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Effects of Pulsed Electromagnetic Field as a Supplement to Topical Dimethyl Sulfoxide and Controlled Exercise in Treatment of Equine SDF Tendonitis

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Abstract

BACKGROUND: Equine superficial digital flexor (SDF) tendonitis is a very common cause of lameness in athletic horses inducing long lameness and prolonged recovery. Multiple treatment protocols have been proposed for this injury none of which have been able to solve the problem completely. Therefore, an affordable, widely available, and non-invasive therapeutic protocol is sought in the horse industry.

OBJECTIVES: The present study aimed to compare the use of topical dimethyl sulfoxide (DMSO) with a combination of topical DMSO and pulsed electromagnetic field (PEMF).

METHODS: The subjects were divided into two groups of five polo ponies. The animals in the control group were treated by topical DMSO and controlled exercise, while the ponies in the experiment group received the same protocol plus PEMF on the injured tendon.

RESULTS: The ultrasonographic factors evaluated in the current study were mostly similar between the two groups except for fiber alignment and echogenicity. The latter variables were shown to have a slightly better improvement in the test group indicating the minimal positive effects of PEMF. In clinical evaluation, both groups were almost identical suggesting no impacts for PEMF.

CONCLUSIONS: In conclusion, applying PEMF using different protocols, such as more extended application at different frequencies is deemed necessary to elicit a favorable outcome of PEMF for the treatment of SDF tendonitis.

KEYWORDS: Dimethyl sulfoxide, Equine tendonitis, Lameness, Pulsed electromagnetic field

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Introduction

The equine superficial digital flexor tendon (SDFT) is a weight-bearing elastic structure sensitive to injury as it bears extreme forces under exercise (Thorpe *et al.*, 2010). The inflamemation of this structure, which is a common treatment challenge, is called SDF tendonitis causing long episodes of lameness (Tipton *et al.*, 2013). The pathophysiology of this injury is not fully understood yet; however, the assortments of treatment strategies are applied by equine practitioners worldwide. Although healing takes place in most patients, few are able to continue their athletic careers without the recurrence of injury (Patterson-Kane and Rich, 2014). The treatment strategies are basically divided into medical and surgical approaches (Dyson, 2004; Witte *et al.*, 2016). Among medical treatments are stall rest with progressive rehabilitation programs, using mesenchymal stem cells, implanting pla-telet concentrates, applying topical dimethyl sulfoxide (DMSO), magnet therapy, and plenty of other treatment methods (Gibson *et al.*, 1997; Geburek *et al.*, 2017; Russell *et al.*, 2016; Durgam *et al.*, 2016; Ortved, 2018). Tendon splitting and superior check desmotomy are assumed as two surgical treatments for this problem (Gibson *et al.*, 1997). It is obvious that practitioners and equestrians seek novel treatment strategies that are inexpensive, widely available, and most importantly minimally invasive.

DMSO, known as a water-soluble, osmotically active organic solvent, was discovered in the nineteenth century. The pain relief characteristics of this agent were first noted in the treatment of human arthritis (Elisia *et al.*, 2016). DMSO was approved to be used topically in equine medicine for acute traumatic swelling and inflammation (Santos *et al.*, 2003). DMSO is an inexpensive, readily available compound, which could be applied on a bowed tendon for pain control resulting in decreased inflammation and enhanced comfort in the patient. All these qualities attributed to DMSO make it an attractive choice for the medical management of SDF tendonitis.

Pulsed electromagnetic fields (PEMFs) are traditionally known to be effective in the management of musculoskeletal problems refractory to conventional medical treatments in humans and animals (Vavken *et al.*, 2009; Huegel *et al.*, 2018). Even though its mechanism of action is still partially elusive, PEMF has been successfully applied in the treatment of delayed or non-union fractures, osteoporosis, and failed arthrodesis (Trock *et al.*, 2003; Markov, 2007b; Tucker *et al.*, 2017). Moreover, PEMF was shown to be influential in the treatment of soft tissue injuries, such as tendon laceration, rotator cuff tendonitis in humans, and wounds in diabetic rats (Goudarzi, *et al.*, 2010; Greenough, 1996; Trock *et al.*, 2003). The PEMF is also known to improve vascularity, peripheral nerve regeneration, and angiogenesis (Trock *et al.*, 2003). The PEMF is applied to the affected body part as a customized body brace with a device generating electromagnetic field at a given frequency (Trock *et al.*, 2003).

