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Original Research

Functional Electrical Stimulation (FES) and the Effect on Equine Multifidi Asymmetry

Diane A. Isbell [a], Sheila J. Schils [b,*], Suzan C. Oakley [c], Ugo Carraro [d], Brian R. Knaeble [e]

[a] Isbell DVM, Livermore, CA
[b] EquiNew LLC, River Falls, WI
[c] Oakley Equine Sports Medicine, Loxahatchee, FL
[d] IIM CIR-Myo Translational Myology Lab, Padova, Italy
[e] Department of Mathematics, Utah Valley University, Orem, UT

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ABSTRACT

Asymmetry of the *multifidi* has been correlated with scoliosis and back pain in humans and has been investigated as a factor in equine back pain as well. The purpose of this study was to determine if FES would affect the symmetry of equine thoracolumbar *multifidi* when compared to controls. Twelve horses received 24 FES treatments bilaterally over the thoracolumbar region for 8 weeks. Twelve additional control horses received no FES treatments. Ultrasonographic measurements of the cross-sectional area (CSA) of the *multifidi* of the treatment horses at seven thoracolumbar levels were compared to determine the change in left and right asymmetry post-FES. The same measurements during the same period were also taken in the control group. All measurements were blinded for evaluation. Statistical significance was assessed utilizing two-sided, matched-pairs *t*-tests, and Welch's (unequal variances) *t*-test (alpha = 0.05). Multiple comparisons were accounted for using the Sidak correction. A significant improvement in *multifidi* asymmetry was observed, post-FES, at all seven thoracolumbar levels, with no evidence of asymmetry improvement in the control group. The difference between mean improvements of the treatment and control groups was statistically significant ($P < .001$). FES significantly improved the symmetry of equine *multifidi,* and evidence was provided for the effectiveness of FES at each of seven thoracolumbar levels. The improvement in symmetry appeared to result from increases, decreases, and maintenance of the CSA of the left and right *multifidi* in various combinations. The FES protocol used in this study has the potential to improve spinal function and assist in reducing back pain in horses.

1. Introduction

Scoliosis is a general term, which is typically defined in the medical literature as an abnormal lateral (side to side) curvature of the spine [1,2]. Research in humans has found that the muscular asymmetry in idiopathic scoliosis has no known association with any neurological or muscular disease [3]. Biomechanical models of the forces on the spine that produce idiopathic scoliosis have indicated that malfunctions of the trunk's neuromuscular system were influential in developing the lateral curvatures of scoliosis [4–7]. Specifically, muscle spasms that are typically unilateral can cause greater ipsilateral bending forces that are likely a major cause of increasing scoliotic curvature [8–12]. The human literature emphasizes the importance of symmetrical spinal stabilization by muscles, including the *multifidi*, to reduce scoliosis and/or low back pain [13–16].

Animal welfare/ethical statement: All authors declare that they have adhered to the Principles of Veterinary Medical Ethics of the AVMA. Informed consent for data collection was obtained from all horse owners and/or caretakers.

Conflict of interest statement: S. Schils is a principle of the company EquiNew, LLC which supplied the equipment used for the FES treatments. D. Isbell, S. Oakley, U. Cararro, and B. Knaeble have no conflicts of interest.

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Data Statement: All data has been archived privately and is available for review. No data were excluded from the analyses.

* Corresponding author at: Sheila J. Schils, EquiNew LLC, N8139 900th St, River Falls, WI 54022 USA.
E-mail address: sbschils@EquiNew.com (S.J. Schils).

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Although lateral bending of the spine has been evaluated in functional studies of the equine back [17–20], limited research has investigated abnormal lateral curvature (scoliosis) in horses [21,22], and specifically, if abnormal lateral curvature of the spine leads to back pain [23]. The conclusion of the equine functional studies was that abnormal lateral bending of the thoracolumbar spine was a measurable outcome related to lameness [17,18,21,23].

The *multifidi* muscles are one of the main spinal stabilizer muscles in humans. The bilateral symmetry of the *multifidi* is known to improve scoliosis and to reduce low back pain [8,12,24–26]. If the *multifidi* muscles are injured, they do not recover full strength and endurance unless specific exercises reactivate the correct motor neuron response [27,28].

Research in horses has also assessed the *multifidi* as important spinal stabilizer muscle [29,30]. The spinal biomechanics of the horse and human are different; however, the function and muscle fiber arrangement of the *multifidi* between these two species appears to be similar [31]. Therefore, it seems that careful extrapolations of research related to the human *multifidi* have the potential to improve the understanding of back pain in the horse.

