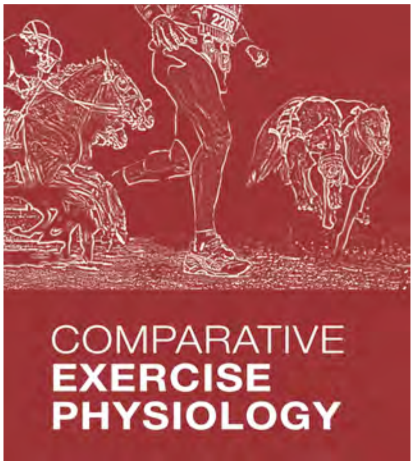

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cep_cr@wageningenacademic.com
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Functional Electrical Stimulation (FES) for Equine Epaxial Muscle Spasms: Retrospective Study of 241 Clinical Cases

S. J. Schils[1], T. A. Turner[2]
[1]Equine Rehabilitation, 8139 900th Street, River Falls, WI 54022; [2]Anoka Equine Clinic, 16445 70th St NE, Elk River, MN 55330
sbSchils@pressenter.com

Abstract
A retrospective study of 241 clinical cases, utilizing over 1800 Functional Electrical Stimulation (FES) treatments to alleviate epaxial muscle spasms, showed that almost 80% (191) of the horses had a 1-grade improvement in muscle spasms after 2 FES treatments, based on the Modified Ashworth Scale adapted to horses. In addition, 60% (142) of these horses showed a sustained improvement for a minimum of 2 months.

Keywords: rehabilitation, electrotherapy, spasm, horse

1. Introduction

Extensive research studies in the area of human rehabilitation have shown that early muscle activation after injury or surgery will improve healing (Kannas *et al*., 1992), and extrapolation of these early mobilization concepts for equine use is compelling (Schils and Turner, 2010). However, application of early mobilization by equine practitioners has been trailing human rehabilitation because of the limited techniques and devices available. Excellent passive mobilization exercises have been evolving (Denoix and Pailloux, 2005; Goff and Stubbs, 2007; Stubbs and Clayton, 2008) and the addition of therapeutic modalities that provide active mobilization options will continue to improve the outcomes of rehabilitation.

One device that can be used for early mobilization in equine rehabilitation is Functional Electrical Stimulation (FES), a specific type of Neuromuscular Electrical Stimulation (NMES) (Schils, 2009). FES is the application of an electrical current through surface electrodes to produce a controlled muscular contraction. A microprocessor generates a train of impulses, which imitate the neural signals that pass between the spinal cord and the peripheral nerves in healthy muscle producing a muscle contraction (Rattay *et al*., 2003). In muscle, where this pathway is disrupted, muscle spasms, atrophy and pain are the result. Spasms originate when there is a hyperexcitability of neurons, which causes the muscle to constantly contract, resulting in pain and tetany (Katx and Rymer, 1989). FES is utilized to disrupt this constant hyperexcitability, returning the muscle to its balanced contraction and relaxation phases, therefore reducing pain (Yarkony *et al*., 1992).

Contractions of muscles by FES at higher intensities produces coordinated limb or body movements generating joint movement. Therefore, controlled movement can be obtained by FES not only by the muscles, but also by the associated tendons and ligaments. The movement attained using FES is almost identical to the movement observed in the functional coordination of muscles needed to perform a task (Stackhouse, 2008), therefore giving the therapy its name. In comparison, other nerve and muscle stimulators do not produce true muscle contractions and obtain only a tremor or a twitch in the muscle that is being stimulated. Joint movement can be obtained by these systems with higher amplitudes, however the voltage needed is typically 10 times higher than required by FES. In addition, joint movements from these types of electrotherapy devices are rough, quick and non-functional.

The correct FES signal is a balanced waveform that does not allow for an accumulation of charge (a galvanic action). Due to the design of the FES system, 'the delivered charge is extracted out of the targeted tissue at the end of every single stimulation pulse' (Masani and Popovic, 2011). This feature is an important aspect when looking at the long-term safety of FES, especially in cases of continual use such as for bladder control or neuroprosthesis. Further evaluation of the safety of the use of FES has focused on fragile, dennervated muscle. In these studies, a decrease in damaged fibers and an increase in functional fibers were found with long-term use of FES for up to 10-years (Carraro *et al*., 2005).

