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# Applying functional electrical stimulation (FES) in the rehabilitation of muscle and tendons in horses

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**Abstract**
Functional electrical stimulation (FES) is a specific class of electrotherapy that has been developed for use in equine rehabilitation. Treatments with FES have shown promise in reducing muscle spasms or atrophy, strengthening muscles and reeducating muscle memory to improve function and symmetry after injury or surgery. In addition, FES has been used in a limited number of cases to improve tendon and ligament healing in the distal limb. FES has been used extensively in human rehabilitation and the potential for use in horses is developing.

**Keywords**
equine, electrotherapy, spasm, atrophy

## Introduction

The use of modalities to aid in rehabilitation protocols is a developing science and there are many tools equine practitioners can use to assist in the implementation of a rehabilitation plan. An understanding of these tools helps the practitioner to decide which modalities should be used, and when. One of these emerging tools for rehabilitation, which will be discussed in this paper, is called Functional Electrical Stimulation (FES).

FES is a specific class of electrotherapy and is distinctly different from other electrotherapy devices such as TENS (transcutaneous electrical nerve stimulator), galvanic and HVPC (high-voltage pulsed-current) stimulators (Schils, 2009). The term FES is sometimes used interchangeably with NMES (neuromuscular electrical stimulation) systems, and while FES is a type of NMES, this exact exchange of names is not accurate. The American Physical Therapy Association outlines the designations of the classes of electrotherapy devices (Alon, *et al*., 2005), but manufacturers do not always carefully follow these designations. Care must be taken when evaluating an electrotherapy device, because some systems may be labeled as a different class from what their parameters are.

FES produces controlled muscular contractions through the use of a specific electrical current that has been generated by software. The electrical signal produced by FES creates an action potential in the peripheral nerve, which then activates muscle contractions in the related muscle tissue (Rattay, *et al*., 2003). The FES signal is designed so that it is almost indistinguishable to those produced by the body's own nervous system (Stackhouse, 2008).

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 obtained 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, for up to 10-years, 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 (Carraro *et al*., 2005).

Differences do exist in how the muscle fiber types respond to electrical stimulation, when compared to the response elicited by the brain. In the normal physiological activation of slow- and fast-twitch fibers, fast-twitch fibers are only activated when quickness and speed are obtained. However, during FES treatments, both slow- and fast-twitch fiber recruitment occurs at the same time (Gregory and Bickel, 2005). This aspect can be very beneficial for many rehabilitation protocols because these fast-twitch muscle fibers may not be accessed for several months. FES can be used to activate all fiber types helping to avoid fiber atrophy during the rehabilitation period, therefore allowing for faster and greater strength gains (Harrelson, *et al*., 1998). In addition, as a further aid to healing, FES has been shown to increase the size of myofibers and cause regeneration of new myofibers (Kern, *et al*., 2004).

Discussing the transfer of the application of FES from human rehabilitation into equine therapy is the focus of this paper. This paper will outline the use of FES in human rehabilitation and conversely how this technology is being implemented in equine rehabilitation protocols.

**FES use in human rehabilitation**

Several decades ago FES was first used in the rehabilitation of spinal cord injury patients to generate muscle movement to prevent atrophy. Today, FES has been shown to be effective for multiple purposes including the treatment of both spastic and flaccid muscle and to restore grasping and reaching functions (Kawashima, *et al*., 2008; Thrasher, *et al.*, 2008). Studies in rats that evaluated the neuroplasticity of reinnervation has shown that FES can delay muscle atrophy by producing better nerve conduction and higher muscle weights (Lim and Han, 2010) and can restore muscle size, and functional and histochemical properties when compared to no stimulation (Marqueste *et al*., 2006). Additional human studies have shown the ability of FES to reverse muscle atrophy for denervated muscle tissue to obtain standing and walking in spinal cord injury patients (Gallien, *et al*., 1995; Graupe and Kohn, 1998; Graupe, *et al*., 2008; Mushahwar, *et al*., 2007; Yarkony, *et al*.,1990) . Other research on humans has shown that FES can prevent and even reverse atrophy of chronically denervated muscles when evaluated by muscle biopsies and knee extension torque (Kern, *et al*., 2002; Kern *et al*., 2005; Kern, *et al*., 2008).