Functional electrical stimulation (FES) is a medical device that safely activates the neuromuscular system and produces functional articular and vertebral motion that is almost indistinguishable from the effect produced by the nervous system [32–36]. It is well established in human literature that FES is a safe and effective means to improve muscle function and tonicity by replicating voluntary or reflex muscle activity [34,37,38]. Functional electrical stimulation has been successfully used to specifically reduce muscle spasms, which then improved kyphotic and scoliosis angles in children with cerebral palsy [39]. In addition, equine studies have shown that FES is a safe and effective means to reduce muscle hypertonicity and improve muscle function [40–42].

Ultrasound imaging has been utilized as a reliable and noninvasive, objective, and sequential tool to measure the cross-sectional area (CSA) of the spinal stabilization muscles, including the *multifidus*, in both human and equine studies, especially when performed by the same technician [43–45]. Ultrasound imaging requires precision, especially when imaging the thicker musculature of the horse. For ensuring the accuracy and repeatability of the measurements vertebral bone anatomy should be used as landmarks to identify the measurement site. If serial images are taken, preferably, one practitioner acquires all images, especially if comparisons between images are to be made [44].

The purpose of this study was to investigate whether the use of FES on equine thoracolumbar muscles affects the left and right symmetry of the thoracolumbar *multifidi*. The outcome of 24 FES treatments performed over 8 weeks was evaluated by ultrasonographic comparison of both left and right CSA at seven thoracolumbar locations of the *multifidi* pre-FES and post-FES treatments, and in non-treated control horses. The hypothesis of the study was that simultaneous bilateral FES treatments would result in the improvement of symmetry of the CSA of the left and right *multifidi*. These results would provide the first objective data on the change in symmetry of the *multifidi* in horses after an FES treatment regime.

2. Materials and Methods

2.1. Horse Demography

Twelve horses of Quarter Horse, Warmblood, Thoroughbred, and Fox Trotter breeding (8 geldings and 4 mares) from the Midwest of the United States were selected as the treatment group for this study from two separate stables. The horses had been used for trail, western pleasure, dressage, and jumping disciplines. Two of the study horses were retired due to back problems, and the remaining were not being ridden due to diagnosed distal limb lameness. The horses ranged in age from 7 to 21 years (mean 12.8 years).

Twelve horses of Quarter Horse, Thoroughbred, Standardbred, Morgan, Clydesdale, and Paso Fino breeding (7 geldings and 5 mares) from the Southeast of the United States were selected as the control group for this study from three separate stables. The horses had been used for racing and trail riding, and 2 horses were broodmares. One horse had been diagnosed with a distal limb lameness, and none of the additional horses had diagnosed back problems. The horses ranged in age from 2 to 14 years (mean 9.1 years).

The horses used in this study had not been ridden for at least 2 months previous to the start of the study and were not ridden during the study. All horses were placed in a free paddock for self-exercise 1–6 hours daily, depending on weather conditions, and were stalled at night. No nutritional or other management changes occurred during the period of the study.

Both treatment and control horses had no known myogenic or neurogenic disorders and had not been tested for those pathologies. No clinical examination was performed prior to the start of the study to determine the presence or absence of current back pain as an inclusion criteria. In addition, the presence or absence of multifidi asymmetry was also not an inclusion criteria for the study. For reducing confounding bias, the inclusion criteria was the same for both groups. All authors declare that they have adhered to the Principles of Veterinary Medical Ethics of the American Veterinary Medical Association and informed consent was obtained for the use of all horses participating in the study.

2.2. Clinical Examination of the Horses

Modified Ashworth Scale (MAS) (Table 1) has been shown to have high interrater reliability [46] and was used to determine the initial level of muscle hypertonicity and to grade the changes observed post-FES treatment. The details explaining the use of MAS for evaluating equine muscle hypertonicity are documented in several previous equine studies [40–42].

Photos were taken of the top line of each treatment horse, before FES treatments and after all treatments were completed. The horses stood on a flat surface and were positioned so that all four limbs were square, and the neck of the horse was in a neutral position with the chin of the horse placed at the junction of the neck and the chest. The prephotos and postphotos were placed side by side, and horizontal lines were drawn over the thoracolumbar region, first at the most ventral position of the thoracolumbar curve and then a second horizontal line was drawn from the most dorsal point of the hip at the region of the tuber sacrale. These two lines were visibly compared in height to determine if a change in thoracolumbar curvature occurred during the treatment period.

2.3. Functional Electrical Stimulation Treatments

For treatment horses, FES was performed three times per week for a period of 8 weeks, yielding a total of 24 treatments per horse. This protocol was similar to the protocol used in a previous study to evaluate mitochondrial density and distribution in response to 22 FES treatments over a period of 8 weeks [41]. The treatments were performed using a pad containing three electrodes on the right and three electrodes on the left placed dorsally approximately between T10 and L4. The horses were not clipped nor sedated during the FES treatments. The pad was carefully placed in the same position for every horse for every treatment, but the exact anatomical position between horses varied slightly due to the difference in the

Table 1
Modified Ashworth Scale (MAS) for grading muscle tonicity.