In addition, the use of FES to reduce spasticity in humans has been reported in the literature for several decades (Billian and Gorman, 1992; Granat *et al*., 1993; Krause *et al*., 2007; Moore and Shurman, 1997; Repperger *et al*. 1997; Scheker *et al*., 1999). FES has successfully decreased muscle spasticity related to multiple sclerosis (Pease, 1998) and has been shown to reduce spasticity and improve dorsiflexor strength and lower extremity motor recovery in stoke patients (Sabut *et al*., 2011). Spastic leg musculature was significantly reduced when FES cycling was implemented with spinal-cord injury patients, resulting in an increase in isometric torque and less fatigue (Szecsi and Schiller, 2009). In other related studies, abnormal joint stiffness associated with spastic muscle decreased up to 53% when FES was used (Mirbagheri *et al*., 2002). In addition, a decrease in quadriceps spasticity, an increase in strength and an increase in stride length were found with the use of FES in partial spinal-cord injury patients (Granat *et al*., 1993). Research has also found that when FES was utilized for treatment of long-term spasticity in hemiplegic patients, a significant improvement in strength resulted (Stefanovska *et al*., 1989).

Appropriate FES can produce action potentials in the motor nerve that are almost indistinguishable from those produced by the nervous system (Robinson and Snyder-Mackler, 2008). To the individual receiving FES, the perception of the muscle contraction feels almost identical to a voluntary contraction. This sensation of a voluntary contraction, rather than of a muscle tremor or twitch, is an important consideration when selecting the appropriate electrotherapy device for equine use. The horse shows a high compliance to FES stimulation, even during deep muscle stimulation, and the ability of FES to closely replicate the motor neuron response could be one of the reasons this is true.

It is well worth noting that there are distinct differences between electrical muscle stimulators (EMS), of which FES is a specific class of, and transcutaneous electrical nerve stimulators (TENS) (Schils, 2009). In addition, the detailed waveform parameters of an electrotherapy device must be observed on an oscilloscope to determine its class, because labeling of a device is not always accurate.

In general, TENS has a current that quickly rises to a high intensity for a short duration and is designed to stimulate only sensory nerves. Motor nerves respond best to a very slowly rising current with a longer duration, which is produced by EMS devices. Sensory nerve stimulators are not designed to produce a muscle contraction, however, the voltage on these units can be increased to generate a muscle tremor or twitch. When an even higher voltage is used with a nerve stimulator, a rough, jerky joint movement can be produced.

To better obtain muscle movement through the targeted stimulation of motor neurons, EMS is used. However, the muscle contractions obtained by most EMS systems actually resemble the response from TENS units, and the waveforms must be evaluated to be able to clearly determine the specific class. The microprocessor-controlled FES system is the most sophisticated version of an EMS and produces smooth contraction and relaxation cycles, mimicking the body's own neuromuscular response.

The adaption of FES from human medicine for use in equine rehabilitation to reduce deep muscle spasms is compelling. Only a few practitioners have used FES during the last 20 years in the rehabilitation of horses, while other types of electrical stimulation have been used more widely. In equine practice, for a limited number of horses, FES has been shown to be a useful modality for the reduction of muscle spasms and atrophy (Schils, 2010). The purpose of this paper is to offer a retrospective review of a large number of case studies where FES was used to reduce epaxial muscle spasms in horses. In addition, a quantitative spasm scale was developed for use with horses as a means of normalizing muscle spasm palpation data by adapting an evaluation tool used in human physical therapy.

2. Materials and Methods

Over a time span of 13 years, 241 horses were treated for dorsal epaxial muscle problems with FES. The total number of FES treatments was 1832. Records were kept of each FES treatment on every horse, including veterinary diagnostics and clinical results as well as palpation findings.

The attending veterinarians either directly referred the horses for FES treatment, or if the clinician was contacted initially by the owner, the veterinarian was consulted before treatments were begun to obtain the diagnostic history of the horse.

The horses were almost all riding horses between the ages of 2-23 yrs, with one 2-mo old foal and 1 yearling. The disciplines ranged from cutting horses, reining horses, western pleasure, dressage, jumping and trail, with the majority of the horses being jumping and dressage.

