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Evaluating the effect of pulsed electromagnetic field (PEMF) therapy on sole depth of the equine hoof: A pilot study

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ABSTRACT

Thin soles and poor palmar angle are common issues among performance horses. Pulse electromagnetic field (PEMF) therapy is frequently used in veterinary medicine for the treatment of bone fractures/bruising, inflammation, and repair, but no studies have been performed to validate this therapy in the equine hoof. Ten adult horses of mixed breed were enrolled in the study and placed into either the PEMF (n=6) or control (n=4) group. The PEMF group received PEMF application (22 Hz) directly to both hooves of the forelimb for 10 minutes on M/W/F, and this treatment protocol persisted for 30 days. Control animals received no intervention. Radiography was performed the day prior to treatment onset in addition to 30 days after treatment onset. Sole depth and palmar angle were evaluated. Statistics were performed utilizing SAS® 9.4, where the effect of treatment was evaluated using a Welch's T-test. Significance was set to $P \leq 0.05$ with trends noted at $P \leq 0.1$. A trend towards an increase in sole depth beneath the distal processes of the right foot (P=0.07) was noted in PEMF-treated animals. No improvement was observed in the sole depth of the apex of the proximal phalanx for either hoof (P=0.65) nor palmar angles (P=0.24). These results suggest that PEMF therapy had mild benefit to the sole depth of the equine hoof, with a trend towards an improvement in the distal processes of a single hoof. Further research targeting PEMF therapy is justified, potentially offer the equine industry a non-invasive option to assist the equine struggling with thin soles.

Introduction

The structure of the hoof impacts overall soundness of the equine athlete, and this includes medial balance, angle of the third proximal phalynx (P3), and both sole and wall depth. The sole of the equine hoof occupies the region between the wall and the frog on the palmar surface of the hoof. This is considered a protective layer to the internal structures of the hoof, including P3. Sole depth can be impacted by a variety of things, including breed, nutrition, surface exposure to the hoof, and injury [1,2]. The distance from the distal apex of P3 to the ground surface can be measured by lateromedial radiography [3,4], with an ideal measurement of 15–18 mm [5]. An increase in the sole depth at the proximal processes relative to the apex of the P3 would indicate a positive impact on the palmar angle of P3, which is ideally between 3 and 5° relative to the ground [6]. Any deviation from these ideals can then predispose the horse to bruising, bone fracture, and even laminitis [7].

A variety of therapies are available to mitigate the impact of inadequate sole depth, although few have been found to improve the internal structures. This includes systemic non-steroidal anti-inflammatory drugs (NSAID), intra-articular injections of P3, and podiatric interventions which are both costly and limited in their availability [8]. Pulse electromagnetic field therapy (PEMF) is a non-invasive therapeutic modality that is routinely used in human medicine for clinical indications including bone healing, wound healing, osteoarthritis, and inflammation [9]. Anecdotally, PEMF is utilized within equine sports medicine practices for reducing inflammation associated with osteoarthritis, muscle rehabilitation pre- and post- exercise, and in the treatment of both wounds and hoof-related defects, including less than desirable sole depth, as it is believed to decrease inflammation and improve tissue and bone repair. Unfortunately, peer-reviewed data is limited on the positive impacts of PEMF therapy in equine veterinary medicine [10–12]. Additionally, a variety of PEMF modalities exist, causing user confusion and interfering with the repeatability of findings. Therefore, the objective of this study was to assess the impact of PEMF

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therapy on sole depth. Our hypothesis was that repeated, low-frequency PEMF therapy would increase the sole depth of the equine hoof.

Materials and methods

Horse selection

All animal procedures were completed in accordance with the Institutional Animal Care and Use Committee (IACUC) of Midway University under the guidelines of the approved protocol 2023–101. Horse (*Equus caballus*) used in this study were of mixed breed, ranging from ages 4–15 and weighing between 450 and 600 kg. Demographic data on enrolled animals is provided in Table 1. Horses were maintained on the same property and remained in their regular exercise and housing schedule. Exercise varied dependent on horse enrolled, but all were exercised five times a week for an average time of 30 minutes.