FES has also been utilized to suppress spasticity in many studies. FES was shown to successfully decreased muscle spasticity related to cerebral palsy (Johnston and Wainwright, 2011) and multiple sclerosis (Krause *et al*., 2007). Even in the cases of strong flexor spasticity in the hands of hemiplegic stroke patients, stimulation of the extensors by FES was able to obtain hand opening. However, it was interesting to note that extensor stimulation did not reduce flexor activity as hypothesized, probably due to the generation of the stretch reflex (Hines, 1994). 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). Even long-term spasticity in hemiplegic patients showed a significant improvement in strength when FES was utilized (Stefanovska *et al*., 1989).

Reeducation of muscle memory has also been shown to be a result of FES. Studies of FES spinal cord injury patients found improved muscle movement even when FES was not being applied (Popovic, *et al*., 2009). An evaluation of the use of FES for gait rehabilitation after stroke, showed that retraining strategies, which included FES, were more effective than retraining alone. Near infrared spectroscopy (fNIRS) was used to determine the neuroplasticity of the cortex, which occurred during retraining with FES (Belda, *et al*., 2001). In addition, FES was used to show improved motor functional recovery and improved range of motion in hemiplegic patients when compared to controls (Wang, *et al*. 2002). Another interesting study of 10 patients with chronic facial nerve paralysis showed improvement in facial muscle movement with electrotherapy when other forms of treatment were non-effective (Hyvarinen, *et al*., 2008).

Cardiovascular exercise can be obtained for spinal cord injury patients using FES to pedal a bicycle. Improvements were observed in muscle endurance, speed, and strength and increases in aerobic metabolism and endurance were seen, although the changes were not more than would be obtained with voluntary exercise (Arnold, *et al*., 1992; Pollack, *et al*., 1989). Other human studies found a significant increase in heart rate and an improvement in blood flow (Faghri, *et al*., 2001), and an increased respiratory rate during FES cycling (Jacobs, *et al*., 2003) for spinal cord injury patients, which improved their overall conditioning and health.

**FES use in equine rehabilitation**

FES has been utilized in equine rehabilitation for almost 20 years, however the number of practitioners using FES is small. The FES technology for equine practice was modified from equipment used for humans, and treatment protocols specific to the horse were developed. FES has been shown to be a useful modality, in a limited number of horses, for the reduction of muscle spasms and atrophy (Schils, 2010), and muscle wasting (Schils, 2012).

The majority of the FES applications on horses has focused on treatments of epaxial and deep muscle spasms and atrophy. Ultrasound video taken during FES stimulation at T17-18 has shown that the signal can penetrate to the psoas muscle.

A pad, similar to a saddle pad, is used to hold 6 electrodes (3 on each side) in place so that the signal is symmetrical when the pad is used over the spine. The intensity of the FES signal is increased slowly until small contractions are felt or seen. The higher the voltage the deeper the signal will penetrate. Typically the first contractions are seen in top line treatments at approximately 3-5 volts. The voltage is increased as long as the horse is comfortable and at 5-9 volts spinal flexion or joint movement is usually observed. The degree of movement is dependent upon the purpose of the treatment and the comfort of the horse. In certain situations, such as acute tendon tears, the voltage is controlled so that only the cells are stimulated and no movement is obtained. Compliance to the treatment is excellent. No sedation is required and sedation is actually contraindicated. This is due to the fact that the horse's reaction to the increase in voltage is important to determine how much movement should be asked for.

The response of the muscle to the stimulation, observed in the degree and type of contractions under each electrode, is noted. Horses, depending on their specific muscular or skeletal problems, will respond differently to the stimulus. Some horses will show slow, steady contractions, followed by a slow, steady relaxation mimicking the signal of the FES system. In contrast, other horses will show distinct fasciculations with no clear pattern or relaxation phase in response to the stimulus. The joint movement during the FES treatments in some horses will be smooth, while other horses will show rough, jerky movement. The association between a smooth, steady contraction/relaxation cycles, that mimics the FES signal, to healthy well-functioning muscle seems to be prevalent.

When the electrodes are positioned so that the signal crosses the spine, bilateral, symmetrical functional movement can be obtained. When the pad is placed over the sacroiliac, the horse sometimes show a twist to the pelvic rotation rather than symmetrical caudal/cranial movement. If the muscle physiology of the horse is distinctly asymmetrical, the movement obtained through FES stimulation seems to reflect that. Therefore, the practitioner can observe the dynamic movement of the muscles and associated joints, or lack of movement, to help determine the progression of the rehabilitation plan. Dynamic movement evaluation is always a valuable tool when evaluating horses, and FES allows the observation of this dynamic motion in a controlled environment.