The primary problems identified upon initial observation of the horses were; gluteal pain (2 horses), thoracic pain (18 horses), and lumbar and sacroiliac pain (221 horses). Eighteen of the horses were diagnosed by a veterinarian as grade 2/5 lame, 9 of the horses were grade 3/5 lame and the remaining 214 (89%) of the horses exhibited decreased performance with no specific lameness identified. Of the 18 horses diagnosed as grade 2/5 lame, 13 were diagnosed as hind-end lameness and 5 as front-end lameness. Of the 9 horses that were diagnosed as grade 3/5 lame, 8 were hind-end lameness and 1 was front-end lameness. Table 1 outlines the categories of the diagnoses and the number of horses in each category.

Diagnosis and Number of Horses												
Diagnosis	**Lumbar/Sacroiliac Pain**				**Thoracic Pain**				**Gluteal Pain**			
Total Horses	221				18				2			
Presenting Complaint	Lame		Decreased Performance		Lame		Decreased Performance		Lame		Decreased Performance	
Number of Horses	23		198		4		14		0		2	
Lameness Grade	Grade 2		Grade 3		Grade 2		Grade 3		Grade 2		Grade 3	
Lameness Location	front	hind	front	hind	front	hind	front	hind	front	hind	front	hind
Number of Horses	5	11	0	7	0	2	1	1	0	0	0	0

Table 1. Diagnostic categories and number of horses.

Clinical observations to determine the diagnosis of epaxial muscle pain were performed by the attending veterinarians during unmounted and mounted observations, on the straight line and on the circle, and in soft and hard surfaces. Palpations of the epaxial muscles were performed on all horses by both the attending veterinarian and the clinician performing the FES treatments. All horses diagnosed as having a graded lameness were determined by the attending veterinarian to have no associated distal limb lameness.

The FES system used was the FES310[a] and provided a pulsed, biphasic, rectangular waveform at 60Hz (Figure 1). The voltage applied to elicit contractions ranged from 3.8 to 11V and the treatment time was 35 minutes. Six surface electrodes, placed into a pad, were used to transfer the FES signal to the horse. The skin was sponged with water and ultrasound gel was used between the pad and the skin to reduce impedance.

Figure 1. Functional Electrical Stimulation (FES) system placement during treatment.

FES treatments were performed on the epaxial muscles of the longissimus, latissimus dorsi, multifidus, psoas, the superficial and middle gluteals and the dorsal edge of the biceps femoris muscle. For thoracic pain, the treatment pad was placed approximately between T10-L2. For sacroiliac and lumbar pain, the treatment pad was placed approximately from L1-S5, and for gluteal pain the treatment pad was placed approximately from L4-Coccygeal3. All the horses were treated with FES by one clinician. Table 2 lists the frequency of FES treatments used for the various epaxial muscle problems treated in this study.

Frequency of FES Treatments

Diagnosis	Category	Treatment
Dorsal Thoracic, Lumbar/Sacral and Gluteal Pain	Acute	2 Tx* within 12-48 hrs 3 Tx within 3 wks
Dorsal Thoracic, Lumbar/Sacral and Gluteal Pain	Chronic	2 Tx within 12-48 hrs 3 Tx within 3 wks 6 Tx within 1 yr
Overriding Dorsal Spinous Processes, Arthritis	Chronic	2 Tx within 12-48 hrs 3 Tx within 3 wks 12 Tx within 1 yr
Decreased Performance	Preventative	2 Tx within 12-48 hrs 2 Tx within 3 wks 4 Tx within 1 yr

Table 2. Average frequency of FES treatments to the epaxial muscles related to diagnosis.
*Tx = treatment

The Modified Ashworth Scale was used to determine the initial level of muscle spasm (Ashworth, 1964; Bohannon and Smith, 1987), and to grade the changes observed after the FES treatments (Table 3). This scale is widely used to objectively evaluate the rehabilitation progress for humans, and has been shown to have a 86.7% ($p<.001$) interrater reliability (Bohannon and Smith, 1987). The "catch" referred to in the scale designates the "jerk" felt by the practitioner at the moment the muscle releases to the steady pressure applied to obtain joint movement. A "catch" is not desirable because the movement of the joint should be smooth.

