UNIVERSITI PUTRA MALAYSIA

ULTRASONOGRAPHIC STUDY ON CORRELATION OF TENDON SHEATH THICKNESS AND TENDON INJURY IN THOROUGHBREDS (*Equus caballus*)

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CERTIFICATION

It is hereby certified that we have read this project entitled "Ultrasonographic Study on Correlation of Tendon Thickness and Tendon Injury in Thoroughbreds (*Equus caballus*)" by Fairuz Hafizah Binti Md Yusoff and in our opinion it is satisfactory in terms of scope, quality, and presentation as partial fulfilment of the requirement for the course VPD 4999-Final Year Project.

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DEDICATION

To my dearest father, Md Yusoff Bin Musa and

my beloved mother, Fathilah Binti Abdul Razak

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I would first like to extend my sincerest gratitude towards my amazing supervisor, Dr Awang Hazmi Awang Junaidi, for all the guidance, support, and endless patience he had mustered for me throughout this entire experience. Having faced many setbacks, this journey was far from a smooth ride. My constant procrastination and delays were consistently met with such understanding yet stern grounding. It kept me in check and undeniably helped me grow as a student.

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Finally, to my family, words could not thank them enough for keeping me going throughout this journey. I sincerely hope the completion of this study, and possibly more in the future, would do their support justice. To my friends, those that had helped sustain my morale; Thanussha A/P Akilan, Zul ‘Ammar Fahmi, Sheikh Ahmad Razeeq, I sincerely thank them and wish upon them all the strength and success in the future.

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LIST OF ABBREVIATIONS / SYMBOLS

CSAL	Cross-sectional Area of Lesion
DDFT	Deep Digital Flexor Tendon
DACB	Digital Accessory Carpal Bone
DFTS	Digital Flexor Tendon Sheath
ECM	Extracellular Matrix
SDFT	Superficial Digital Flexor Tendon

ABSTRAK

Abstrak daripada kertas projek yang dikemukakan kepada Fakulti Perubatan Veterinar untuk memenuhi sebahagian daripada keperluan kursus
VPD 4999-Final Year Project

KAJIAN ULTRABUNYI TENTANG KORELASI KETEBALAN SARUNG TENDON DAN KECEDERAAN TENDON KUDA THOROUGHBRED

Disediakan oleh

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Kuda-kuda dalam industri perlumbaan sering diletakkan di bawah bebanan kerja fizikal yang berat, mendedahkan mereka kepada pelbagai kecederaan tisu lembut, terutamanya pada tendon dan sarung tendon. Pelan rawatan yang dirumus oleh pegawai veterinar bertujuan mengembalikan struktur ini kepada keadaan asal dan mendapat semula fungsi insrinsik. Kajian ini menilai keadaan Tendon Fleksor Digit Superfisial (SDFT) dan Sarung Tendon Fleksor Digit (DFTS) pada kuda Thoroughbred (*Equus caballus*) setelah mendapat rawatan dan intervensi veterinar pada peringkat akut dan kronik kecederaan SDFT. Sejumlah 10 ekor kuda Thoroughbred dewasa (n=5 kuda bagi setiap peringkat kecederaan) digunakan dalam kajian ini. Ultrabunyi pada tendon dan sarung tendon dilakukan pada petanda 5 cm, 15 cm dan 25 cm dari DACB. Ketebalan SDFT diukur melalui dua diameter melintang berseranjang, manakala ketebalan DFTS diukur pada aspek dorsal dan palmar. Pada kuda yang dirawat secara akut, ketebalan tisu-tisu pada kaki yang terjejas dan kaki kontralateral tindak menunjukkan perbezaan statistik kecuali pada sarung tendon di 15 cm DACB ($P<0.05$). Walau bagaimanapun, pada kuda yang dirawat secara kronik, perbezaan ketebalan yang ketara ($P<0.05$) antara kaki yang terjejas dan kaki kontralateral dilihat pada tendon dan juga sarung tendon pada 15 cm DACB. Korelasi linear yang positive ($P<0.05$) juga dilihat antara tendon dan sarung tendon pada kuda yang dirawat secara akut (15 cm DACB) dan secara kronik (5 cm dan 15 cm DACB). Penemuan ini berpotensi mendorong kajian baharu untuk mendapatkan ilmu lebih mendalam mengenai tisu-tisu lembut ini, kecederaan-kecederaannya, pelan rawatan serta kepentingannya dalam industri perlumbaan kuda ini.

Kata kunci: Kecederaan tendon, sarung tendon, Thoroughbred (*Equus caballus*), ultrabunyi

ABSTRACT

An abstract of the project paper presented to the Faculty of Veterinary Medicine in partial fulfilment of the course VPD 4999-Final Year Project.