Modified Ashworth Scale	
Grade	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension
1+	Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the range of motion
2	More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected part(s) rigid in flexion or extension

conformation of each horse. For helping to standardize the pad placement, the surcingle was placed where the girth would normally lie to hold a saddle in place, and the cranial electrode in the pad was then positioned cranial to the front edge of the surcingle. During the FES treatments, the voltage was increased until the dorsoventral movement of the thoracolumbar area was obtained (Supplementary items 1–3).

The FES system (EquiNew, LLC, N8139 900th St, River Falls, WI 54022) used was a 16-bit digital microcontroller and provided a pulsed, biphasic, rectangular waveform at 60 Hz, with a 0-net charge. The signal was pulsed at a rate of an average of 2 seconds on and 2 seconds off for a single-session treatment time of 35 minutes. For each horse, the number of bursts per 35 minutes session was 525 or 63,000 pulses (525 $\times$ 60 Hz $\times$ 2 seconds), and the total number of bursts per week was 1575 or 189,000 pulses.

2.4. Ultrasound Measurements

Both control and treatment horses were imaged standing squarely on a flat surface without stocks, and their heads were held straight while images were taken. All horses were either unsedated or lightly sedated and were not clipped. Isopropyl alcohol 70% was used as a coupling medium.

The same ultrasonographer imaged both the pre*multifidi* and post*multifidi* images for the treatment horses (DI) and the control horses (SO). Both ultrasonographers were highly skilled equine veterinarians, with each having over 20 years of imaging experience, and both have taught numerous courses in ultrasound techniques. In addition, SO is a certified International Society of Equine Locomotor Pathology (ISELP) member and is a diplomat of the American College of Veterinary Sports Medicine and Rehabilitation.

Images were acquired with a portable Fujifilm Sonosite Edge (Fujifilm Sonosite, Inc, 21919 30th Dr SE, Bothell, Washington 98021) ultrasound machine, and a 60-mm curvilinear macroconvex probe, which has a blended frequency from 2 to 5 MHz was utilized. The 18th rib was identified by ultrasound and then followed dorsally to the T18 dorsal spinous process (DSP). From that point, the DSP was identified by manual palpation by counting the dorsal aspect of the DSP cranial and caudal from T18. This count was done twice to ensure the correct location. In addition, ultrasound was also used to identify the ribs and lumbar transverse process to confirm the manual palpation results. The desired DSP were marked with white out so that the count would not have to be repeated for imaging at each location.

Ultrasound images of the multifidus muscles were acquired bilaterally at T10, T12, T14, T16, T18, L2, and L4 from the left side of the horse at each site. The probe was placed perpendicular to the skin and DSP to obtain the optimal transverse image of the *multifidus* at the bone attachment on the DSP and lamina of the desired vertebrae. The ultrasonographer stood on a stool on the left side of the horses for all images. This enabled greater visualization of the probe alignment, obliquity, and anatomy than standing at the side of the horse. The stool was repositioned from cranial to caudal for each imaging site. The articular facet joint with the adjacent cranial vertebrae was identified via ultrasound, and then the probe was slowly slid caudally to just past the caudal edge of the cranial articular facet joints of the desired DSP.

The image was then saved as a JPEG at the most cranial aspect of the DSP, where the dorsal process's smooth junction with the lamina could be identified. The left side was imaged first and placed on the left side of the screen. The probe was then slid across the spine in the same transverse plane to image the right side. By using a split screen with the left side image of the horse on the left, the probe was placed on the right so that the bone markers and the angulation of the dorsal spinous process were identical to the left. This enabled confirmation of the same anatomical site on the left and right side and also decreased the angulation and obliquity issues created by reaching across the horse. In addition, differences in muscle topography from side to side and from premeasurements to postmeasurements, which would affect probe angulation and obliquity, were reduced.

This anatomical site for measurement was used because: (1) At this spot, the entire muscle near the middle of the DSP of the vertebrae could be visualized. (2) By avoiding the joint region, bone modeling due to joint disease would not deform the shape of the muscle from preimaging to postimaging. (3) This site could be easily and accurately located by utilizing the boney markers for the posttreatment imaging.

For the posttreatment measurements, a tablet with the pretreatment image for each site was held adjacent to the ultrasound screen. The posttreatment image was taken when the boney markers on the posttreatment images matched those on the pretreatment images in shape, position, angulation, and obliquity. This enabled accurate probe placement between imaging sessions and allowed the probe angle to be similar between sessions despite changes in muscle shape that may occur where the probe was placed. The time interval between preimages and postimages for both the treatment and control horses was 8 weeks, and all horses within each group were imaged on the same day.