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 ROM*
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

Table 3. Modified Ashworth Scale for grading muscle spasms.
* ROM (range of motion)

Before each FES treatment, the grade of muscle spasm was determined thorough palpation of the epaxial muscles approximately 10 cm ventral to the dorsal spine together with palpation along the dorsal spine. Three palpations were performed over each area using the clinician's fingers on both sides of the horse. The same clinician performed all of the palpations and performed all of the grading of the muscle spasms based on the Modified Ashworth Scale. The degree and location of muscle spasms were recorded in the clinical notes before each FES treatment.

Descriptive statistics were used to analyze the data and explore the results of the study. There can be no inference made to the population with descriptive statistics, however many statisticians emphasize that descriptive statistics are useful to summarize and quantify the relevance of the data (Howell, 1987).

3. Results

Ultrasound was used to determine the depth of the FES signal utilizing an average treatment voltage of 7 volts with the placement of the treatment electrodes centered over the sacroiliac. During FES treatments, ultrasonagraphic video was taken with the probe placed at T17-T18. The video showed a clear view of the multifidus, which lies along the transverse processes of the spinal vertebrae, the longissimus muscle, which lies dorsal to the multifidus and the psoas that lies below the multifidus. The videos showed clear contraction and relaxation of the longissimus, multifidus and psoas muscles in synchronization with the pulsed stimulus during FES.

About 50% (119) of the horses in the study received 2 to 4 treatments, while the other 50% (122) received a minimum of 5 treatments (Table 4). Almost 30% (71) of the clients continued with serial FES treatments of over 10 treatments because they determined that the treatments were beneficial to the continued progress and comfort of their horses even after the initial spasm was resolved.

Percentage of Horses	Number of FES Treatments
49.4	2 to 4
21.2	5 to 9
15.4	10 to 19
14.1	20 to 66

Table 4. Percentage of horses receiving a specific number of FES treatments.

Many of the horses that received 2 to 4 treatments were horses where the clinician traveled a long distance to treat the horses. Due to this distance, return trips were sometimes not possible to provide further treatments.

The length of time the horses underwent FES treatments varied from 2 days to 6.5 yr (Table 5). Thirty-three percent (80) of the horses had treatments under 1 mo and 40% (96) of the horses had treatments for 6 mo to 6.5 yr. During the treatment period the owners were encouraged to exercise their horses through mounted and/or unmounted exercises and to discuss with the clinician any specific changes they were feeling in the movement of the horse.

Percentage of Horses	FES Treatment Duration
33.0	2 days to <1 mo
25.0	1 mo to 5 mo
12.5	6 mo to 11 mo
22.0	1 yr to 3 yr
5.5	3.1 yr to 6.5 yr

Table 5. Percentage of horses compared to duration of FES treatments.

Palpation by the same clinician was used to determine the grade of the muscle spasm during the initial observation before the first FES treatment. The spasm grading was based on the Modified Ashworth Scale (Table 3). The majority of the horses (117) were rated at Grade 2, indicating a high level of muscle spasm although spinal movement was possible (Table 6).

Percentage of Horses	Initial Spasm Grade
0.4	1
12.0	1+
73.5	2
14.1	3

Table 6. Percentage of horses at each grade of spasm (Modified Ashworth Scale).

Improvements were defined as a change in the spasm scale to a lower grade, indicating reduced muscle spasms. These evaluations were performed by palpation of the horse's back before each subsequent FES treatment, and the spasms were also graded based on the Modified Ashworth Scale. In addition, visual examination of the horse's movement at the walk, trot and canter, and evaluations by the rider and/or trainer were recorded. The attending veterinarian also offered information concerning the progress of the horse.

Table 7 shows that an improvement by 1-grade of muscle spasm happened quickly. Almost 80% (193) of the horses improved by one grade of spasm after 2 treatments, and an additional 14% (33) of the horses showed a change in one grade of spasm after 3 treatments. During this time, none of the horses had any additional interventions that would have skewed the results, including joint injections, chiropractic or acupuncture treatments, or nutritional changes.