ULTRASONOGRAPHIC STUDY ON CORRELATION OF TENDON SHEATH THICKNESS AND TENDON INJURY IN THOROUGHBREDS

By

Fairuz Hafizah Binti Md Yusoff

2023

Supervisor: Dr. Awang Hazmi Awang Junaidi

Co-Supervisor: Dr. Shri Kanth Kanaesalingam

Horses in the racing industry are consistently placed under heavy physical workloads which predisposes them to a variety of soft tissue injuries, such as to the tendons and tendon sheaths. Treatment plans constructed by veterinarians aim to return these structures to their original state and regain its intrinsic functionality. This study evaluates the Superficial Digital Flexor Tendon (SDFT) and Digital Flexor Tendon Sheath (DFTS) conditions post-treatment in Thoroughbreds (*Equus caballus*) given veterinary intervention at the acute and chronic stages of SDFT injury. A total of 10 adult Thoroughbreds (n=5/injury stage) were used in this study. Ultrasound of the tendons and tendon sheaths were performed at the 5 cm, 15 cm and 25 cm DACB landmarks. The SDFT thickness was measured as 2 perpendicular transverse diameters and the DFTS thickness was taken at the dorsal and palmar aspects. In acutely treated horses, the thickness of structures in the affected and contralateral limbs showed no statistical differences except for the tendon sheaths at 15 cm DACB ($P<0.05$). However, in chronically treated horses, significant differences in thickness ($P<0.05$) between the affected and contralateral limbs were seen in both the tendons and tendon sheaths at 15 cm DACB. Positive linear correlations ($P<0.05$) were also found between the affected tendons and tendon sheaths in acutely (15 cm DACB) and chronically (5 cm and 15 cm DACB) treated horses. These findings could prompt a new study to uncover knowledge regarding these soft tissues, its injuries and treatment plans as well as its significance in the equine racing industry.

Keywords: Tendon, tendon sheath, Thoroughbred (*Equus caballus*), ultrasonography

1.0 INTRODUCTION

Thoroughbreds are widely known in the equine racing industry for their agility and speed. These horses are developed and trained specifically for races from an age as young as 2 years as speculated by Logan and Nielsen (2021). The study states that Thoroughbreds put to race at as early as 2 years old had had more lifetime starts, wins, money earned and longevity in the industry as compared to those starting to race later in life. The consistent high intensity workloads combined with their heavy body weight predisposes them to a variety of soft tissue injuries. Tendons in Thoroughbreds, especially the SDFT, commonly suffer from strain-induced injuries as this breed works closest to its mechanical limits during training and competitions (O'Sullivan, 2007). Although the palmar and plantar aspect of the distal limbs include both the SDFT and the Deep Digital Flexor Tendons (DDFT), the SDFT acts as a more critical system to store and release energy during high-speed events. Given its crucial role, the SDFT is inclined to endure and accumulate more exercise-related microdamage which in turn leads to higher susceptibility of injury even from normal activities (Patterson-Kane et al., 2012). For this reason, this study is pivoted around the SDFT from its significance in the horses' locomotion.

Repetitive mechanical insults to the tendons stimulate fibroblast activation and microvessel modification which then leads to excessive scar formation. The abundant fibroblasts in these tissues and its production of extracellular matrix (ECM) promotes cell adhesion (Reinke & Sorg, 2012). Adhesions of the injured SDFT to adjacent structures, especially to the DFTS, would disrupt its normal gliding motion within the tendon sheath. Snedeker and Foolen (2017) had stated that these scar tissues also prevent the re-establishment of proper compartmentalisation of the tendon and tendon sheath. The combination of these pathologies would eventually result in both structures inferior to the intrinsic strength and elasticity of the original, adversely affecting the mechanics of locomotion in the limbs. As such, treatment of the tendon injuries alone would not be sufficient to return and maintain the performance of the horse. Its tendon sheaths should also be taken into consideration, and therefore this study strives to establish the significance of its involvement.

Such injuries are conventionally identified via lameness evaluations and external palpations. However, these methods have certain downsides to their usage as tendon injuries may not necessarily manifest clinically in the horses' gait and as aforementioned by Smith (2008), palpations serve for limited assessment of severity and diagnosis. Ultrasonography could reveal these pathologies before pain and swelling may be observed in later stages of injuries. Practitioners could also recognize atypical healing of chronic lesions, which are vulnerable sites of re-injury, with the use of ultrasonography. As such, this diagnostic tool would also prove invaluable in making vital decisions during rehabilitation (Smith and Schramme, 2003). Thus, this particular modality encourages prompt interventions to be made for management of tendon injuries, which is one of the premises to be conveyed with this study.

1.1 Objectives

To determine the correlation of tendon sheath thickness and tendon injury, and the significance of swift tendon injury management in Thoroughbreds (*Equus caballus*)

2.0 LITERATURE REVIEW

2.1 Thoroughbreds in the equine racing industry

The equine racing industry is one that generates a variety of controversial and opposing views due to the frequency of unfavourable incidents documented. It involves a rigid and often unforgiving routine of rigorous training for the animals. Given the nature of the practice, a predisposition exists for them to sustain a multitude of injuries, especially to the soft tissues, and often leads to failure to return to race. As reported by Ulke et al. (2020), the loss rates of Thoroughbreds from the racing industry due to soft tissue insults such as tendonitis stands tall at a staggering 25%. For the purpose of this study, more emphasis is placed on specifically the tendons of these horses from its sheer abundance of occurrences. For example, approximately 1,100 to 1,200 of the racehorses under the Japan Racing Association (JRA) suffer from inflammation of the tendons, or tendinitis (Oikawa and Kasashima, 2002). Further elaborated by Barrett and White (2008), racehorses are the most common sufferers of tendon injuries as they are required to trot at sharp paces for long periods of time. In addition, various literatures have also mentioned the propensity of certain breeds to develop certain types of injuries such as studied by Verkade et al. (2019). The study clearly speculated that Friesians suffer from fewer occurrences of SDFT injuries as compared to Standardbreds while significantly more suspensory ligament injuries as compared to Warmbloods. As such, tendon injuries were reported in Thoroughbreds with an incidence rate of 11 to 30 % with delayed resumption to work of up to 18 months and high rates of deletion from the racing industry (Patterson-Kane and Firth, 2009). A retrospective study on Thoroughbred racehorses done by Chan et al. (2006) also supports the immensity of these soft tissue injuries, especially the SDFT, whereby out of 447 lameness cases, 273 were diagnosed with superficial digital flexor tendinitis. These findings indicate the inclination of the SDFT to injury among Thoroughbreds in the racing industry.