The present study aimed to compare topical DMSO with a combination of topical DMSO plus electromagnetic field. Being non-invasive and relatively inexpensive, both DMSO and PEMF therapy are the existing options for the treatment of SDF tendonitis in the horse. Therefore, the authors tried to find out whether PEMF can be an effective supplement to topical DMSO in the treatment of an extremely common cause of lameness in the horse.

Materials and Methods

Subjects

Ten adult athletic horses of polo sport already diagnosed with SDF tendonitis by practitioners were chosen for this study. The horses aged 4-18 years with a mean age of 10 years and weighed approximately 350-450 kg. They were kept in individual stalls for the whole period of study with free access to water and were fed a balanced ratio consisting of concentrate and alfalfa hay (Dehghan *et al.*, 2007). During the study, the horses were only hand walked for 30 min daily and were not ridden.

Diagnosis

The SDF tendonitis was suspected primarily by observing the bowed tendon. Afterwards, the injury was confirmed ultrasonographically and the core lesions were identified in tendons (Dyson, 2004).

Ultrasonography

In ultrasonographic evaluation, three factors of fiber alignment, echogenicity, and core lesion to cross-sectional area (CSA) ratio (CSA of the core lesion divided by the CSA of the SDFT at maximum injury zone) were measured at the maximum injury zone (MIZ). The MIZ was located at the first ultrasonographic study and its distance from the accessory carpal bone was measured and recorded for each horse (Dehghan *et al.*, 2007).

The ultrasonographic evaluation was performed using a Sonosite Micromaxx Ultrasound Machine with a 10-13 MHz transducer. Each horse was sedated with 15 mg of acepromazine maleate prior to examination. The palmar surface of the affected limb was clipped, washed with water, and cleansed with alcohol before applying the coupling gel to be prepared for the examination. Factors studied in the ultrasonographic exam were measured and recorded at the MIZ (Dehghan *et al.*, 2007).

Fiber alignment was measured based on a scale of 0-3 in which 0, 1, 2, and 3 were 76%-100%, 51%-75%, 26%-50%, and 0%-25% of fibers parallel, respectively (Rantanen *et al.*, 2011). Echogenicity was defined according to a scale of 0-3, in which 0 is normal or near-normal echogenicity, 1 represents that 25%-50% of the area has lost echogenicity, 2 refers to 50% echoic and 50% anechoic areas, and 3 means mostly to completely anechoic (Rantanen *et al.*, 2011). The core lesion to CSA ratio was calculated by dividing the surface area of the core lesion by the surface area of the tendon at the MIZ (Dehghan *et al.*, 2007; Dyson, 2004). All the sonographic evaluations were carried out on days 1, 21, and 60.

Clinical Evaluation

Horses were clinically evaluated using two factors of lameness and the combination of pain, swelling, and heat on the affected area by a Visual Analogue Scale (VAS). Lameness was assessed on a scale of 0-5 as suggested by the American Association of Equine Practitioners (0=sound and 5=nonweight-bearing) and VAS was determined as 0=absent swelling and response to touch and 10=severe swelling and response to touch. Clinical evaluations were carried out on days 1, 21, and 60.

Experimental Design

The ten horses were blindly allocated to two groups with five subjects in each group. In addition to stall rest and daily controlled hand walk, the first group received 10 ml of topical DMSO gel (90% DMSO supplied by TULSA, OK 74116) on the bowed tendon rubbed for 5 min. As a common practice among practitioners in Iran, DMSO gel was carried on for four successive days.