Percentage of Horses	# of Tx for One Grade Change
79.3	2
14.1	3
2.9	4 to 5
3.7	No improvement

Table 7. Percentage of horses and number of treatments to obtain one grade of muscle spasm improvement (Modified Ashworth Scale).

From this group of 193 horses, 191 were ridden and 75% (143) of these riders commented that the performance of the horse notably improved after 2 treatments. Some of the most common remarks were that the horses felt “looser”, “more willing to move forward”, “more up in the back”, ”steadier” and “smoother with their stride”.

The 3.7% (9) of horses that showed no improvement in spasticity had 5 or fewer treatments, with the majority of these horses (7) having only 2 or 3 treatments. Only one of the horses rated at grade 3 spasm showed no improvement during the FES treatments.

The horses diagnosed with a graded lameness also showed improved lameness scores. Treatments were only performed on the epaxial muscles of the horses graded as lame. The treatment site was selected by determining, through palpation, where the highest degree of muscle spasm existed. After 6-8 treatments, 20 of the 27 horses were graded as not lame and the remaining 7 horses showed an improvement in 1 grade of lameness. Once the spasms were reduced in the treated horses, the return of the epaxial muscles to a better symmetry was observed. (Figure 2)

Long-term follow up of the cases found that 60% (142) of these horses had a sustained reduction in the targeted muscle spasm for a minimum of 2 mo. After 2 mo, almost 30% (72) of the clients continued with more than 10 FES treatments because they determined the treatments were beneficial to the continued progress and comfort of their horses, and reduced reinjury rates.

Of the remaining 99 horses, where sustained improvement of 2 mo or more was not observed, 92% (91) of these clients saw some improvement in their horses but elected to not continue due to the cost of the treatments, sale, or retirement of the horse. Only 8% (8) of these clients saw no changes in their horses after the FES treatments and one of those clients commented that the horse got worse.

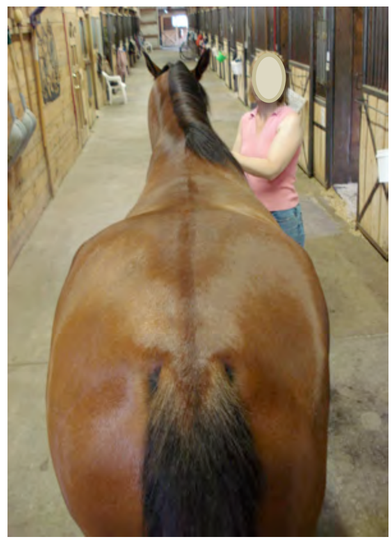
4. Discussion

The benefits of FES in human rehabilitation have been well documented in the literature for several decades. FES has been used to reduce atrophy, decrease muscle spasticity, reduce inflammation and scar tissue, re-educate muscle function, and strengthen muscles and tendons (Deftereos *et al*., 2010; Lake, 1992; Pease, 1998; Quittan *et al*., 2001). FES can be used to stimulate deep muscle tissue and therefore strong muscle contractions are possible which are needed to produce functional movement. Functional movement works both agonistic and antagonist muscles helping to reduce unbalanced muscle development. In addition, if the functional movement is obtained symmetrically, lateral limb overuse or underuse can be reduced. Studies have also found that stronger muscle contractions are more effective for reducing pain and the benefits are longer lasting (Duranti *et al*., 1988; Picker, 1988a; Picker, 1988b; Sjolund *et al*., 1977). In human research FES has been shown to be safe even with long-term use for up to 10 years on denervated muscle (Carraro *et al*., 2005).

Pre-FES Treatments

After 7 FES Treatments

Pre-FES Treatments



After 7 FES Treatment

Figure 2. Pre and post FES treatment evaluations showing improvement in symmetry of topline.

FES stimulation of the muscle at higher intensities will generate joint movement, therefore obtaining controlled movement of not only the muscles, but also of the associated tendons and ligaments. Human research has found that using electrical stimulation early in the rehabilitation process of anterior cruciate ligament reconstruction and total knee arthroplasty improved the functional ability of the knee when compared to the controls that received no electrical stimulation (Stevens-Lapsley *et al*., 2012; Synder-Mackler *et al*., 1994a; Synder-Mackler *et al*., 1994b; Synder-Mackler *et al*., 1995). In addition, the maintenance of muscle strength during the rehabilitation process was significantly better with electrical stimulation than with the control.