In horses that show asymmetrical movement to the FES signal, the goal of further FES treatments is to obtain movement that will become more and more symmetrical, due to the reeducation of the muscle memory through repetition. Most horses that begin FES treatments with an asymmetrical, twisting and rough rotation in the pelvis, showing no clear contraction/relaxation cycle will gradually become more symmetrical with a straight, smooth rotation in the pelvis and a clear contraction/relaxation cycle. The symmetry that develops in the top line can then support a more correct biomechanical loading of the joints in the body as well as in the limbs. Many overuse injuries are due to asymmetrical overloading of the muscles and joints as well as pathological rotation. Therefore, changing the muscle memory to obtain symmetrical movement is a valuable tool in rehabilitation.

FES treatments to the neck can also help reduce spasms and atrophy in the cervical spine region. Six self-adhering electrodes (3 on each side) are placed symmetrically on each side of the neck. Several different arrangements of the electrodes are used based on which muscles of the neck are being addressed. The reaction of the neck muscles to the FES signal is similar to the response of the epaxial and deep muscles of the back. Some horses will have a twist in their neck, as a reaction to the treatment, while other horses will show smooth, straight movement.

Specific sites in the shoulder area and the hindquarters can also be treated unilaterally by placing self-stick electrodes on the targeted site or by holding a pad with electrodes over the site. It is always suggested that if one side of the horse is treated, that the other side is also treated to evaluate and maintain symmetry. Typically, the “normal” side is treated initially to obtain the parameters of the level of voltage the horse will comfortably accept and the horse’s reaction to the treatment, so that a comparison can be made during the treatment of the “abnormal” side.

For FES treatments on the limbs, a smaller pad is used containing 6 electrodes (3 on each side) that are smaller than those used in the back pad. Upper leg FES treatments of the flexor and extensor muscles of the forearm and gaskin can be used to assist in treating lower-leg tendon and ligament issues. At higher voltages, some horses will flex or extend the lower legs in response to the treatment, however this type of movement is rare. Improvements in the quality of the tendons and ligaments, using ultrasound evaluations, have been limited when the pad is placed on the front or hind upper leg.

FES treatments on the lower legs below the knee and hock will produce more movement in the tendons. The FES signal on the lower legs can be adjusted so that the voltage used will obtain no flexion in the fetlock, a 25% flexion in the fetlock, a 50% flexion in the fetlock, or a complete lifting of the leg in response to the treatment. Using this position of the FES signal on the legs has produced better healing of tendons and ligaments, when evaluated by ultrasound, than on the upper leg. Clinicians using FES on the lower legs have noted an improved rate of healing and a higher quality to the healing tissue. This data is limited and more treatments, with additional data, needs to be collected.

Suspensory ligament, superficial flexor and deep digital flexor strains, sprains and tears have all been treated with FES. The benefits of using FES for these issues includes; an activation of the stretch reflex to assist in fiber alignment during healing, activation of the tissues to reduce edema, and controlled movement to help reduce excessive fibrin and scar tissue that may develop during healing.

When FES treatments are applied to the limb of the horse, body treatments are performed as well. These body treatments can be to targeted sites such as the shoulders or hindquarters, as well as to the top line. Asymmetries in the body will affect the limb in the same way that asymmetries in the limb will affect the body.

Performance enhancement is another benefit of FES treatment. Horses that are asymmetrical load their body and limbs in a manner that predisposes itself to breakdown. Pathological rotations are the result of incorrect loading, and kinesiological consequences are not far behind these problems. When a practitioner observes an asymmetrical knot of muscle in the loin and this spasm is reduced through the use of FES, the chances of compensatory biomechanical changes in the limbs due to this spasm are reduced. Perhaps this change can then help to reduce a breakdown in the future.

Data from hundreds of case studies, showing thousands of treatments of FES to the top line of the horses have documented improvements pre and post FES treatments. These results together with muscle biopsies taken pre and post FES treatments and ultrasound measurements of the multifidus taken pre and post FES, are all studies being prepared for publication. The positive results from many practitioners throughout the world who are using FES shows that this modality may be worth another look as a tool to assist in moving the science of equine rehabilitation forward.

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