The second group received DMSO treatment identical to the first group plus magnet therapy as follows: horses in the magnet group received a PEMF of 600 Gauss at a frequency of 50 Hz on their affected metacarpal region as episodes of 60 min daily continued for seven days (Alrashid, 2011; Rantanen *et al.*, 2011). Moreover, it should be mentioned that the inclusion of a control group (affected horses receiving no treatment) was both unethical and unfeasible as all the affected horses included in this study were clinical cases with owners expecting proper treatment.

Customized Magnet

For the treatment of the magnet group, a customized electromagnet capable of producing 600 Gauss of PEMF at a frequency of 50 Hz was engineered and devised (Hart, 2018; Pathak, 2016). The piece that applied PEMF to the metacarpal region consisted of a coil placed inside the pocket of a leg wrap. In addition to producing a magnetic field of 600 Gauss, several criteria needed to be considered, including:

1. Capability of producing a high magnetic field with a variation of lower than 10% in layers, which penetrates up to 1 cm below the skin in the injured tendon area.

2. Capability of producing a magnetic field in a length of 7 cm, which is proved to be sufficient to cover the biggest core lesions.

3. The part applied to the metacarpal region of the horse does not weigh more than 1 kg.

4. Not generating unacceptably high temperatures that lead to thermal damage to the animal.

5. Applying alternating current (AC) magnetic field.

Parameters that should be taken into consideration for this structure are the radius and height of the coil cylinder, number of turns, current, and core material. According to condition number 2, the coil needs to be finite. Therefore, full-wave simulations using HFSS software (Ansys) were used. The system was designed to apply two parameters, namely the height and radius of the cylinder. Consequently, we tried optimization procedures on the radius value to reduce the relative portion of the magnetic field around the coil (1 cm away from the surface of the coil) to field magnitude at the central point. Two juxtaposed coils, each of which producing 300 Gauss, were designed using cast iron as cores.

Following conducting some experiments to calculate the permeability of cast iron core, a cylinder 18 mm in radius and 6 cm in length was utilized covered in 24000 Ampere-turns per meter. All the measurements were completed by a Hall-effect sensor named UGN3503UA being capable of measuring magnetic fields up to 900 Gauss. In order to observe condition number 4, all the wires were used from the suitable ratings to be able to tolerate the related currents while not producing excessive heat. All our design sections were devised to omit the need for other electronic devices except for a transformer with suitable ratios.

Statistical Analysis

First, arcsine transformation was performed for the data associated with lesion percentage (CSA of the core lesion divided by the CSA of the tendon at MIZ) to be analyzed as continuous data. All data were analyzed using the MIXED procedure, including RANDOM and REPEATED statements in the model to specify the covariation between and within groups, respectively. In addition, the LSM-EANS statement was utilized for multiple comparisons. All analyses were carried out by Statistical Analysis System (SAS) software version 9.4 (SAS Institute Inc., NC, USA). Data are presented as mean±SEM. P-value≤0.05 and 0.05<P-value<0.1 were considered as statistically significant and tending to significant, respectively.

Results

Lameness

As can be seen in Figure 1, treatment and treatment×time interaction did not influence lameness degree (P>0.05). However, in both groups, the degree of lameness subsided continuously throughout the study (P<0.01).

VAS

We found that treatment and treatment×time interaction did not affect VAS (P>0.05). On the other hand, VAD was influenced by time and declined during days 0-21 and 21-60 in both groups (P<0.01) (Figure 2).

Lesion Percentage

According to Figure 3 lesion percentage was not affected by treatment×time interaction (P>0.05). Regardless of timepoints, lesion percentage was higher in the DMSO gel group compared with the DMSO gel magnet group

(P=0.038). In addition, irrespective of experimental groups, the size of the lesion constantly dwindled over time ($P \leq 0.05$).