However, there are some differences in the physiological response of muscle tissue to electrical stimulation when compared to a normal muscle contraction. The main difference is the method of recruitment of muscle fiber types (and the associated nerves) between electrical and normal contractions. There are two views concerning the recruitment pattern. One view is that the muscle fiber recruitment during FES is the opposite of the normal recruitment order. It is theorized that with electrotherapy, the large diameter fibers (fast twitch) are activated before the smaller diameter fibers (slow twitch) probably due to the wider spacing between nodes (Andersen *et al*., 1996; Binder-Macleod *et al*., 1995).

Other research, that suggests the second view on muscle fiber recruitment during FES, has shown that the recruitment pattern is nonselective and therefore all motor units are activated simultaneously (Gregory and Bickel, 2005). For rehabilitation purposes, it is not that important which of these theories of recruitment are correct. However, it is important that if all muscle fiber types can be recruited during the early stages of rehabilitation, there will be a significant benefit to the overall rehabilitation outcome. The typical rehabilitation program after injury or surgery involves low stress to the muscles and joints so the fast-twitch fibers would rarely be recruited. With FES, these fast-twitch fibers can be recruited early in the rehabilitation process allowing for faster and greater strength gains (Andrew *et al*., 1998).

The use of FES in this study to reduce muscle spasms showed that improvements by one degree of spasm, based on the Modified Ashworth Scale, happened quickly. Within 2 treatments, more than half of the horses had a sustained reduction in the targeted muscle spasm for a minimum of 2 mo. Clients were pleased with the results of the FES treatments and almost 30% of the clients elected to continue treatments over 10 sessions due to the fact they felt the horses continued to improve their performance even after the initial spasm was reduced.

The clients who elected to continue with long-term treatments of over 6 mo, commented that once the initial problem was resolved, they felt that the FES treatments helped the horses achieve a faster and improved rate of training and improved performance over time. Serial FES treatments were not only able to assist in alleviating the primary muscle spasms and make the horses more comfortable, but may also have been useful in dealing with improvements in the overall symmetry of the horses.

The horses accepted the sensation of the FES stimulus willingly without sedation and displayed comfortable posture during almost every treatment. This high compliance is most likely due to the fact that FES mimics the body's natural motor neuron response, so the movement obtained by FES feels like voluntary muscle contractions to the horse.

A limitation of this study included the fact that the information presented was initially gathered as treatment notes, rather than data for a predesigned study. However, due to the detailed notes and objective scoring system used during the evaluations and treatments, the data could be compiled and compared between large numbers of horses over a period of several years. Another limitation of the study was that the Modified Ashworth Scale, which was used to objectify improvements in the horses, was taken from human rehabilitation. While this scale may not be a perfect means to objectify the change in degree of epaxial muscle spasms for horses, the author found the scale to be useful to obtain subjective palpation evaluations. Other means could have been employed to objectify the reduction in spasms, such as pressure algometry, and could be used in future studies.

These case studies show that the use of FES to decrease muscle spasms and pain in horses can be a viable treatment option. The horses responded well to the treatments and even the deep epaxial muscles of the horse could be treated. A relatively quick reduction in muscle spasms were observed, client satisfaction was high and sustainment of the treatment results were obtained. An expanding use of FES in the future will provide additional information regarding the usefulness of this specific class of electrotherapy in equine practice. FES can be an effective modality for treatment of muscular pain in horses, however it is not extensively utilized.

5. Conclusions

Functional Electrical Stimulation (FES) has been successfully used in human rehabilitation to reduce muscle spasms, and has also been shown to reduce spasms in a limited number of equine cases. A retrospective study of the use of FES in 241 horses, with a total of 1832 treatments, found improvements of 1-grade of muscle spasm, based on the Modified Ashworth Scale, after 2 FES treatments in 80% (191) of the horses. Long-term follow up of these horses found that 60% (142) had a sustained reduction in the targeted muscle spasm for a minimum of 2 mo. Almost 30% (71) of the clients continued with more than 10 FES treatments because they determined the treatments were beneficial to the continued progress and comfort of their horses.

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[a] FES310, EquiNew LLC, River Falls, WI 54022

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