaller portion of the ligament was explored by ultrasound, limiting the comparison to position A. Hence, it is possible to infer that no possible distal alterations were identified.

Our investigation revealed distinctive features in the ultrasonographic examination of the CL-DIPJ, including fiber orientation, positioning within the hoof, and division into fascicles. These specific characteristics can pose challenges for evaluators, making it difficult to distinguish between anatomical variations and actual injuries. To minimize this challenge, different probe angulations were used in conjunction with the contrast enhancement technique to show the anisotropy of the CL and identify true injuries, as recommended in the literature (Denoix *et al.*, 2011a).

Additionally, the comparison between contralateral limbs played a crucial role in discerning individual variations. As previously described, the linear transducer was identified as a suitable tool for capturing images of the CL-DIPJ (Góss *et al.*, 2018, 2021). Furthermore, the use of a stand-off pad in conjunction with the transducer improved the ultrasound image quality by reducing the difficulty associated with transducer



Source: author's collection.

Figure 1. Ultrasonographic images of the collateral ligaments of the distal interphalangeal joint (CL-DIPJ). (A) Transverse ultrasound section of the CL-DIPJ that appears as an oval and echogenic structure. (B) Longitudinal (proximodistal) ultrasound section of the CL-DIPJ that presents a regular pattern of parallel echogenic fibers. 1: Collateral fossa of the middle phalanx; 2: Collateral ligament of the distal interphalangeal joint (CL-DIPJ); 3: coronal cushion; 4: corium limbi and periople.

positioning, particularly in the pastern and hoof region where the contact surface area is limited. This finding aligns with previous literature (Dyson; Blunden; Murray, 2008; Evrard *et al.*, 2012; Góss *et al.*, 2021).

The CL-DIPJ was found to have an average thickness of 7.0 ± 0.9 mm, a width of 11.7 ± 1.4 mm, and a cross-sectional area of 0.77 ± 0.17 cm^2. These values are similar to those found in another study with Quarter Horses (Sage; Turner, 2002) and to those observed in other breeds, such as Criollos (Góss *et al.*, 2018, 2021), Paint Horses, and Arabian (Sage; Turner, 2002).

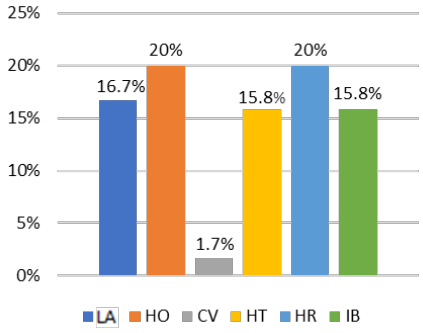
No significant difference was observed between the lateral and medial ligaments or the right and left limbs in the comparison of average thickness, width, and cross-sectional areas of the CLs. Although the ultrasonographic examination of CL-DIPJ has been previously described (Denoix *et al.*, 2011a; Dyson; Murray, 2004; Evrard *et al.*, 2012), these studies did not analyze the same ligament in non-clinically lame Quarter Horses.

In our study, slight variations in the shape of the CL-DIPJ were observed, with some individuals presenting a rounder shape and others a flatter shape, possibly due to different position of the ligament in relation to the coronary band. Different shapes of the CL-DIPJ were also observed in another study (Denoix *et al.*, 2011a; Evrard *et al.*, 2012; Góss *et al.*, 2018). As described by other authors (Denoix *et al.*, 2011a; Evrard *et al.*, 2012; Góss *et al.*, 2018), the lateral CL (LCL) was found to be more easily visualized than the medial CL (MCL) due to the higher medial wall of the hoof which creates an acoustic shadowing impairing the visualization of the distal part of this ligament. Furthermore, authors have reported that the MCL is located more distally within the hoof capsule, making it more challenging to examine (Evrard *et al.*, 2012). We observed that the quality of images obtained from the MCL was lower than those obtained from the LCL, as previously reported (Dyson; Murray, 2004). The hooves were subjectively classified as flat and narrow by the evaluator. It was easier to obtain images of the CLs from flat feet (73%) than from narrow and straight feet (27%) with high and vertical hoof walls, which was also observed by Denoix *et al.* (2011a). The individual characteristics related to the hoof capsule format may worsen image quality in some cases (Dyson; Murray, 2004; Evrard *et al.*, 2012; Góss *et al.*, 2021; Sage; Turner, 2002).