2.2 The superficial digital flexor tendon and digital flexor tendon sheath

The flexor tendons present within the lower region of the limbs can be identified as the SDFT and DDFT. The SDFT is located palmaromedially to the DDFT and is semi-circular shaped which then thins in a dorsopalmar direction distally. It provides mechanical support to the metacarpophalangeal (MCP) and proximal interphalangeal joints during the stance phase and flexes them as well as the carpus joint during the swing phase (Patterson-Kane and Firth, 2009). As mentioned by Yamasaki et al. (2001), it is also a crucial weight-bearing structure for the horses during locomotion, providing effective transfer of kinetic energy converted from stored elastic energy. Additionally, it provides stability in movement via its extension, the manica flexoria, which is a ring of tissue that envelops around the DDFT. When comparing the SDFT to the DDFT, the former is more prone to suffering insults in racing Thoroughbreds. O'Sullivan (2007) posits that this is due to the spring-like role of the SDFT to store and transfer muscular energy, especially in high-paced events such as races. Such events place an extremely heavy demand on the SDFT, and these structures are then exerted to near the point of their mechanical limits. This allocates only a small safety margin for any other external factors to increase the loads borne by the tendons and thus leading to injury (O'Sullivan, 2007).

The DFTS is a structure extending from the distal metacarpal or metatarsal region down to the palmar or plantar aspect of the third phalanx. It encases the digital flexor tendons and contains synovial fluid for lubricated movement of its enveloped structures. The digital flexor tendons and the DFTS work in close proximity and immense interrelation. This causes the latter to be involved in any occurrences of its tendon injuries (Barrett and White, 2008). Inflammation of the tendon sheath is known as tenosynovitis, and it is a common condition overlooked in the field. It should be noteworthy to practitioners that the adhesions formed from trauma to these structures leads to significant changes in their inherent shape, position, and mechanism of function (Smith, 2008). These alterations undeniably manifest as changes in the horse performance and thus influences its longevity in the racing industry.

2.3 Tendon injury and its mechanism

Tendon fibres are longitudinally oriented with large subunits known as fascicles which are separated by the endotenon. The endotenon is composed of loose connective tissues with blood vessels, nerves, and lymphatics. The smaller subunits of the fascicles are the fibrils, in which the adult mature tendon, collagen accounts for 75% of its dry mass and consists predominantly of type I collagen (Patterson-Kane and Firth, 2009). Tenocytes are fibroblastic cells located within the fascicles and are responsible for turnover of the ECM and aids in the intercellular transfer of nutrients through the avascular region. As further detailed by Barrett and White (2008), changes of the tendon structures are normally occurring with the advancement of age and are inadvertently affected by its straining during exercise. The study deems that such training is necessary for the development and remodelling of strong and capable tendons, however such activities in excess for long durations would also pose adverse effects through repetitive microdamage. Tendon injury generally occurs from the cumulative effects of these exercise- and the aforementioned age-related microdamage as the structure is no longer capable to adapt to and overcome the stresses placed upon it. Patterson-Kane et al. (2012) have speculated that tenocytes consistently repair these damages to the tendon albeit at low rates under normal circumstances, as if not, all tendons in the body would rapidly lose its integrity and rupture. However, the tenocyte repair efficacy might eventually be impeded by multiple factors. Should the duration between each insult be too short, or the frequency of occurrences be too high, the breakdown of ECM would be excessive and thus overburden the anabolic repair mechanisms by the tenocytes and reduce the integrity of the tendon (Patterson-Kane and Firth, 2009).

The tendon centre is known to be more blood vessel-deficient in nature as vascularisation extends only up to the endotenon under normal circumstances (Patteson-Kane et al., 2012). As such, the propensity of the region to suffer from hypoxia during high demands in exercise is facilitated by this characteristic. Tendons in horses are assumed to be reliant on oxidative energy metabolism. This supports the proposition, however, yet to be proven, that it may face high oxygen tension levels during exercise and excess reactive oxygen species production such as hydrogen peroxide (H2O2) and superoxide anions upon cessation of exercise (Patterson-Kane and Firth, 2009). Another premise in various literature touches on the effects of exercise-induced hyperthermia from the minimal vascularization. Exercise undeniably generates heat, especially to the tendon centre, which bears the most concentrated forces of loading. As such, Yamasaki et al. (2001) posits that the cooling mechanism from active blood flow is insufficient in the tendon centre which leads to temperatures higher than acceptable. These conditions not only cumulatively damage the tendon fibres, but it also significantly hinders the survival of tenocytes as well.