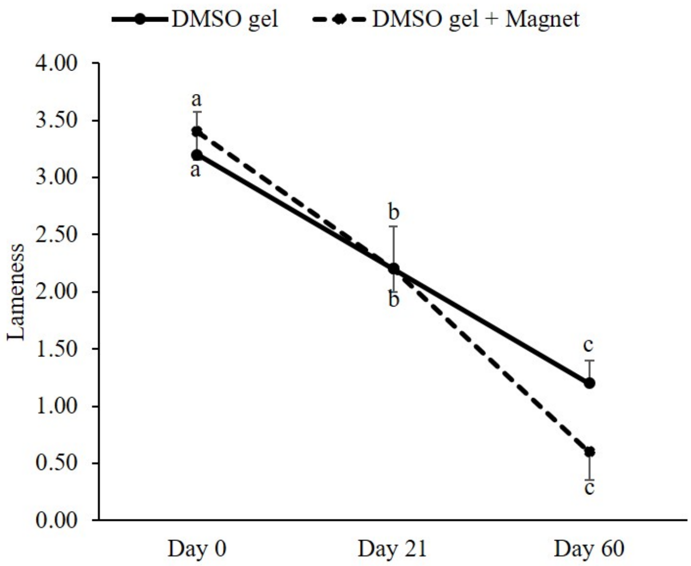

Figure 1. Lameness degree in DMSO and DMSO + Magnet groups on days 0, 21 and 60. Data are presented as mean ± SEM.

[abc]Various letters indicate significant difference among different timepoints within each experimental group ($P<0.05$).

Lameness was assessed on a scale of 0 to 5 as suggested by the American Association of Equine Practitioners (0=sound and 5=non-weight bearing)

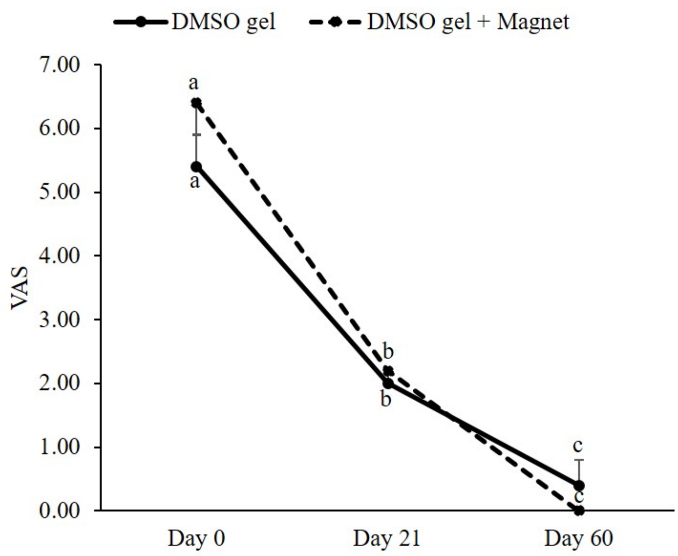

Figure 2. VAS in DMSO and DMSO + Magnet groups on days 0, 21 and 60. Data are presented as mean ± SEM.

[abc]Various letters indicate significant difference among different timepoints within each experimental group ($P<0.05$).

VAS was determined as 0=absent swelling and response to touch and 10=severe swelling and response to touch.

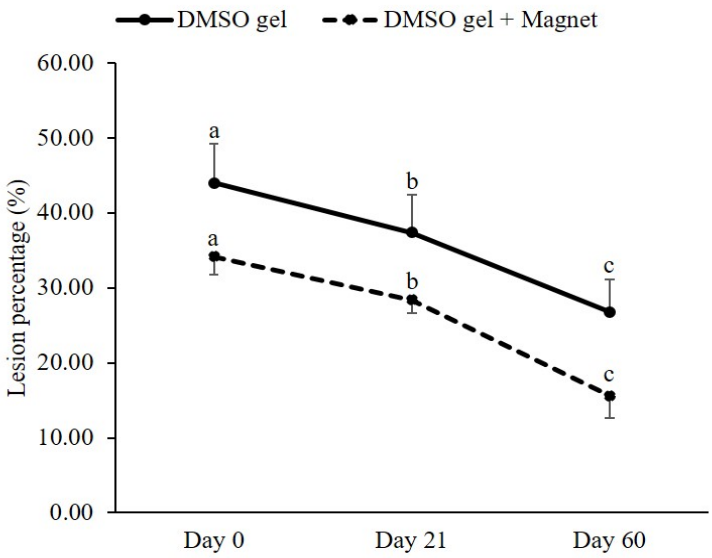

Figure 3. Percentage of lesion in DMSO and DMSO + Magnet groups on days 0, 21 and 60. Data are presented as mean ± SEM.