Measurements of the *multifidi* CSA were originally saved as JPEG images. ImageJ (ImageJ.NIH.gov) software was used to make the measurements on the saved images (Fig. 1). The investigator doing the measurements was blinded as to whether the images were pre or post through the use of Random (Random.org, 8 Dawson St, Dublin 2, D02N767, Ireland) software, which generated random numbers for all images. The name and date on each image were redacted and replaced with the assigned random number. Cross-sectional area measurements were taken of each side until 5 measurements in a row were within a margin of 5% for each image. Then the next three measurements were recorded and averaged for the sampled area. All measurements were performed by the same investigator. Missing data were due to an error in saving the data to the software during imaging.

2.5. Statistical Analyses

For each horse in the treatment group, both pre-FES and post-FES, and for each of the seven thoracolumbar levels (T10-L4), left and right location-specific measures of the average CSA of the *multifidi* were calculated from the data obtained through ultrasound. As stated in the materials and methods section, the average CSA of the *multifidi* was an average of 3 raw measurements at each site, and this average is referred to as a location-specific measurement.

Location-specific measurements of horses were averaged, and the resulting means are displayed in Table 2, using combinations of labels "left", "right," "pre-FES," and "post-FES." Post-FES location-specific mean values were subtracted from pre-FES location-specific mean values, and this difference is designated as the CSA change for both the left and right sides and labeled as "left change" and "right change" in Table 2.

Next, for each horse and at each location site, both pre-FES and post-FES, left and right location-specific measurements were paired to compute the absolute value of their differences, which was called asymmetry. Like the location-specific measurements from which it is constructed, asymmetry depends on the horse, location, and time (pre-FES or post-FES). Symmetry is improved when the measure of asymmetry decreases in value.

Then, for each location, pre-FES and post-FES, its location-specific mean asymmetry was computed by averaging over the sample of horses. The resulting means of asymmetry are displayed in Table 2 and labeled as "asymmetry pre-FES" and "asymmetry post-FES." Post-FES minus pre-FES changes in mean asymmetry are labeled in Table 2 as the "asymmetry change." The same calculations were performed for the control horses, and the results are found in Table 3.

Post-minus pre-FES changes in mean location-specific asymmetries in Tables 2 and 3 were tested for statistically significant differences from zero using matched pairs, two-sided, *t*-tests at the 0.05 level. Significance at this level was indicated with a single asterisk. In addition, Sidaks correction for multiple comparisons was used to conservatively determine statistical significance at each of the seven location sites simultaneously. When a location-specific comparison was still significant after application of the Sidak correction, that significance was indicated with two asterisks in Tables 2 and 3

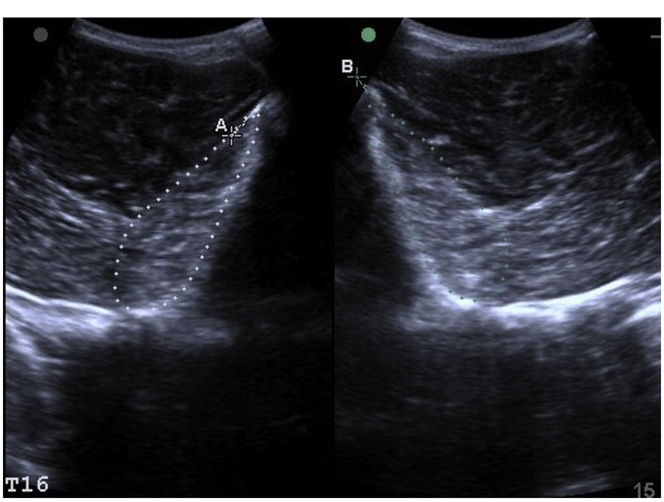

Fig. 1. Ultrasound measurements of cross-sectional area (CSA) of right and left *multifidi*.

For thoroughly responding to any concerns about statistical assumptions underlying the multiple comparison correction, the horse-specific asymmetry was then summarized. For each horse, pre-FES and post-FES, its mean asymmetry was computed by averaging its location-specific asymmetry values. The resulting means are referred to as horse-specific asymmetry scores and are labeled as the "asymmetry pre-FES" and "asymmetry post-FES" in Table 4. Asymmetry scores and postminus prechanges in asymmetry scores are displayed in Table 4, and changes in asymmetry scores are labeled as "asymmetry change." Symmetry is improved when the measure of asymmetry decreases in value. The same calculations were performed for the control horses, and the results are found in Table 5. A two-sample, matched-pairs, *t* test at the 0.05 level was used separately on Tables 4 and 5 to test whether the observed changes in asymmetry scores were statistically significant. The results of the tests are described in the table captions.