PEMF treatment

All animals were clinically sound at the onset of the study, and no podiatric work was performed during the confines of the study. Clinical soundness was assessed as baseline soundness by a licensed veterinarian. A power analysis indicated that approximately 5 horses would be needed in the treatment group to detect an improvement on sole depth based on the findings from previous studies with 80 % power and α=0.05. Prior to study onset, horses underwent standard hoof trimming, and lateromedial radiographs were taken to establish pre-treatment values the day prior to treatment onset. Animals were then randomly assigned to groups of either PEMF treatment (n=6) or control (n=4). Horses within the treatment group received PEMF treatment Monday/Wednesday/Friday for a total of 30 days, and the study was performed during the winter of the Northern Hemisphere. PEMF treatment consisted of placing both front hooves upon the Magnawave® Large Pet Mat which was then attached to the Magnawave® Julian Duo set at 22 Hz for 10 min. Treatment was performed in the mornings to control for time of day or interval between treatment sessions. Upon cessation of the 30 days of treatment, lateromedial radiography was again performed immediately following the final treatment session.

Radiographic/photographic method

All radiographic examinations were performed by a single investigator who was blinded to treatment (D.A.) as previously described by Butler *et al.* [13]. In brief, lateromedial radiographic views were obtained of both front feet with the hooves placed on a block 20 cm high and the x-ray beam centered approximately 1 cm distal to the coronet, and midway between the distal and palmar aspects of the hoof. Horses stood on a horizontal level surface, bearing weight evenly on all limbs. Film focal distance (FFD) was set to 65 cm, while object film distance (OFD) was assessed by positioning the panel directly against the medial aspect of the anatomy. Digital radiographs were performed on both the left and right foot, and the individual hooves were analyzed as separate variables.

Image analysis

All digital radiographs were assessed by a single investigator who was blinded to treatment (C.F.). This was performed using image analysis software (RocketPACS) and the following variables were measured: i) the angle of the solar border of the distal phalynx (P3) to the horizontal (palmar angle), ii) the depth of the sole from the apex of the P3 to the block (toe), and iii) the depth of the sole from the apex of the digital cushions to the block (heel). These measurements are described in Fig. 1. Additionally, each animal was categorized for poor sole depth (<12 mm), poor palmar angle (<3°) and hoof asymmetry, which was determined as having a singular hoof which met these criteria while the other was classified as having appropriate industry standards for hoof quality, and these findings are described in Table 1.

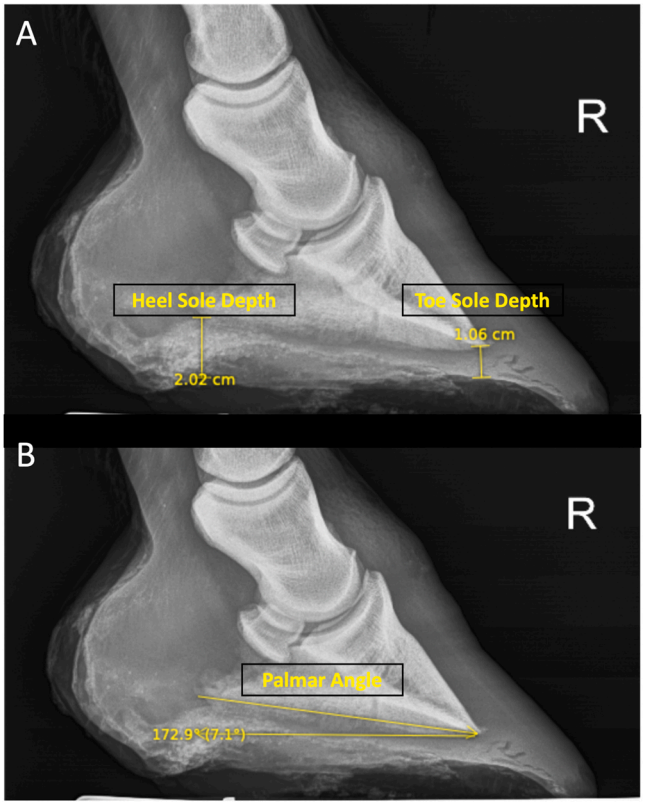


Fig. 1. Representative image to identify where measurements for sole depth of the toe of the P3, the heel of the P3, and the palmar angle of the P3.

Table 1
Classification of animals prior to PEMF treatment.