2.4 Ultrasonography for tendon and tendon sheath injuries

Conventional methods for diagnosis of tendon injuries are based on history and the development of signs of inflammation, as evidenced by palpation. However, confirmation and assessment of severity as well as prognosis of the condition require additional modalities such as ultrasonography. Additionally, ultrasounds provide efficient follow-up examinations which facilitate management decisions throughout the rehabilitation phase (Smith, 2008). Practitioners could optimize both standard and angle contrast ultrasound techniques consisting of on- and off- beam angles to allow visualization of targeted structures. Injuries can then be identified and analysed by structures involved, the location as well as the extent and amount of the damage sustained (Werpy and Axiak, 2013). The principles upon ultrasonographic diagnosis include echogenicity, size, pattern, shape, position, margination and even vascularity, made possible with the Doppler modality.

SDFT injury could be assessed semi-objectively as suggested by Smith (2008), via multiple variables such as the cross-sectional area of lesion (CSAL), percentage and type of lesion within the tendon as well as the fibre alignment score (FAS). Werpy and Axiak (2013) had stated that there are multiple reliable findings indicating tendon injury such as enlargements, enthesopathies and hypoechogenecity. Similarly, evaluation of the digital sheath requires ultrasonographic views from the metacarpal or metatarsal region down to the palmar or plantar aspect of the foot. This structure presumably becomes more apparent upon injury due to effusion, a digression from its intrinsic nature of containing only small amounts of synovial fluid (Smith, 2008). With minimal alterations of the tendon sheaths, or under normal circumstances, the tendon sheath may be better visualised with improved angle contrast. As such, ultrasonography is an invaluable tool to diagnose these soft tissue injuries, provided baseline values, or controls, are available to differentiate normal individual characteristics and variations to disruptions and insults the intrinsic nature of the structures (Reis and Baccarin, 2010).

3.0 MATERIALS AND METHODS

3.1 Animal subject selection

Adult Thoroughbreds (*Equus caballus*) accommodated in Selangor Turf Club were subjected to selection according to specific criteria. The inclusion criteria were the history of injury to the SDFT and provision of treatment according to the turf club database. The exclusion criterion was the evidence of unsoundness of the limb contralateral to that of the affected tendon. These would either be the presence of lameness upon examination as done in Figure 1, or evidence of pain or disrupted tendon gliding motion within the tendon sheath upon palpation as seen in Figure 2. Only horses fulfilling these criteria were selected to acquire the minimum number of animal subjects (n=10). Individual demography such as name, Malaysian Racing Association (MRA) brand number, age, sex, weight, and height were tabulated. The chronicity of the injury at the point of treatment was also recorded.

3.2 Sedation and skin preparation

Detomidine hydrochloride (Ranvet's Calmant Injection, Australia) was injected intravenously as in Figure 3, at 0.01mg/kg to provide mild sedation and reduce swaying throughout the ultrasound evaluation. This was done with 23G hypodermic needles and 3ml syringes following disinfection with 70% ethanol. After sedation has taken effect, hair on the palmar aspect of both the affected and contralateral limbs were clipped from just distal of the DACB down to the fetlock joint. This was done using a razor blade and the clipped regions were later rinsed with tap water.

3.3 Ultrasonographic evaluation

Both the SDFT and DFTS were evaluated with a mobile ultrasonographic device (Honda HS-1600V, Honda Electronics Co., LTD., Japan) and an 8 to 10 MHz linear probe at three different Regions of Interest (ROI) set at approximately 5cm, 15cm and 25cm distal from the DACB, as seen in Figure 4, on both limbs. Each contralateral limb served as a referral in every subject animal. Both transverse and transverse oblique views were utilised.

3.3.1 Superficial Digital Flexor Tendon

A transverse view was utilised for this evaluation. The SDFT was assessed first in terms of its condition with regards to the injury faced. The cross-sectional area of the tendon and the lesion were acquired with measurement modalities of the ultrasound device as shown in Figure 5, 6 and 7. The areas were recorded in mm^2 and the percentage of CSAL was calculated according to the formula in Figure 1 (a). A CSAL of 0% to 15% was categorised as mild, 16% to 25% as moderate and anything above 25% was considered severe. Additionally, the location of the lesion is noted as either core, eccentric, peripheral or rather as enlargement of the tendon. Thickness of the SDFT was also recorded as two perpendicular transverse diameters in mm, ensuring to exclude the tendon sheath in the measurements.

3.3.2 Digital Flexor Tendon Sheath

A transverse oblique view was used for this evaluation. The thickness of the DFTS were taken at both the most dorsal and palmar aspects as in Figures 5, 6 and 7, and an average was calculated to represent the overall thickness as in Figure 8 (b).

3.4 Data tabulation and statistical analysis

All data were collected from the point of subject selection up to the ultrasonographic evaluation and presented as mean ± standard deviation (SD). Data tabulation was organized into subject demography, the SDFT and the DFTS to allow for a concurrent and more holistic analysis, especially in regard to the condition of the SDFT. These data were then analysed using the Statistical Package for Social Sciences (SPSS) (IBM Corp. Released 2019, IBM Statistics for Windows Version 26.0, Armonk, NY), specifically through the t-test and Pearson correlation test.