In cross-sectional images, the most common findings included changes in echogenicity of the fibers and thickening of the CL, which was measured by the cross-sectional area of the ligament. The ligament area was considered thickened when it increased by at least 20% compared to the contralateral ligament (Denoix *et al.*, 2011a).

Figure 2 shows the frequency of ultrasonographic alterations in the CL-DIPJ observed in all horses regardless of age. Table 1 shows the frequency of ultrasonographic alterations in the CL-DIPJ according to the age groups.

Nineteen of the 120 CLs (15,83%) assessed had at least one sonographic alteration. We found that 15,83% (19/120) of the CL-DIPJ examined were thickened. When considering MCLs and LCLs individually, 13,33% (8/60) and 18,33% (11/60) of the ligaments, respectively, were



Source: author's collection.
LA: Increase in the ligament area; HO: hypoechogenicity; CV: collapse of coronal vessels; HT: heterogeneity; HR: hyperechogenicity; (IB): irregularity of ligament borders.
Figure 2. Frequency of ultrasonographic alterations in the collateral ligament of the distal interphalangeal joint (CL-DIPJ) in non-lame Quarter Horses regardless of age.

Table 1. Frequency of ultrasonographic alterations in the collateral ligaments of the distal interphalangeal joint (CL-DIPJ) in the forelimb of non-lame Quarter Horses across age groups.

Variables	Group A (n = 40)	Group B (n = 40)	Group C (n = 40)	TOTAL (lesion/ all lesions)
Increase of the ligament area (LA)	5.0% (2)[b]	22.5% (9)[a]	20.0% (8)[a]	**16% (19/1**
Hypoechogenicity (HO)	12.5% (5)	22.5% (9)	25.0% (10)	**21% (24/114)**
Collapse of coronal vessels (CV)	2.5% (1)	2.5% (1)	0.0% (0)	**2% (2/114)**
Heterogeneity (HT)	2.5% (1)[b]	15.0% (6)[b]	50.0% (10)[a]	**15% (17/114)**
Hyperechogenicity (HR)	12.5% (5)	27.5% (11)	30.0% (12)	**25% (28/114)**
Irregularity of ligament borders (IB)	5.0% (2)[b]	17.5% (7)[ab]	37.5%[a] (15)	**21% (24/114)**
TOTAL (group/all lesions)	**14% (16/114)**	**38% (43/114)**	**48% (55/114)**	

Values followed by different letters are significantly different.
Group A: horses aged between three and four years old; group B: horses aged between five and 10 years old; group C: horses aged over ten years old.

identified as displaying thickening. The frequency of increase of the ligament area (LA) was significantly higher in groups B (22.5%) and C (20.0%) ($p < 0.05$) compared to group A (5.0%) (Table 1). In group B, this result can be related to the age of these horses (5 to 10 years). During this phase of life, they are at the peak of their athletic careers and, consequently, are consistently subjected to exercises that may increase the risk of ligament injuries. In group C, the LA may be related to the existence of scar tissue resulting from chronic alterations, as these animals were repeatedly exposed to and for extended training periods on irregular floors (Denoix, 1999; Denoix *et al.*, 2011b). Conversely, group A was composed of animals at the beginning of their athletic career. Additionally, horses in groups B and C tended to present an increase in the frequency of hyperechogenicity (HR) (27.5 and 30.0%, respectively) (Table 1). Although not statistically significant, this finding is worth mentioning, as this increase in echogenicity may have occurred due to the presence of scar tissue resulting from ligament injuries during the athletic life of these horses.