[abc]Various letters indicate significant difference among different timepoints within each experimental group (P<0.05). Lesion percentage refers to the surface area of the core lesion divided by the surface area of the tendon at the MIZ.

Fiber Alignment

In the DMSO gel group, the fiber alignment score did not change between days 0 and 21, while was lower on day 60 than both days 0 and 21 (P≤0.05). In the DMSO gel+magnet group, the fiber alignment score was lower on days 21 and 60, compared to day 0 (P<0.01). However, the latter variable did not alter significantly after day 21 (P>0.05). Therefore, the fiber alignment score did not differ between the two groups on days 0 and 60. On the other hand, it was lower in the DMSO gel+magnet group than the DMSO gel group on day 21 (P=0.015) (Figure 4).

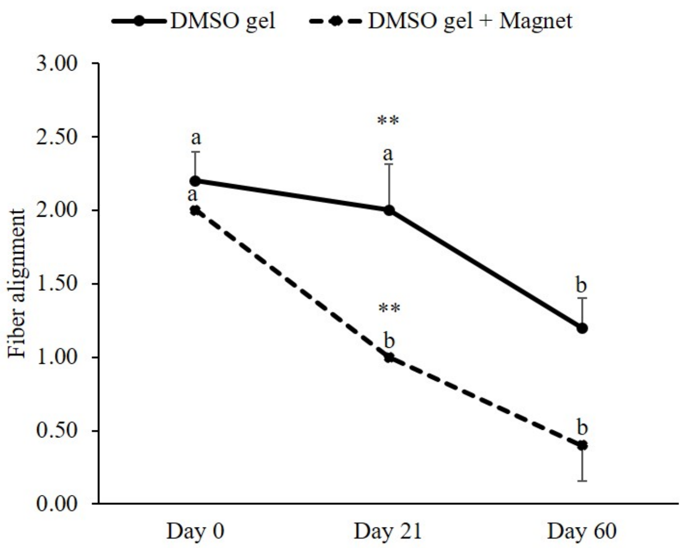

Figure 4. Fiber alignment in DMSO and DMSO + Magnet groups on days 0, 21 and 60. Data are presented as mean ± SEM.

[ab]Various letters indicate significant difference among different timepoints within each experimental group (P<0.05). Asterisks (**) indicate significant difference between two experimental groups at the specified timepoint (P<0.05).

Fiber alignment was measured on a scale of 0 to 3 in which 0=76-100% of fibers are parallel, 1= 51-75% of fibers are parallel, 2=26-50% of fibers are parallel, and 3=0-25% of fibers are parallel.

Echogenicity

In the DMSO gel group, the echogenicity score did not have a significant difference between days 0 and 21 and days 21 and 60 ($P>0.05$). However, echogenicity was lower on day 60 than on day 0 ($P=0.007$). In the DMSO gel+magnet group, the echogenicity score decreased constantly from day 0 to 60 ($P<0.05$). Accordingly, the echogenicity score did not differ between the two groups on days 0 and 21 ($P>0.05$), while it tended to be lower in the DMSO gel+magnet group than the DMSO gel group on day 60 ($P=0.057$) (Figure 5).