Fig. 1. Lameness examination via lunging to accentuate lameness when circled on hard surfaces (tar road)

Fig. 2. Palpation of the tendon gliding motion within tendon sheath of both the affected and contralateral limb

Fig. 3. Sedation with detomidine hydrochloride intravenously prior to skin preparation and ultrasonographic evaluation

Fig 4. Ultrasonographic evaluation of the tendon and tendon sheath at the 25cm DACB landmark using a linear probe

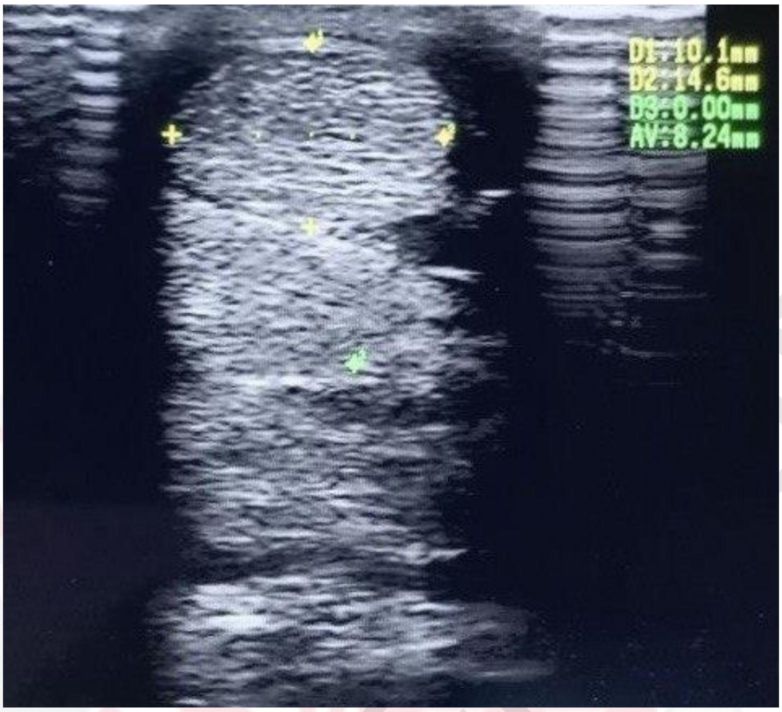

Fig. 5. Transverse ultrasonographic view showing the DFTS, SDFT, DDFT and suspensory ligament (palmar to dorsal aspect) at the 5 cm DACB landmark.

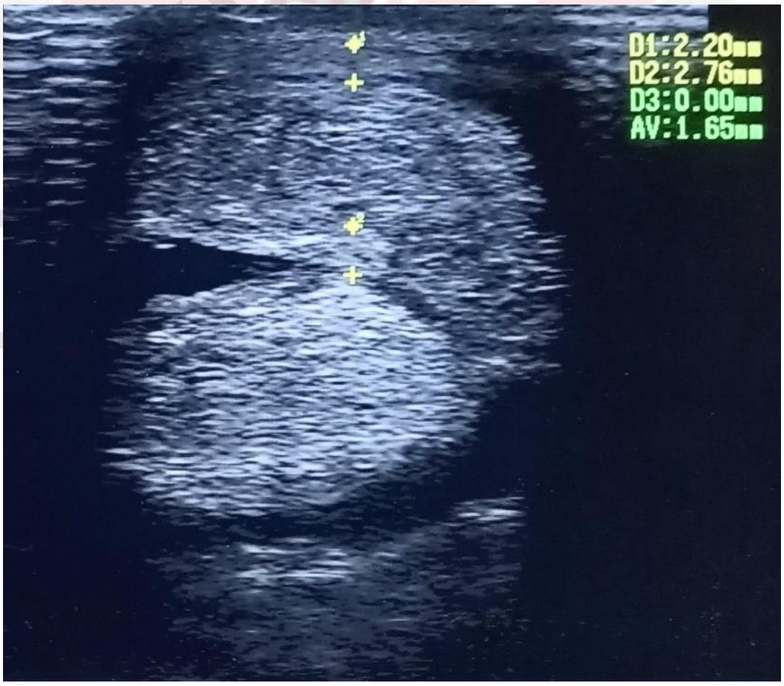

Fig. 6. Transverse ultrasonographic view showing the DFTS, SDFT, DDFT and suspensory ligament (palmar to dorsal aspect) at the 15 cm DACB landmark.

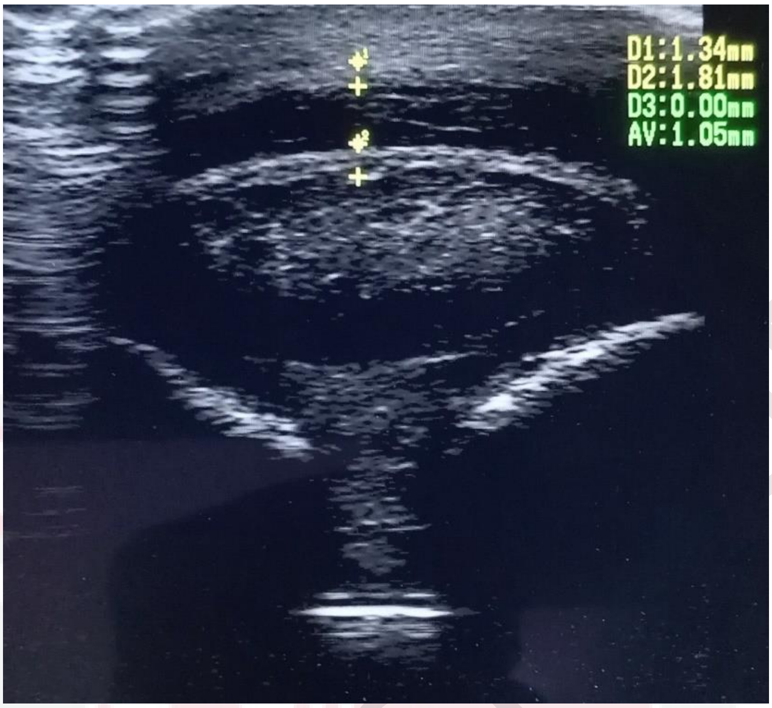

Fig. 7. Transverse ultrasonographic view showing the DFTS, SDFT, DDFT, suspensory ligament and apical aspect of the proximal sesamoid bones (palmar to dorsal aspect) at the 25 cm DACB landmark.