We found that group C, which was comprised of horses over the age of 10 years, had a higher frequency of ultrasonographic heterogeneity (HT) in the fibers of the CLs (Table 1). This supports the idea that these ligaments have more chronic injuries. Nevertheless, despite these findings, it was noted that an increase in the cross-sectional area (LA) of the ligament occurred in 55% of cases associated with hypoechogenicity (HO) or hyperechogenicity (HR). This suggests that the presence of HO or HR is not always related to increased LA, as previously described (Denoix *et al.*, 2011b) in horses presenting lameness. Hypoechogenicity (HO) was only observed in 20% (24/120) of the examined ligaments, and there was no significant difference among the groups (Table 1). It is important to note that this study only evaluated non-lame horses. It is known that HO is typically associated with acute injuries that often lead to lameness, except for individual variations (Turner; Sage, 2002). Additionally, border irregularity (IB) was observed in 37.5% (15/40) of the CL in Group C, which was significantly higher than those in Group A (Table 1). This indicates a greater likelihood of chronic injuries in older animals.

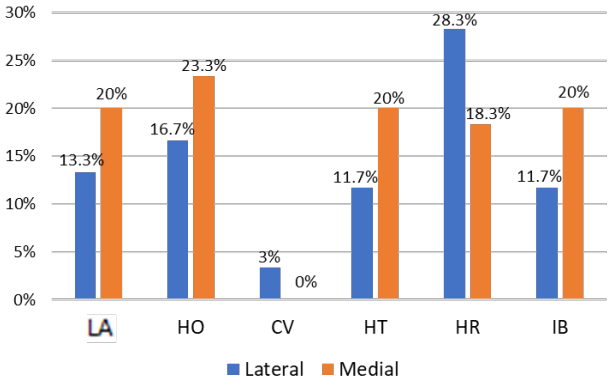
None of the evaluated animals presented alterations that exceeded more than two-thirds of the CL. A correlation has been described between the degree of lameness and the severity of the lesion in horses that presented recent desmopathy (Denoix *et al.*, 2011b). As this study was limited to non-lame animals, this finding was expected. When comparing MCL to LCL, the first one was more likely to present alterations with higher frequency and area correlation (16,66% [10/60]) than the second one (13,33% [8/60]), which indicates a higher incidence of injuries to the MCL and confirms the findings of other studies (Denoix *et al.*, 2011b; Dyson; Blunden; Murray, 2008; Evrard *et al.*, 2012; Whitcomb, 2009). Figure 3 shows the frequency of ultrasonographic alterations identified in the MCL and LCL in non-lame Quarter Horses.

Our findings indicate that older horses are more prone to displaying ultrasonographic alterations in the CL-DIPJ, not necessarily related to lameness (Table 1). The most commonly observed ultrasonographic findings were alterations in the echogenicity of the fibers (HO + HR) and thickening of the ligament (LA), accounting for 73.33% (88 out of 120) of the examined ligaments. Notably, the MCL exhibited alterations more frequently than the LCL. The lack of correlation with histological evaluations of the CLs was a limitation of this study. Nevertheless, the utilization of horses in authentic real-life conditions, including training, track usage, management, and housing, enhances the credibility and applicability of the study's findings. Additionally, the use of ultrasonography as a diagnostic tool for injuries in the CL-DIPJ is limited by individual variations in hoof shape, posing challenges in comparing images across different horses.

CONCLUSIONS

In conclusion, this study provided a characterization of the ultrasound examination of the CL-DIPJ, in the position A, on the forelimbs of non-lame Quarter Horses subjected to exercise routines. The findings demonstrate that even in non-lame horses, ultrasonographic alterations can be observed in position A of the CL-DIPJ. Notably, older horses are more showed more alterations, primarily marked by changes in fiber echogenicity and ligament thickening, with the MCL showing a higher frequency of involvement than the LCL.

While this research provides valuable insights into the ultrasonographic assessment of CL-DIPJ in clinically non-lame Quarter Horses, further investigations are important to establish correlations between ultrasonography and histological



Source: author's collection.

LA: Increase in the ligament area; HO: hypoechogenicity; CV: collapse of coronal vessels; HT: heterogeneity; HR: hyperechogenicity; (IB): irregularity of ligament borders.

Figure 3. Comparison of frequency of ultrasonographic alterations identified in the medial and lateral collateral ligament of the distal interphalangeal joint (CL-DIPJ) in non-lame Quarter Horses.

evaluations of the ligaments. Such correlations would significantly enhance the diagnostic capabilities for CL-DIPJ injuries in horses. Therefore, the findings of this study may be used as references in future research on the evaluation of Quarter Horses with CL-DIPJ injuries.

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