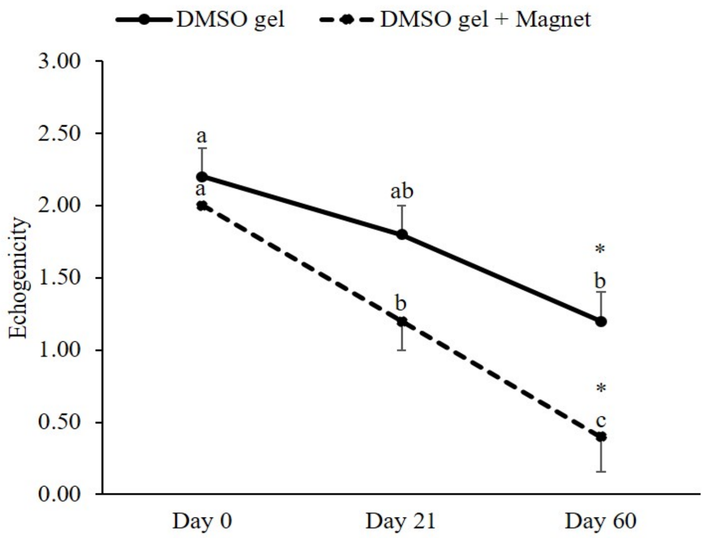

Figure 5. Echogenicity in DMSO and DMSO + Magnet groups on days 0, 21 and 60. Data are presented as mean ± SEM.
[abc]Various letters indicate significant difference among different timepoints within each experimental group ($P<0.05$). Asterisks (*) indicate significant difference between two experimental groups at the specified timepoint ($0.05<P<0.10$).
Echogenicity was defined on a scale of 0 to 3, in which 0=normal or near normal echogenicity, 1=25-50% of the area has lost echogenicity, 2=the area is 50% echoic and 50% anechoic

Discussion

Factors assessed in the present study fall into two categories of clinical and ultrasonographic findings. In the case of clinical factors, lameness, VAS of swelling and pain, and touch response were assessed.

Lameness score deescalated during the study constantly and no significant difference was observed between the two groups on the three timepoints. This alleviation in lameness was predictable and could be attributed to the combination of therapies (stall rest, limited exercise, and medical and magnet therapy) administered to the affected horses. This decrease in the lameness score as a result of different therapeutic approaches has also been reported by some other researchers (Dehghan *et al.*, 2007; Gibson *et al.*, 1997; Firth *et al.*, 2006; Davidson, 2016).

Furthermore, the VAS developed to represent pain and swelling underwent a constant decline with no significant difference between the two groups on the three timepoints. This finding has also been supported by other authors applying conservative therapy to SDF tendonitis. Gibson *et al.* (1997) reported alleviated affected tendons using medical therapy. These results are also close to the findings of Dehghan *et al.* (2007) and Alzola and Freeman (2019).

The constant improvement of clinical factors throughout the study without significant differences between the DMSO gel and DMSO gel+magnet groups on the three timepoints indicates that the effect of magnet was not significant. This finding is similar to other studies reporting no significant impact for PEMF. For instance, Greenough (1996) revealed that the use of PEMF did not influence the healing of injured tendons in the rabbit. Huegel *et al.*

(2020) showed no specific positive effects on the healing of the Achilles tendon in the rat. Contrary to our findings, Trock *et al.* (2003) reported the efficacy of utilizing magnets in the alleviation of pain caused by osteoarthritis in human patients. Goudarzi *et al.* (2010) observed positive effects for PEMF on wound healing in rats. Osti *et al.* (2015) claimed that PEMF improved post-operative pain and diminished the need for analgesics after rotator cuff repair surgery. Moreover, Rosso *et al.* (2015) found positive in vitro impacts for PEMF in tendon regeneration. Li *et al.* (2015) demonstrated PEMF to be beneficial in wound healing through inducing angiogenesis. The positive effect of PEMF on tendon injuries can be elicited by the application of more extended protocols of PEMF at different frequencies.

One ultrasonographic factor studied in our work was lesion percentage (the CSA of the core lesion divided by the CSA of the tendon at MIZ), which dwindled during the study with no significant difference between the two groups. Furthermore, the echogenicity score of tendon decreased (indicative of healing taking place) during the study in both groups and the difference between the two groups was not significant on day 21. However, this factor tended to be significant on day 60 with the DMSO gel+magnet group showing a mild improvement.

