Journal of Equine Veterinary Science 113 (2022) 103934

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

Effectiveness of Neuromuscular Electrical Stimulation and Dynamic Mobilization Exercises on Equine Multifidus Muscle Cross-Sectional Area☆

Raquel Gómez Lucas[a,*], Isabel Rodríguez-Hurtado[b], Carla Troteaga Álvarez[a,1], Gustavo Ortiz[c]

[a] Veterinary Teaching Hospital, Hospital Clínico Veterinario, Universidad Alfonso X el Sabio, Avenida de la Universidad s/n, Villanueva de la Cañada, Madrid, Spain
[b] Veterinary School, Facultad de Veterinaria, Universidad Alfonso X el Sabio. Avenida de la Universidad s/n. Villanueva de la Cañada, Madrid, Spain
[c] Veterinary Teaching Hospital, Hospital Clínico Veterinario Complutense. Universidad Complutense de Madrid. Ciudad Universitaria s/n, Madrid, Spain

ARTICLE INFO

Article history:
Received 19 January 2022
Received in revised form 4 March 2022
Accepted 14 March 2022
Available online 18 March 2022

Keywords:
Equine rehabilitation
Equine back pain
Multifidus muscle
Neuromuscular electrical stimulation
Dynamic mobilization exercises

ABSTRACT

Equine back pain can potentially initiate an unstable intervertebral situation that results in atrophy and dysfunction of the epaxial muscles even after back pain has resolved. Several physiotherapy approaches are advocated to promote the strengthening of the multifidus muscle. This study aimed to asses and compare the effect of dynamic mobilization exercises (DME) and neuromuscular electrical stimulation (NMES) in 8 adult horses (4 individuals by group) to increase the cross-sectional area (CSA) of this muscle after a 7-weeks period treatment. The epaxial muscles of NMES group were electrical stimulated during 10 minutes per session, 4 days a week for 7 weeks, yielding a total of 28 sessions per individual. Horses included in DME group were trained to move the chin to a specific position (three different cervical flexions, one cervical extension and three different lateral bending exercises) to the left and right sides, repeated 5 times per session, completing 28 sessions. Ultrasonographic images of the left and right multifidus muscle were acquired at 3 different spinal locations (T12, T16 and L2) at the initial and the end of the experiment. Significant increases ($P < .050$) in its CSA were obtained at all levels considered (except at T16), consistent with a 18.65% and 13.41% increase after NMES and DME, respectively. These results suggest that a 7-week period of DME or NMES treatments are useful to increase the CSA of the multifidus muscle in horses, and hence, these two therapies could be combined during a back-rehabilitation program to improve the spine stabilization in horses.

1. Introduction

Control of flexibility, mobility and stability of the back have been widely investigated in horses. These concepts are integral to the equine core, which includes the body axis (spine and its associated soft tissues like ligaments and muscles from the cervical region to the pelvis) and extrinsic muscles of the limbs. The equine core is essential for maintaining body posture and for providing suppleness in the generation of locomotor forces [1].

Several muscle groups contribute to ensuring back strength and facilitate movement. The more superficial epaxial muscles (*iliocostalis* and *longissimus m.*) have long fibers that span along many vertebral levels [2], whereas the deeper epaxial *multifidus m.* is divided in five short fascicles for each spinal level that spread cranio-caudally over five intervertebral joints [3]. Additionally, the abdominal muscles (*transversus, rectus abdominis*, and the *internal and external oblique m.*) and the hypaxial sublumbar group lie ventrally to the transverse processes of the vertebrae [4].

Functionally, the *longissimus m.* contributes to extend the spine [5], and participates in lateral bending movements [6], whereas

☆ Conflict of interest statement: None.
Animal welfare/ethical statement: This study was approved by the Ethical Commission of Animal Use of the University Alfonso X el Sabio in accordance with the ethical principles of animal experimentation to RD 53/2013.