Finally, to rigorously test for a significant causal effect of treatment, the treated changes in asymmetry scores were compared to the control changes in asymmetry scores using Welch's two-sample, unequal variances, two-sided, *t*-test of size alpha $= 0.05$. Change in asymmetry was averaged over the horses in the treated and control groups. The treated mean change in asymmetry was statistically significantly different from zero. The mean control change in asymmetry was not statistically significantly different from zero. This suggests that the treatment caused the statistically significant improvement observed in the treated group and was formally tested using Welch's test described above. The visual summary of this comparison is shown using box plots displayed in Fig. 2. All statistical analyses were carried out using the statistical software R (https://cran.r-project.org.).

3. Results

3.1. Clinical Results

The majority of the treated horses (10/12) were initially rated by the MAS in grade 3, indicating a high level of muscle hypertonicity, making spinal movement by hand manipulation difficult. A hypertonicity grade of 2 was found in 2 out of the 12 horses, indicating that although muscle tone was greater than normal, some joint movement was possible with manipulation. The treatment horses used in this study required an average of 9.8 treatments to achieve a 1-grade MAS improvement in muscle hypertonicity.

The still photographs of most, but not all, horses showed a distinct improvement in the degree of the thoracolumbar curve and an increase in the size and symmetry of the musculature of the epaxial muscles (Fig. 3). While there are many inaccuracies that can be attributed to this measurement technique, it provides some useful visual clinical outcome information of any changes in muscular symmetry.

3.2. Functional Electrical Stimulation Results

The voltage used to obtain dorsoventral movement in both the control and treatment horses was similar and varied from 7.2 to 12.0 volts, with the average being 10.0 volts. The voltage was gradually increased during the 35 minutes treatment time until the horses obtained a distinct dorsoventral movement and then that voltage was sustained throughout the treatment period. On average, the horses obtained dorsoventral movement for a minimum of 20 minutes during each treatment period.

Table 2
Multifidi cross-sectional area (CSA) location-specific means of the treated horses.

Location	Left Pre-FES (cm^2)	Left Post-FES (cm^2)	Left Change (cm^2)	Right Pre-FES (cm^2)	Right Post-FES (cm^2)	Right Change (cm^2)	Asymmetry Pre-FES	Asymmetry Post-FES	Asymmetry Change
T10	9.3	9 .9	0.6 n = 10	9.4	10.0	0.6 n = 10	0.8	0.2	−0.6[b] n = 10
T12	10.6	10.2	−0.4 n = 10	10.6	10.3	−0.3 n = 10	0.6	0.2	−0.4[b] n = 10
T14	11.2	11.3	0.1 n = 10	11.0	11.3	0.3 n = 10	0.6	0.2	−0.4[a] n = 10
T16	11.6	12.4	0.8 n = 12	11.3	12.5	1.2[a] n = 12	0.5	0.1	−0.4[b] n = 12
T18	12.2	13.5	1.3[b] n = 12	12.1	13.6	1.5[b] n = 12	0.6	0.1	−0.5[b] n = 12
L2	12.9	14.1	1.3[b] n = 11	13.1	14.1	1.0[a] n = 11	0.5	0.1	−0.3[b] n = 11
L4	13.4	14.2	0.8[a] n = 12	13.3	14.2	0.9[a] n = 12	0.3	0.1	−0.2[a] n = 12

Asymmetry is the absolute value of the left CSA measurement minus the right CSA measurement.
Change in asymmetry is post functional electrical stimulation (FES) asymmetry minus pre-FES asymmetry.
Asymmetry improved when the change was negative.
[a] Statistically significantly different from zero at the 0.05 level.
[b] Statistically significantly different from zero at the 0.05 level after adjustment for multiple comparisons using the Sidak correction.

3.3. Statistical Results

Table 2 displays changes in both left and right location-specific measurements, and changes in asymmetry for all seven thoracolumbar location sites, T10-L4. Interestingly, nonsignificant changes at 7 of the 14 treatment locations indicated in the table with “left change” and “right change” were found in the CSA of the *multifidi*. However, at every location, a statistically significant improvement in asymmetry was observed.

Table 3 shows the results of the same asymmetry calculations for the control horses as described above for the treatment horses. Changes in CSA, at each individual location (T10-L4), of the left and right *multifidi* post-FES were nonsignificant, as indicated in the table as “left change” and “right change.” In addition, the changes in asymmetry for the individual-site locations, labeled as “asymmetry change,” were all nonsignificant.

Statistical significance is determined by the difference in means and the magnitude of the sample variances. The sample variances were smaller in the treatment group. For instance, at L4, the asymmetry change was −0.2 for both treatment and control groups. However, this change was significant for the treatment group and not significant for the control group.