$$(a)\ \%\,CSAL = \frac{Area\ of\ lesion\ (mm^2)}{Area\ of\ tendon\ (mm^2)}\ X\ 100\%$$

$$(b)\ DFTS\ Thickness\ (mm) = \frac{Dorsal\ border\ (mm) + palmar\ or\ plantar\ border\ (mm)}{2}$$

Fig. 8. The formula for calculation of (a) the percentage of cross-sectional area of lesion (% CSAL) and (b) the thickness of the DFTS

4.0 RESULTS

4.1 Limbs affected with tendon injury

Among the 10 Thoroughbreds studied, 60% (n=6) of the horses had the left forelimb affected with tendon injury while only 40% (n=4) of the horses were affected on the right forelimb.

4.2 Tendon and tendon sheath thickness in acutely treated horses

Among acutely treated horses, the thickness of the SDFT in both the affected and contralateral limbs showed no statistically significant differences at the 5 cm (9.62 ± 0.5 and 8.17 ± 1.1, $p > 0.05$; $p = 0.27$), 15 cm (9.49 ± 0.4 and 8.57 ± 0.7, $p > 0.05$; $p = 0.36$) and 25 cm (11.79 ± 1.5 and 11.28 ± 0.9, $p > 0.05$; $p = 0.5$) DACB landmarks. However, the DFTS in the affected limbs were not statistically different from that in the contralateral limbs only at the 5 cm (0.74 ± 0.2 and 0.67 ± 0.3, $p > 0.05$; $p = 0.68$) and 25 cm (1.38 ± 0.2 and 0.95 ± 0.1, $p > 0.05$; $p = 0.86$) DACB landmarks. At 15 cm DACB, the tendon sheaths in the affected limbs (0.65 ± 0.4) and the contralateral limbs (0.75 ± 0.1) did show statistically significant differences ($p < 0.05$; $p = 0.004$). These results were tabulated as shown in Table 1.

4.3 Tendon and tendon sheath thickness in chronically treated horses

The thickness of the SDFT showed no statistically significant differences between those in the affected and the contralateral limbs at the 5 cm (9.96 ± 0.2 and 8.49 ± 0.4, $p > 0.05$; $p = 0.15$) and 25 cm (10.29 ± 1.6 and 13.01 ± 0.4, $p > 0.05$; $p = 0.18$) DACB landmarks. Similarly, the DFTS were not statistically different in the affected and contralateral limbs at 5 cm (0.91 ± .2 and 0.87 ± 0.2, $p > 0.05$; $p = 0.76$) and 25 cm (0.98 ± 0.3 and 0.79 ± 0.3,

$p > 0.05$; $p = 0.7$) DACB. Besides that, both the SDFT (7.36 ± 2.8 and 7.95 ± 1.1) and DFTS (0.79 ± 0.5 and 0.91 ± 0.1) showed statistically significant differences ($p < 0.05$; $p = 0.046$ for SDFT thickness, $p = 0.004$ for DFTS thickness) in the affected and contralateral limbs at 15 cm DACB. These results were tabulated as shown in Table 2.

4.4 Correlation of tendon and tendon sheath in acutely treated horses

In acutely treated horses, the SDFT and DFTS thickness showed varying degrees of correlation at each landmark. The 5 cm DACB landmark showed a negative linear correlation ($p > 0.05$; $r = -0.17$) while at 15 cm DACB, there was evidence of a strong positive linear correlation ($p < 0.05$; $r = 0.88$). On the other hand, there was an absolute absence of linear correlation ($p > 0.05$; $r = 0$) at the 25 cm DACB landmark. These findings were tabulated as shown in Table 3.

4.5 Correlation of tendon and tendon sheath in chronically treated horses

Chronically treated horses showed different correlations between SDFT and DFTS thickness at different landmarks as well. Both the 5 cm ($p < 0.05$; $r = 0.44$) and 15 cm ($p < 0.05$; $r = 0.97$) DACB landmarks showed positive linear correlations, whereby the degree of correlation was moderate at 5 cm DACB and strong at 15 cm DACB. Conversely, the 25 cm DACB landmark showed a negative linear correlation ($p > 0.05$; $r = -0.2$) instead. These findings were then similarly tabulated as shown in Table 3.

Table 1: Tendon and tendon sheath thickness in acutely treated horses.

Structure	Location (cm DACB)	Thickness (mm)	
		Affected Limb	Contralateral Limb
Tendon	5	9.62 ± 0.46	8.17 ± 1.09
	15	9.49 ± 0.43	8.57 ± 0.65
	25	11.79 ± 1.45	11.28 ± 0.93
Tendon Sheath	5	0.74 ± 0.19	0.67 ± 0.25
	15	0.65 ± 0.36 [a]	0.75 ± 0.08 [b]
	25	1.38 ± 0.22	0.95 ± 0.12

Data are mean ± SD, n=5

Data with different letters within the row are significantly different (p<0.05)

Table 2: Tendon and tendon sheath thickness in chronically treated horses.