* Corresponding author at: Raquel Gómez Lucas, LV, PhD, DACVSMR, Veterinary Teaching Hospital - Equine Sport Medicine and Rehabilitation Service, Universidad Alfonso X El Sabio, Avda. de la Universidad n1, 28691 Villanueva de la Cañada, Madrid, Spain.
E-mail address: rgomeluc@uax.es (R.G. Lucas).
[1] Present address: Equine Veterinary Medical Center, Al Shaqab gate 9, Education City, Doha, Qatar

https://doi.org/10.1016/j.jevs.2022.103934
0737-0806/

the *multifidus m.* has a significant role in the segmental stabilization of the intervertebral joints and maintains the vertebral motion segments neutrality in several species, including horses [7]. *Multifidus* m. also avoids an abnormal rotation during the contraction of antagonist muscles, being activated in anticipation along with the *transversus abdominis m.* in order to stabilize the spine prior to and during body movement [8,9]. The abdominal and hypaxial sublumbar muscles ensure flexion of the spine [4].

Back pain is one of the main complaints that impair athletic performance in sport horses. In this scenario, a vicious cycle of discomfort inhibits muscle activity that results in intervertebral joint instability. It is well known that back pain in people inactivates the *multifidus m.*, and therefore decreases the spine stabilization [10]. Similar findings supporting a clear relationship between back pathology and muscle wasting have been described in previous reports. Progressive atrophy of *multifidus* and *longissimus m.* has been observed following back pathology in the horse [11,12]. Also, this condition has been identified as a predisposing factor in recurrent back pain and related lesions, such as osteoarthritis of the intervertebral joints [3,13]. In addition, asymmetry of the *multifidus m.* may be found with unilateral back pain both in man [14] and horses [12,15], with persistent atrophy and lack of functionality leading to intervertebral instability even after back pain has resolved [13,16].

Changes in the *multifidus m.* can be identified with ultrasonography. This imaging modality enables evaluation of the symmetry and cross sectional area (CSA) of the *multifidus m.* in response to therapeutic exercises aimed toward muscle activation and strengthening [16].

For all these reasons, and based on the human model of back pain, different physiotherapy strategies have been developed in horses in order to activate the *multifidus m.* Previous reports suggest that cervical dynamic mobilization exercises (DME), that target the cervical and thoracolumbar spine, may be useful for activating the deep epaxial and abdominal musculature and to promote hypertrophy of the *multifidus m.* at all spinal levels after a 3-month period of therapy [16]. Electrical stimulation has been widely used to strengthen and prevent atrophy of both normal and de-enervated muscles, to enhance muscular function and reeducation following a neurological damage [17]. Neuromuscular electrical stimulation (NMES) has been advocated as an effective mean in rehabilitation inducing muscle strengthening and motor recovery in human patients [18]. This therapeutic approach aims to produce controlled and visible muscle contractions generated by electrical high intensity impulses, which are directed toward the target muscle through a surface electrode [19]. NMES of the *multifidus m.* has been described to improve the control of intervertebral motion in the sagittal and frontal planes in people [20].

The aim of this study was to evaluate and compare two different therapeutic strategies, dynamic mobilization exercises and neuromuscular electrical stimulation, to increase the cross-sectional area of the *multifidus m.* at different back levels after a 7-week period treatment on sound horses.

2. Material and Methods

This study was approved by the Ethical Commission of Animal Use of the University Alfonso X el Sabio in accordance with the ethical principles of animal experimentation.

2.1. Subjects

Eight crossbreed retired horses that had been previously used mainly for pleasure riding, now belonging to the Veterinary Teaching Hospital of Alfonso X el Sabio Universitys̈ teaching herd, were used in this study. All horses were not trained nor ridden for more than 12 weeks before the research was initiated, so they were assumed in a homogeneous pretraining level. They were turned out in small paddocks of 4×6 meters dimension, 12 hours daily, depending on weather conditions, and were stalled in box at night. They were neither in a regular training program nor ridden during the study period.

Inclusion criteria specified sound horses with no evidence of back pathology or overt back pain during the initial clinical examination.

The horses were randomly divided in two different treatment groups. Four horses (two mares and two geldings), aged from 15 to 26 years of age (mean ± SD; 19.75 ± 4.87) were used in the neuromuscular electrical stimulation group (NMES group). Dynamic mobilization exercise group (DME group) included four horses (three mares and one gelding), aged from 9 to 31 years of age (mean ± SD; 16 ± 8.77 years).