Treatment Group	Animal ID	Breed	Weight (kgs)	Age	Sex	Hoof Asymmetry (Y/N)	Poor Sole Depth (<12 mm) (Y/N)	Poor Palmar Angle (<3°) (Y/N)
Control	D1	TB	476	6	G	Y	Y	Y
	N1	TB	600	14	G	N	N	N
	F1	WB	521	9	M	N	N	N
	J1	TB	544	4	G	Y	N	Y
PEMF	M1	TB	521	15	G	Y	Y	Y
	J2	TB	476	5	G	Y	N	Y
	J3	TB	589	11	G	N	N	N
	T1	WB	600	14	M	N	N	N
	S1	TB	498	7	M	N	Y	Y
	J4	TB	476	6	G	Y	Y	Y

Statistical analysis

Data were analyzed using SAS® 9.4 (SAS Institute Inc., Cary, NC, USA). Data was assessed for normality using a Shapiro-Wilkes test and equal variances with a Bartlett's test. Individual post-treatment measurements were normalized to pre-treatment values to standardize the effect of treatment by animal. This data was analyzed utilizing a Welch's T-test for unequal variances. Significance set to $P \leq 0.05$ with statistical trends $P \leq 0.1$. Data are presented as box plots with the median and interquartile ranges shown.

Results

No significant differences were noted in the pre-treatment measurements when comparing control to PEMF treated animals of sole depth noted under the apex of the P3 (12.4±0.9 vs. 13.6±0.9 mm respectively; P=0.34) or depth of the digital cushion from the proximal processes when comparing control to PEMF treated animals (21.6±2.2 vs 19.2±1.4 mm respectively; P=0.64) (Fig. 2).

Sole depth was measured in two locations, including the apex of the P3 to the solar surface of the hoof (toe), in addition to the digital cushion beneath the palmar processes of the P3 (heel). Data was transformed to the change in sole depth noted within horse to control for animal variability in hoof quality, as pre-treatment sole depth ranged immensely between animals when assessing the sole depth under the apex of the P3 (8–19 mm) in addition to the depth of digital cushion (13–33 mm).

When assessing the impact of PEMF therapy on sole depth, a trend towards a significant increase in the sole present between the palmar processes of the distal phalanx and the solar surface of the foot was noted in the right hoof (P=0.07, Fig. 3D). On average, this aspect of the hoof structure increased 2.2±1.4 mm over the course of the 30-day treatment period in PEMF-treated horses, and this was in contrast to an average loss of 0.4±0.2 mm in control animals. The distance between the apex of the distal phalanx to the solar surface was not altered in either foot (P=0.65), nor was the distance between the palmar processes of the distal phalanx of the left hoof (P=0.64) (Fig. 3A/B/C).

Due to the trend towards an increase in sole depth at the proximal processes without an alteration at the apex in the right hoof, palmar angles of the P3 was assessed. No significant improvement on palmar angle was noted when comparing PEMF treated to control groups (5.0° ±1.4 vs 3.2°±07 respectively. P=0.24) (Fig. 4).

Discussion

It is accepted that equine performance is directly influenced by hoof condition, and yet despite this, few interventions to improve hoof condition have been critically analyzed, offering minimal therapeutic options [14]. Here, we report a trend towards a positive impact of pulsed electromagnetic frequency (PEMF) therapy on the sole depth of the proximal processes of P3, indicating a potential benefit of a noninvasive therapy for soundness and performance in the horse. To our knowledge, this is the first study to critically assess the impact of PEMF on hoof parameters including sole depth and palmar angle.

The equine hoof consists of the distal end of the second phalanx (P2), the distal phalanx (P3), and the navicular bone, all of which are enclosed within the hoof capsule. The hoof can be separated into multiple structures, including the hoof wall, the bars, the sole adjacent to the sole-wall junction, and the frog [6]. When any aspect of this structure deviates from the norm, whether from genetics, exercise, injury, nutrition, or farrier practices, the biomechanics of the horse are perturbed, and lameness may follow. The hoof sole acts as cushion and support to many of these internal structures, and although it varies in thickness, 15 mm is thought to be the minimum required for protection [5]. Historically, the impact of thin soles on performance has been mitigated with podiatry intervention [15], supplementation with vitamins and minerals [16], and attention to environment [1], although few of these factors have been critically evaluated.