Table 4 lists the horse-specific measures of asymmetry for the treatment group, and the mean change in asymmetry was found to be highly significant ($P < .001$). Table 5 shows the same horse-specific measures of asymmetry performed for the control group, and the mean change in asymmetry was found to be insignificant ($P = .39$).

The box plots in Fig. 2 show the distributions of changes in asymmetry scores for the treated group and the control group. Note how the two sample distributions do not overlap. This is strong evidence that the treatment was effective on all treated horses. The mean change in asymmetry score differed significantly ($P < .001$) between the treated and control horses.

4. Discussion

The importance of symmetry of the spinal stabilizer muscles has been demonstrated extensively in human literature as a direct link to low back pain [8,25,47,48]. Research has found that greater muscular development on the side of the dominant limb causes greater bending forces and may increase scoliotic curves on that side [4,9,11,12]. The *multifidi* are one of the spinal stabilizer muscles in humans, and the asymmetry of the *multifidi* has been found to be a factor in scoliosis [49]. The *multifidi* of the horse and humans have been shown to be similar in function and structure [31]. Therefore, a careful extrapolation of information from human research on the importance of the *multifidi* to equine spinal health appears probable.

The purpose of this study was to determine if FES can improve thoracolumbar *multifidi* symmetry. Subsequent studies could then determine if this improvement in *multifidi* symmetry correlates with a reduction back pain. The results of this study found a significant ($P < .001$) improvement in the *multifidi* muscle symmetry (Table 4) after 24 FES treatments. In addition, when treatment results were compared to controls (Fig. 2), the difference in the changes was also highly significant ($P < .001$). It appears that FES has the potential to improve symmetry of the thoracolumbar *multifidi*, which is one of the spinal stabilizers in the horse, and therefore, could be a means to reduce back pain in the horse.

The treatment horses used in this study required an average of 9.8 treatments to achieve a 1-grade MAS improvement in muscle hypertonicity which was generally higher than the typical horse in previous studies [40–42]. No statistical calculations to determine significance between the pre-MAS and post-MAS score and

Table 3
Multifidi cross-sectional area (CSA) location-specific means of the control horses.

Location	Left Pre (cm^2)	Left Post (cm^2)	Left Change (cm^2)	Right Pre (cm^2)	Right Post (cm^2)	Right, Change (cm^2)	Asymmetry Pre	Asymmetry Post	Asymmetry Change
T10	7.0	7.6	0.6 n = 7	7.3	8.1	0.8 n = 7	0.4	0.9	0.5 n = 7
T12	8.1	8.8	0.7 n = 11	7.9	7.9	0.04 n = 11	0.4	0.9	0.4 n = 11
T14	9.2	9.7	0.6 n = 11	9.1	9.7	0.7 n = 11	0.5	0.3	−0.2 n = 11
T16	9.4	10.7	1.3[a] n = 11	9.9	10.2	0.3 n = 11	0.5	0.6	0.1 n = 11
T18	10.9	10.7	−0.2 n = 11	10.8	10.9	0.06 n = 11	0.6	0.5	−0.1 n = 11
L2	12.6	11.8	−0.8 n = 12	12.2	11.5	−0.8 n = 12	0.7	0.6	−0.2 n = 12
L4	12.5	11.9	−0.6 n = 12	13.0	12.1	−0.9 n = 12	0.6	0.4	−0.2 n = 12

Asymmetry is the absolute value of the left CSA measurement minus the right CSA measurement.
Change in asymmetry is postasymmetry minus preasymmetry.
Asymmetry improved when the change was negative.
[a] Statistically significantly different from zero at the 0.05 level.

Table 4
Multifidi cross-sectional area (CSA) horse-specific asymmetry scores of the treatment group.

Horse	Asymmetry Pre-FES	Asymmetry Post-FES	Asymmetry Change
1	0.44	0.27	−0.16 n = 7
2	0.66	0.28	−0.38 n = 7
3	0.73	0.17	−0.56 n = 7
4	0.85	0.08	−0.77 n = 5
5	0.56	0.10	−0.46 n = 7
6	0.70	0.08	−0.62 n = 7
7	0.53	0.16	−0.36 n = 7
8	0.35	0.14	−0.21 n = 6
9	0.34	0.10	−0.24 n = 6
10	0.32	0.12	−0.20 n = 5
11	0.47	0.13	−0.33 n = 6
12	0.49	0.10	−0.39 n = 7

Each horse has an asymmetry score that is the mean of its location-specific asymmetry scores.
Asymmetry Change is the postfunctional electrical stimulation (FES) asymmetry score minus the pre-FES asymmetry score.
An asymmetry score has improved when the change is negative.
n = the number of pairs of left/right measurements.
The mean asymmetry change was different from zero ($P < .001$).

multifidi symmetry was made; however, future studies could evaluate this relationship since the initial data is intriguing.