2.2. NMES Treatment

The horses included in this group received NMES therapy for 10 minutes per session, 4 days a week for 7 weeks, yielding a total of 28 sessions per animal. The protocol selection, treatment duration, and the number of sessions per week were based on previous published literature where they were associated with a significant effect on muscle tone and strength after this therapy in both human [21] and veterinary patients [15,17,22].

Prior to NMES therapy, the skin of each horse at the right and left parasagittal back muscles was clipped and prepared with water and ultrasound gel to create good contact surface between the electrode and the skin.

Two channels with 2 electrodes each of 50×100 mm[1] were used to transfer the electrical signal. The electrodes were placed over the epaxial muscles of the horses, approximately at the level of T12 and T18, where two motor points were identified and created an effective muscle contraction when stimulated electrically. The electrodes were individually and slightly modified in position to identify the motor point that created the muscle contraction. Both right and left epaxial muscles were stimulated simultaneously (Image 1).

The electrical stimulation was performed with a portable muscle stimulator (Sonopuls 492[1]) held by an elastic belt around the horse thorax, that provided a pulsed, biphasic and rectangular waveform at 60 Hz and a pulse width set to 300 μs. The signal pulse included a ramp up phase lasting 2 seconds followed by a sustained phase of muscle contraction for 2 seconds, and a final decreasing ramp down for 2 more seconds.

The current intensity was set individually for each animal in order to produce an obvious visual and palpable contraction of the epaxial muscles, without creating any apparent discomfort for the horse. The voltage applied ranged from 12 to 14 mA at the beginning of the study and was increased during subsequent adaptation to stimulation sessions until 13.2 to 14.2 mA at the end of the experiment (see supplemental document).

2.3. DME Therapy

The four horses included in this group performed the exercises with the same frequency as the NMES group – 4 days per week during 7 weeks for a total of 28 sessions. The mobilization exercises were baited stretches as described previously [16], in which the horse was trained to move the chin to a specific position, and included three cervical flexions (chin to chest, chin to carpi, chin to fore fetlocks), one cervical extension and three lateral bending

[1] Enraf Nonius Iberica, Spain.

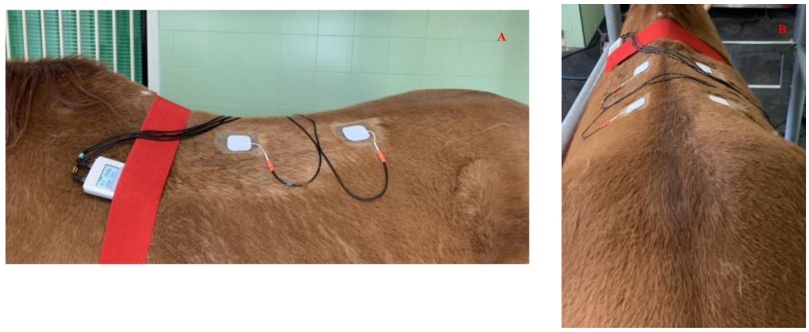

Image 1. Electrodes position over the epaxial muscles of NMES therapy horses. (A): lateral view; (B): caudal view. NMES, neuromuscular electrical stimulation.

Image 2. Examples of dynamic mobilization exercises: (A): chin to carpi; (B): chin to hip.

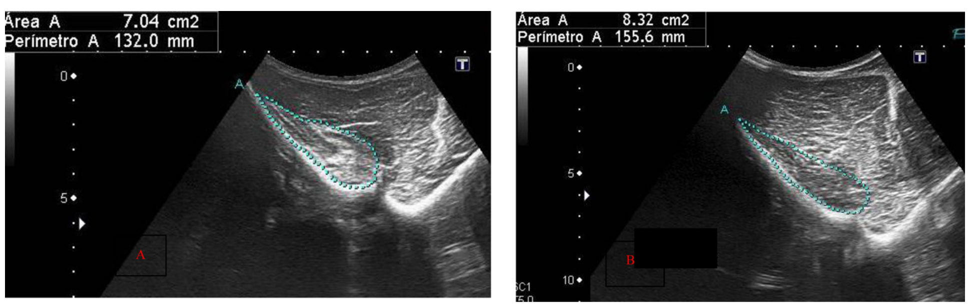

Image 3. Ultrasonographic image of the right *multifidus m.* at the level of L2. (A): initial evaluation (CSA: 7.04 cm^2); (B): final evaluation (right, CSA: 8.32 cm^2). CSA, cross-sectional area.