In this study, a tendency towards improvement on sole depth in the heel of the right hoof was noted in PEMF-treated animals. On average, sole depth of the right hoof increased by 2.4 mm in this group. In this limited study, this trend towards an increase in sole depth appeared to be a horse-dependent event and was anecdotally noted in the horses which entered the trial with sole depth lesser than the industry standard (<12 mm), although a significant impact of this finding could not be determined within the confines of this study due to low power. PEMF is a non-invasive therapy which utilizes pulsing electromagnetic fields to impact tissues. Exposure to PEMF causes a release of intracellular Ca2+ which then leads to an increase in binding of the Ca2+ to calmodulin (CaM) [17]. This results in a variety of signaling pathways that are

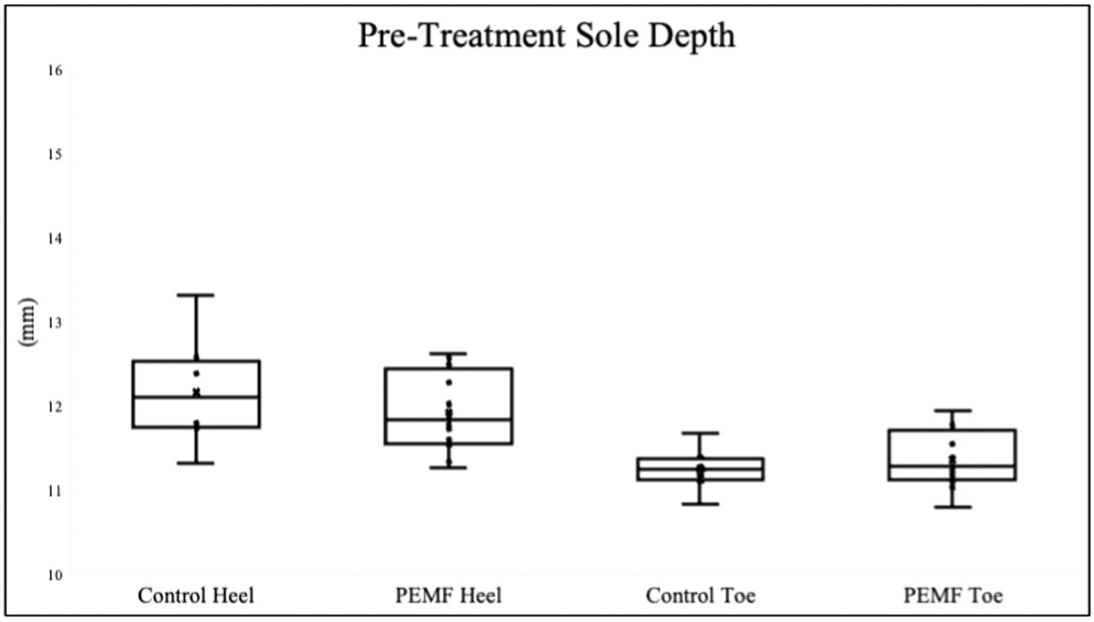


Fig. 2. Pre-treatment sole depth values of the equine hoof. There was no difference in the amount of sole depth (mm) at either the apex of the P3 (toe; P=0.34) or the amount of digital cushion below the proximal processes (heel; P=0.64) in animals before treatment onset.