Structure	Location (cm DACB)	Thickness (mm)	
		Affected Limb	Contralateral Limb
Tendon	5	9.96 ± 0.2	8.49 ± 0.43
	15	7.36 ± 2.82 [a]	7.95 ± 1.08 [b]
	25	10.29 ± 1.63	13.01 ± 0.39
Tendon Sheath	5	0.91 ± 0.16	0.87 ± 0.16
	15	0.79 ± 0.51 [a]	0.91 ± 0.13 [b]
	25	0.98 ± 0.31	0.79 ± 0.27

Data are mean ± SD, n=5

Data with different letters within the row are significantly different (p<0.05)

Table 3: Correlation of tendon and tendon sheath thickness.

	Location (cm DACB)	Tendon Sheath Thickness (mm)	
		Acute	Chronic
Tendon Thickness (mm)	5	-0.168	0.435 [a]
	15	0.883 [b]	0.969 [c]
	25	0	-0.199

Data shown are significance values

DACB = Digital Accessory Carpal Bone

Data with superscripts represent positive linear correlation

5.0 DISCUSSION

The results of this study can be discussed according to its three major findings; the limbs affected with tendon injury, the thickness of the tendon and tendon sheath in affected and contralateral limbs as well as the correlation between the tendon and tendon sheath.

It was found that 60% of the horses used for this study were affected with SDFT injury in the left forelimb and 40% were affected in the right forelimb. Despite the small sample size, this finding, to a certain extent, is in alignment with a study by Chan et al. (2006). This study reported that out of 447 horses, 268 horses with Superficial Digital Flexor tendonitis are found mostly affected in the left forelimb (50.7%) followed by the right forelimb (35.8%). Given that both these studies were conducted in Malaysia, a country practicing anti-clockwise racing, it can be speculated that this occurrence is in direct relation to the different levels of workload faced by the limbs on the racetrack, through which more burden is placed onto the lead or inside leg. This is further supported by an experiment conducted by Yamasaki et al. (2001) in which horses galloped in the right-handed direction showed a significantly higher temperature of the left forelimb SDFT as compared to that in the right forelimb. This is attributed by the role of the tendon as a storage of elastic muscular energy which is then converted to kinetic energy and approximately 5 to 10% of the residual energy being released as heat during exercise.

Upon tendon injury and treatment administration, it was mostly shown that the tendon and tendon sheath thickness in the affected and contralateral limb are not statistically different. This implies that these structures generally return to their original condition, more so with the promptness of intervention. As such, acutely treated horses showed only significant difference in thickness of the tendon sheath at 15 cm DACB. In chronically treated horses, similar findings were obtained but with the addition of tendon participation. This is suggestive of the success of prompt intervention to reduce scar tissue formation and surrounding tissue participation. However, in regions where affected structures are significantly different from its contralateral counterparts, the supposed unaffected structures are evidently thicker. In contrast to expectations by which injured structures would appear thicker from fibrosis and scar tissue formation, it is now suggested that the contralateral structures are sustaining early stages of injury instead. This is speculated to be from compensation as having one side affected with injury, the loading and risk of injury onto the contralateral side is increased (Smith, 2008).

Furthermore, this finding emphasizes the relatively higher occurrence of tendon injury at the 15 cm DACB landmark and its reduced capability to return to the original state. As reported by Patterson-Kane and Firth (2009), the cross-sectional area is the smallest at the mid-metacarpal region, approximately at the 15 cm DACB landmark. This is suggested to contribute to its propensity of sustaining injury. Tendon size is proven to directly affect its stiffness, a crucial characteristic in the storage and release of energy. A smaller CSA stands for weaker stiffness or lack of compliance in exercise and according to Young's Modulus, the stress faced by tendons can be quantified as force divided by CSA. Hence, the smaller the CSA, the more stress it would relatively sustain. Additionally, it is found that the mid-metacarpal region is preferentially loaded during exercise (Bradshaw, 2012). The asymmetrical loading to this structure then further encourages the occurrence of such injuries in this region.

Additionally, it is said that functional blood flow to the mid-metacarpal region is deficient during exercise and thus anabolism responses to microdamage would also be less efficient, leading to further insult. These factors contribute to the repetitive microtrauma, or the 'tendinosis cycle', whereby cellular repair is overwhelmed by catabolism of the tendon matrix (Patterson-Kane & Firth, 2009). The repetitive insult would then overburden the resident tenocytes from adequate cellular repair possibly due to insufficient time between episodes. Tenocyte activity in the SDFT is also reported to be low, even under normal conditions. Aligned with the reports from Bradshaw (2012), these factors combined would contribute to the higher rate of degeneration with age and repeated trauma to the region as compared to other levels within the SDFT.