In addition, the fiber alignment score declined during 60 days and the difference between the two groups was significant on day 21 in favor of the DMSO gel+magnet group. The enhancement of ultrasonographic variables during treatment has similarly been reported by other researchers, such as Dehghan *et al.* (2007) and Ashraf Abdulrazaq *et al.* (2018).

The significant difference in fiber alignment score between the two groups on day 21 suggests the efficacy of applying PEMF for treating equine tendonitis in at least one sonographic factor. Ashraf Abdulrazaq *et al.* (2018) had similar results regarding improved fiber alignment in the tendons of donkeys treated with PEMF. Researches either supporting or opposing the efficacy of magnetic field in the treatment of soft and hard tissues are numerous and no consensus regarding this matter is yet reached.

Conclusion

In conclusion, using PEMF in the treatment of equine tendonitis did not lead to clinically significant improvement in affected horses. However, some ultrasonographic factors enhanced significantly. Therefore, the efficacy of PEMF in the improvement of injured SDF cannot be ruled out. Furthermore, it could be concluded that further studies are required applying more extended courses of magnet therapy at different frequencies on a bigger population of affected horses to elucidate the impacts of electromagnetic fields on the treatment of equine tendonitis.

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Conflict of Interest

The authors declared no conflict of interest.

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اثرات میدان مغناطیسی نبض‌دار به‌عنوان مکملی بر دی‌متیل سولفوکساید موضعی و فعالیت بدنی کنترل‌شده در درمان التهاب تاندون خم‌کننده سطحی انگشت در اسب

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زمینه مطالعه: التهاب تاندون خم‌کننده سطحی انگشت در اسب یک علت بسیار شایع ایجاد لنگش در اسب‌هایی با کاربرد ورزشی است که باعث بروز لنگش و دوره بهبود طولانی مدت می‌گردد. برای درمان این عارضه پروتوکل‌های درمانی متعددی پیشنهاد شده است که هیچ‌یک منجر به رفع کامل این مشکل نشده‌اند. ازاین‌رو ابداع یک پروتکل درمانی ارزان، دردسترس و غیر تهاجمی در صنعت اسب مورد نیاز است.

هدف: مطالعه حاضر با هدف مقایسه استفاده از دی‌متیل سولفوکساید موضعی در یک گروه با استفاده از دی‌متیل‌سولفوکساید موضعی به همراه میدان مغناطیسی نبض دار در گروه دیگری از اسب‌ها در درمان التهاب تاندون انجام شده است.

روش کار: در این مطالعه دو گروه از اسب‌های چوگان مبتلا به التهاب تاندون خم‌کننده سطحی انگشت متشکل از پنج اسب در هر گروه انتخاب شدند و اسب‌های گروه کنترل به‌وسیلهٔ دی‌متیل‌سولفوکساید موضعی و ورزش کنترل‌شده تحت درمان قرار گرفتند. اسب‌های گروه آزمایش علاوه بر درمانی عینا مشابه با گروه کنترل، به‌وسیله اعمال میدان مغناطیسی نبض‌دار روی تاندون مبتلا هم درمان قرار شدند.

نتایج: فاکتورهای سونوگرافی مورد مقایسه بین دو گروه تا حد زیادی مشابه بود به‌جز دو فاکتور امتداد فیبرها و اکوژنیسیته که در گروه آزمایش بهبود بیشتری نسبت به گروه کنترل نشان می‌داد. این یافته‌ها از اثرات مثبت جزیی میدان مغناطیسی در التیام آسیب تاندون حکایت دارد. در فاکتورهای بالینی مورد ارزیابی اختلاف معنی‌داری بین دو گروه مشهود نبود.

نتیجه گیری نهایی: برای حصول نتیجه مطلوب‌تر در استفاده از میدان مغناطیسی نبض‌دار باید پروتکل‌های متنوع دیگری اعم از درمان‌های طولانی مدت‌تر با فرکانس های متنوعی آزمایش شوند.

واژه‌های کلیدی: تاندونیت اسب، دی‌متیل‌سولفوکساید، لنگش، میدان مغناطیسی نبض‌دار

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