The still photographs of the treatment horses post-FES (Fig. 3) showed subjective clinical improvement in the degree of the thoracolumbar curve in the epaxial muscles of some, but not all, horses. Both the subjective evaluations of MAS scores and the comparison of prephotos and postphotos present useful information, which the authors have utilized in clinical practice to help guide their protocols for muscular rehabilitation, as well as to better interpret the objective results of this study.

For the treatment group, Table 2 illustrates significantly ($P < .05$) improved change in *multifidi* symmetry at each location (T10-L4), as indicated in the “asymmetry change” column of the table. In contrast, the control group (Table 3) shows no significant improvement in *multifidi* “asymmetry change” for all location-specific sites.

Interestingly, in the treatment group, indicated as “left change” and “right change” in Table 2, significant CSA changes post-FES were observed at some locations but not at other locations. In addition, while not significant, some individual-location CSA values actually decreased post-FES training or remained essentially the same. This data indicates that *multifidi* symmetry improvement may not only be determined by increasing the left and right CSA of the *multifidi*, but rather, to improve overall bilateral symmetry,

Table 5
Multifidi cross-sectional area (CSA) horse-specific asymmetry scores of the control group.

Horse	Asymmetry Pre	Asymmetry Post	Asymmetry Change
1	0.99	0.93	−0.06 n = 7
2	0.57	0.44	−0.13 n = 6
3	0.54	0.73	0.19 n = 7
4	1.27	1.28	0.01 n = 7
5	0.46	0.38	−0.08 n = 7
6	0.26	0.31	0.05 n = 6
7	0.48	0.51	0.03 n = 7
8	0.78	0.72	−0.06 n = 3
9	0.61	0.60	−0.01 n = 6
10	0.15	0.34	0.19 n = 7
11	0.33	0.43	0.10 n = 5
12	0.28	0.35	0.08 n = 7

Each horse has an asymmetry score that is the mean of its location-specific asymmetry scores.
Asymmetry change is the postasymmetry score minus the preasymmetry score.
An asymmetry score has improved when the change is negative.
n = the number of pairs of left/right measurements.
The mean asymmetry change was not significantly different from zero ($P = .39$).

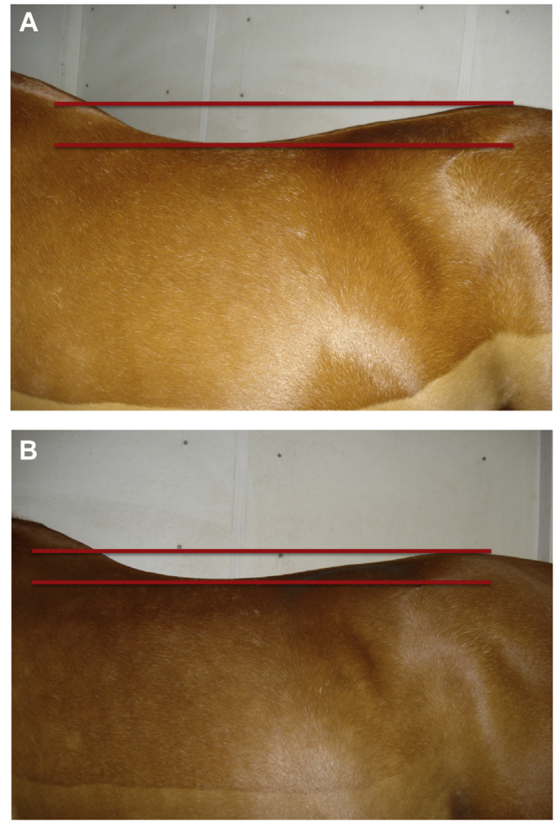

Fig. 2. Photos of the study horse showing the reduction in thoracolumbar curve of epaxial muscles over an 8 weeks functional electrical stimulation (FES) treatment protocol. A. Pre-FES treatment; B. Post-FES treatment.