This study also proves the interconnection of tendon injury, signified by the SDFT thickness, to its tendon sheath, the DFTS thickness. The strongest relationship between the tendon and tendon sheath would be the positive linear correlation at 15 cm DACB in both acutely and chronically treated horses, followed by the 5 cm DACB landmark in those chronically treated. This is also aligned with the findings as aforementioned regarding the relatively higher workloads sustained at the mid-metacarpal region of the SDFT. This strong positive correlation solidifies the suggestion that the tendons and tendon sheaths are highly associated, especially in sustaining injuries. Thoroughbreds in the racing industry place such high amounts of shearing stress and friction loads onto the SDFT due to the consistent repetitive motions on the racetracks as illustrated in Figure 2. The DFTS are more prone to share these insults with the tendons as compared to in occurrences of tensile stress during quick direction changes or jumping motions, and compressive stress when tendons are compressed when passing over bony protuberances (Roscher, n.d.). This further supports the importance of concurrent interventions for both the tendons and tendon sheaths when diagnosed with tendon injury. Failure to treat both structures would result in the accumulation of damage, progressive loss of its intrinsic function in locomotion and eventually recurrence. This could continue up to the point of deletion from the racing industry from loss of investment for intervention or irreversible catastrophic events.

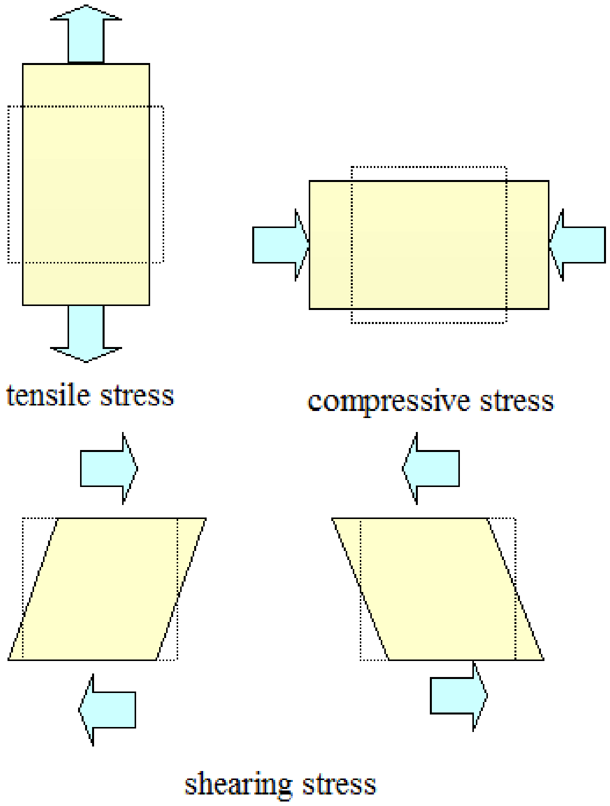

Fig. 9. An illustration of types of stresses placed on tendons. Tensile stress represents the forces placed on the tendon which elongates it along the axis of the applied force such as during jumping while compressive stress is that of which compresses the tendon instead such as when tendons pass through bony protuberances. Shearing stress is the combination of the former stresses during repetitive motions such as while racing on track.

6.0 CONCLUSION

This study has successfully established the presence of correlation between tendon sheath and tendon injuries as well as the increasing severity of the condition with delayed intervention, indicating the significant role of swift tendon injury management.

7.0 RECOMMENDATIONS

Sample size

A sample size should be numerically adequate to be generalised to the intended population as well as possess the potential to predict future occurrences. It should be sufficiently large to be of statistical significance yet not so large as to unethically sample more animals for a diminutive increase in result accuracy. A significantly larger sample size (n=150 to 323) is to be proposed for future studies of this nature as calculated according to the formula in Figure 10 using values for a confidence level of 95% whereby the error margin is 0.05 and the z score is 1.96. This is in accordance to the population proportion of SDFT injury prevalence as reported by Tamura et al. (2018) stating an 11-30% occurrence in racing Thoroughbreds specifically. In the case of this study, only a small number of horses (n=10) were involved due to the limited availability of cases aligned with the set criteria. In addition, time constraints had also limited the expansion of subject recruitment for this study as cases extending to only a few months prior were able to be tracked down.

Random sampling

A stratified random sampling method should be applied upon further studies conducted. This allows for elimination of various factors that could possibly hinder accurate results and better represent the targeted population. For example, subject animals could be categorised into different genders and age strata. Additionally, certain predilections or relationships among the strata could be studied as well.

Besides that, one could propose to select subject horses from different racecourse practices such as left-handed courses against the right-handed to prove predilection of soft tissue injuries to the lead or inside leg.

Control group

A proper control group should be recruited in future studies for a better comparison against the subjects. In similar cases as this study, a control group should consist of horses of the same gender and age group as well as having never been trained to race. The soft tissues would not be subjected to any hypertrophy or prior injuries of any kind and thus represent closest to its intrinsic conditions. Additionally, these horses should be thoroughly examined before conducting the study to ensure that these structures of interest are clinically sound.

Evaluation parameters

More parameters could be evaluated in future studies for a better understanding and more holistic view of the condition. One could propose to measure the CSAL, location and severity of tendon lesion and even tendon fibre alignments upon longitudinal ultrasonographic views. Certain parameters could be of higher value in data interpretations of the study. The increased amount of time invested for data collection and analysis would be worth in visualising the extent of injury and providing predictive values for future recurrences as well.

Unlimited population: $$n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

Finite population: $$n' = \frac{n}{1 + \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2 N}}$$

where
- **z** is the z score
- **ε** is the margin of error
- **N** is the population size
- **p̂** is the population proportion

Fig. 10 Formula to calculate sample size

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