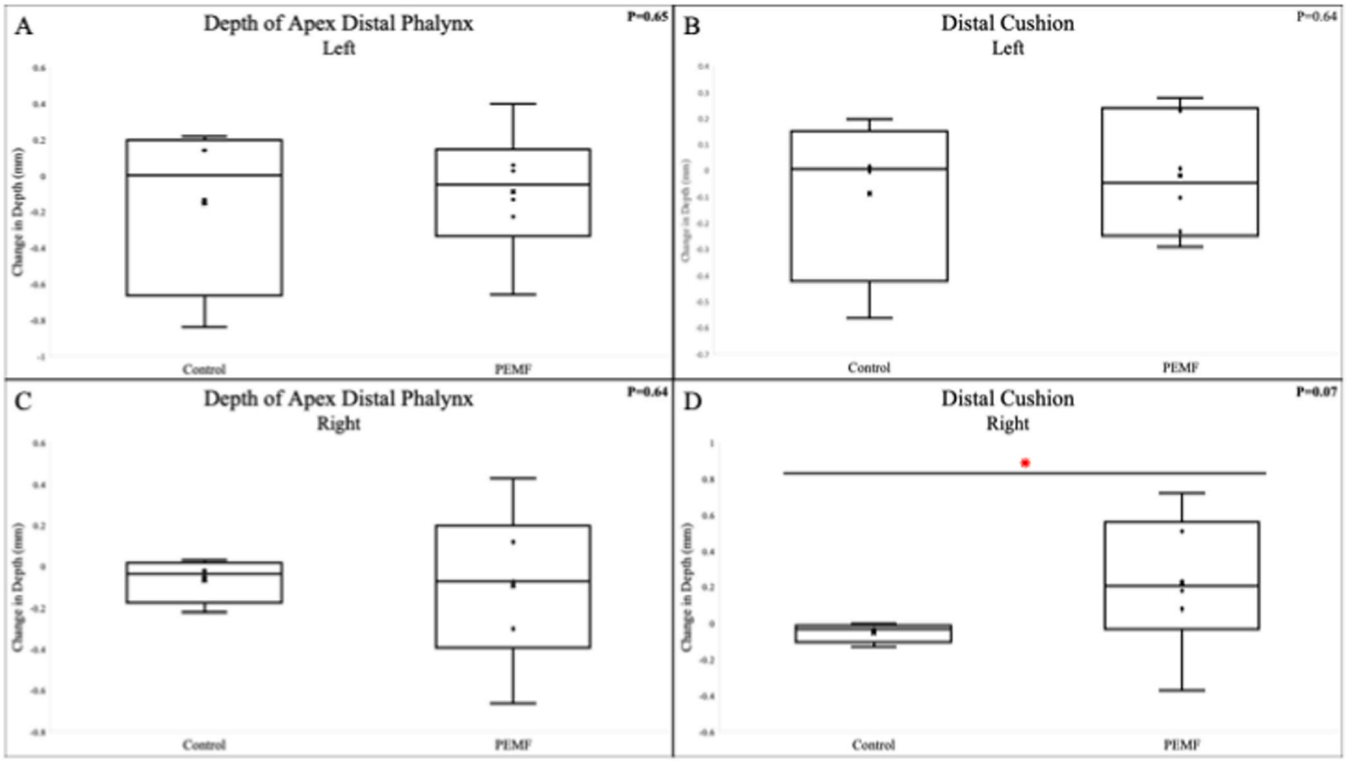


Fig. 3. Effect of PEMF treatment on sole depth of the equine hoof. While no effect of PEMF treatment was noted on the sole depth of the left hoof or the apex of the right hoof, a trend towards a significant increase in the sole depth between the proximal processes and the solar surface of ground was identified following treatment with PEMF in the right hoof. Asterix (*) indicates $P<0.1$.