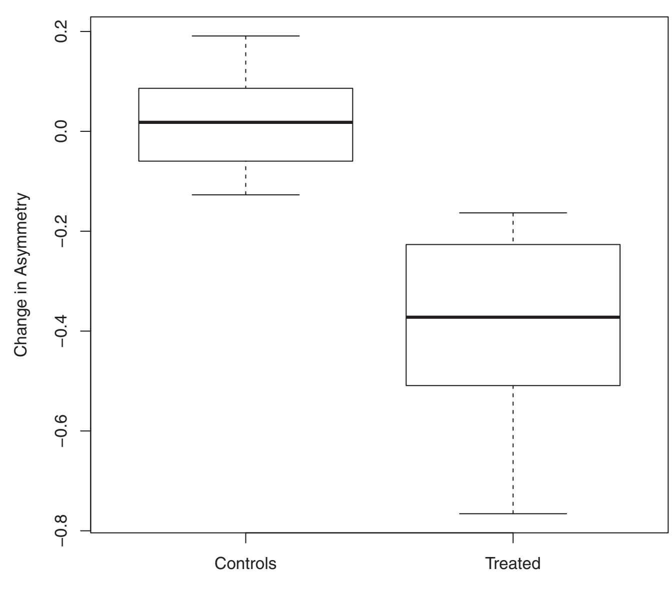

Fig. 3. Box plots indicating a significant difference ($P < .001$) between the treated group mean change in asymmetry and the control group mean change in asymmetry. Asymmetry improved when the change was negative.

some individual locations may increase, decrease, or show no significant change in *multifidi* CSA.

Functional electrical stimulation has been used to reduce muscle spasms, as well as to recover muscle from atrophy and has been shown to improve scoliosis [50–56]. Therefore, the decreased asymmetry of the *multifidi* post-FES, through either an increase or decrease of the left and right *multifidi* CSA found in this study, is in agreement with the literature. In addition, if only unilateral change in the CSA of muscle is necessary to obtain symmetry, then the CSA of the contralateral muscle most likely remains essentially the same. In general, any means that only produces a unilateral increase of the CSA of a muscle may not be advisable if that increase brings the bilateral musculature out of balance.

Asymmetry was evaluated at each location site, but to overcome concern about statistical assumptions underlying corrections for multiple comparisons, we summarized location-specific measures of asymmetry to produce asymmetry scores for each horse. The mean change of this horse-specific asymmetry score for the treatment group (Table 4) was highly significant ($P < .001$), reflecting the multiple, location-specific, significant results (each $P < .05$) from Table 2. In contrast, Table 5 shows the same horse-specific calculations performed for the control group, and the mean change in asymmetry was insignificant, reflecting the insignificant location-specific results found in Table 3.

Finally, to determine that a significant difference existed between the treatment and control groups, Fig. 2 shows that changes in asymmetry between the two groups were significantly different ($P < .001$), with the treatment horses becoming homogenously more symmetrical post-FES when compared to controls. This homogeneity is apparent in the “asymmetry post-FES” column of Table 4. Therefore, the results indicate that the FES protocol used in this study shows strong evidence of an improvement in thoracolumbar *multifidi* symmetry in comparison to horses that did not receive FES treatments.

The results of this study differ from the results of previous studies, which found an increase in bilateral multifidi CSA after specific exercises were performed from the ground for 3–5 days per week for 6–12 weeks [30,57,58] with one of the studies, including the addition of under-saddle exercise [57]. Human research has indicated that to improve spinal symmetry, the hypertonic muscles are trained to be less active, and the hypotonic muscles are trained to be more active [59], supporting the results of this study. Future research could compare the use of FES and ground exercises to improve the symmetry of the thoracolumbar *multifidi*.

The limitations in this study include the loss of some location-specific data for some horses during imaging, and this was accounted for by averaging only over those locations with existing values of measurement. Treatment was not randomly assigned; however, treatment and control groups were chosen without bias, and the groups were considered representative of the population of horses. In addition, the Sidak correction for multiple comparisons leads to a reduction of type 1 errors at the expense of type 2 errors. The Sidak correction is justified by our assumption of positive dependencies between spillover treatment effects across locations. Since the precise nature of these spillover effects remains unknown, loss of power from the conservative Sidak correction leaves open the possibility that some location-specific positive treatment effects have not yet been clearly identified. Future multilevel experiments with random treatment assignment to horses and site-locations could precisely determine parameters describing the spillover effects. In addition, further research could also investigate the correlation between asymmetrical *multifidi* CSA and back pain.

After treatment for each treated horse with 24 FES treatments to the thoracolumbar region over 8 weeks, compared to controls receiving no FES treatments, the results of this study found:

1. A significant ($P < .001$) improvement in symmetry of the *multifidi* in the treatment horses when compared to controls.
2. Significant improvements in *multifidi* symmetry in the treatment group (each $P < .05$) at each thoracolumbar location site.
3. A combination of increases, decreases, and maintenance of the CSA of the left and right *multifidi* may be necessary to improve symmetry.
4. A clinical improvement in muscle symmetry in the post-FES horses was observed, which was likely related to the bilateral muscle contraction and perfusion induced by FES treatment.

Thus, the FES protocol used in this study presented evidence of a positive effect on the improvement in symmetry of the thoracolumbar *multifidi,* which may, therefore, assist in improving spinal function and reducing back pain in the horse.

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Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jevs.2020.103255.

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