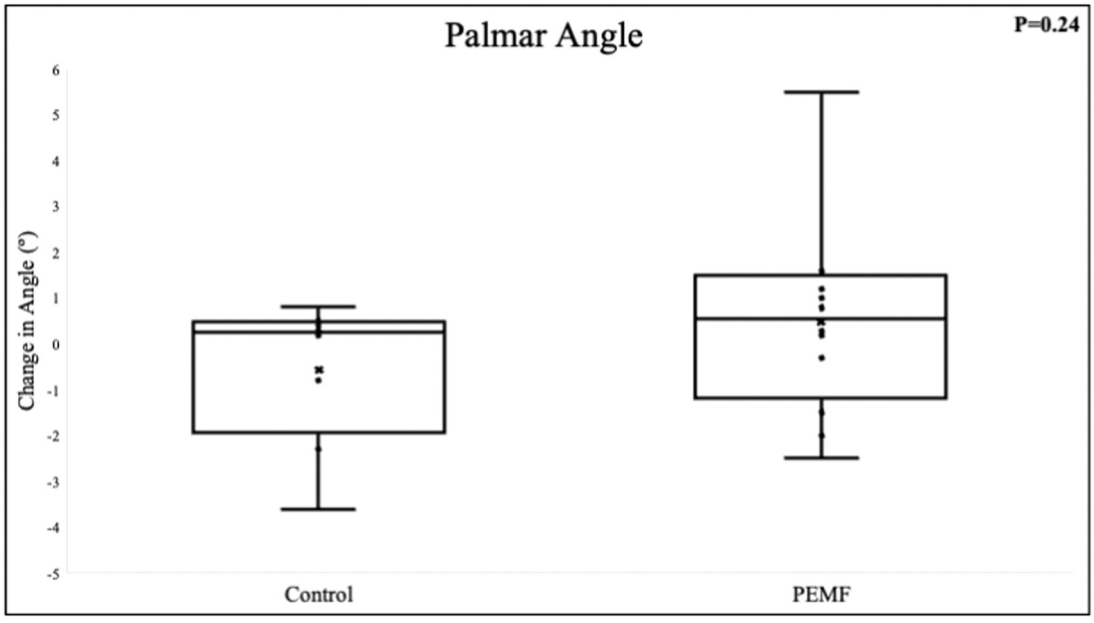


Fig. 4. Effect of PEMF treatment on palmar angle of the third proximal phalanx. No effect of treatment on palmar angle was observed when evaluating the impact of PEMF treatment.

related to inflammation, apoptosis, metabolism, and vascular tone [18]. PEMF has also been shown to induce production of nitric oxide, which can reduce inflammatory gene expression as well as enhance circulation and promote dilation of blood vessels [17]. This reduction of inflammation can thereby impact tissue repair, presumably including in the keratinous material of the hoof. While research is lacking on the effect PEMF on keratin production, work has been done on bone growth factors and synthesis of cartilage as well as the impact on differentiation and proliferation of osteoblast cells [19,20], all of which support the use of PEMF in cellular growth.

The tendency towards an increase in sole depth under the proximal processes of the right P3 coincided with no alteration in the depth of sole under the apex. The lack of significant impact on palmar angle may be explained by the small number of animals assessed (n=6), the low

frequency of treatment (22 Hz), the short amount of time treated (10 min) or the low number of days that the study took place over (30 days). The PEMF modality utilized within the present study is capable of 50 Hz of electromagnetic frequency, indicating that a higher frequency was possible, and may have been improved outcomes. Additionally, treatment could have been lengthened within treatment session, additional number of days, in addition to duration of study. With regards to the low number of animals assessed, the reports of significant trends should be heeded, as a type II statistical error is more likely than that of a type I. Regardless, additional work in a larger population is needed to determine if PEMF therapy has any positive impact on palmar angle. When determining the frequency and length of PEMF exposure for this research, a variety of findings from previous studies were considered. In a study looking at the effect of vibration on hoof growth rate in horses, it was noted that significant growth in the hoof was observed after 60 days, but the main increase occurred during the first 30 days [21]. Additionally, studies have shown that PEMF application for only 5–10 minutes is able to activate cellular signaling transduction, and after 30 minutes this response is greatly dulled [22]. Because of this, we believe that the 10-minute treatment duration was adequate in the assessment of response.

It is unknown why only the right hoof responded to treatment, although we hypothesize that this may be due to the dissymmetry in the hooves of the animals enrolled prior to treatment. Eight of the ten animals were thoroughbreds, and this breed is commonly described as having asymmetrical feet [5,23]. This asymmetry, commonly referred to a high/low mismatched forefeet can cause compensatory changes in the muscling of body, the weight load of soft tissue structures, in addition to stride symmetry [24]. While average pre-treatment sole depth did not differ when comparing groups (PEMF vs. Control), the range of sole depth noted between animal was vast, ranging from 8 to 19 mm at the apex of the P3 and 13–33 mm at the proximal processes. Additionally, palmar angle ranged from 0.7° to 8.6°, indicating dissimilarities between horse. These ranges indicate that while some of the horses entered the study with poor hoof structure, others did not, and therefore an animal (and foot) specific response would be expected (Fig. 4), possible explaining the impact on a single hoof.

In conclusion, this pilot study indicates that application of PEMF therapy may potentially improve sole depth of the equine hoof. While only noted in one hoof and at the proximal processes of P3, this finding indicates that future research is justified into the impact of PEMF on overall equine hoof health. This tendency towards an increase in sole depth was not associated with improvement in palmar angles, which are pertinent to equine health and performance. This study indicates a need for additional research into the impact of this noninvasive therapeutic modality on soundness and performance in the equine athlete.

Ethical Statement

All animal procedures were completed in accordance with the Institutional Animal Care and Use (IACUC) of Midway University under the guidelines of the approved protocol 2023–101.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Magnawave PEMF provided the PEMF device and associated products. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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