(chin to girth, chin to hip, chin to hocks) exercises to the left and right sides, that were repeated 5 times per session (Image 2). The horse was encouraged to hold each position for 5 seconds.

2.4. Ultrasonography

Ultrasonographic images of the left and right *multifidus m.* were acquired at 3 locations (T12, T16 and L2) at the initial and at the end point of the study in order to evaluate the effect of NMES and DME therapies across the length of this muscle in the back of the horses. After clipping and skin cleaning, ultrasonographic examination (Toshiba Xario XG)[2] of the *multifidus m.* was performed using a curvilinear probe ranging from 2 to 6 MHz (Toshiba PVT-375BT)[2]. The probe was placed perpendicular to the dorsal midline and followed the skin curvature of the epaxial muscles at an angle of approximately 45°. Images were captured between the cranial and caudal articular processes of selected vertebrae, where the following structures were clearly visible: the dorsal spinous process, the ventral bony margin of the rib or transverse process, and the lateral fascial border between *multifidus* and *longissimus dors*i *m.* (Image 3).

[2] Toshiba, Diagnostic Ultrasound System, Japan.

Three ultrasonographic images were acquired at each location on the left and right sides. *Multifidus m*. cross sectional area (CSA) measurement was performed using the software on the ultrasound machine (Toshiba Xario SSA-660A v. 5.00*R003). Three measurements for each image were registered by an experienced ultrasonographer who was blinded to horse, spinal level and time period.

2.5. Data Analysis

Categorical variables were presented as percentages. For continuous variables, data distribution normality was evaluated with the Kolmogorov-Smirnov test. Continuous data were presented as mean (standard deviation, SD) or median (interquartile range [IQR]).

A t-paired test was performed to determinate the change between initial and final CSA of the *multifidus m*. in both treatments, divided by localization and side. The variation in muscle size was defined as a percentage by the following formula: [final CSA media – initial CSA media)/final CSA media] * 100.

The three measures of the CSA of the *multifidus m*. performed at each anatomical landmark were used to calculate the arithmetic mean. An intraclass correlation coefficient was calculate with CI95% to determinate the reliability. To assess the quantitative estimation a Feiss' kappa scale was used.

Table 1
Cross-sectional area (CSA) of the *multifidus m.* (mean ± SD) before (initial evaluation) and after (final evaluation) performing neuromuscular electrical stimulation (NMES group) and dynamic mobilization exercises (DME group) for 7 weeks.

Treatment	Initial		Final		Increase (%)	P
	Mean	SD	Mean	SD		
NMES	10.45	2.32	12.84	3.20	18.65	<.001
DME	8.80	1.14	10.17	1.82	13.41	<.001

Table 2
Cross-sectional area (CSA) of the *multifidus m.* (mean ± SD) before (initial evaluation) and after (final evaluation) performing neuromuscular electrical stimulation (NMES group) for 7 weeks.

NMES	Initial		Final		Increase (%)	P
	Mean	SD	Mean	SD		
Localization						
T12	9.98	2.39	13.23	4.02	24.61	.005
T16	11.09	2.43	12.20	2.73	9.13	.131
L2	10.28	2.31	13.09	3.06	21.50	.014
Side						
Left	10.46	2.19	13.03	3.13	19.77	.003
Right	10.44	2.55	12.65	3.40	17.50	.009

Table 3
Cross-sectional area (CSA) of the *multifidus m.* (mean ± SD) before (initial evaluation) and after (final evaluation) performing dynamic mobilization exercises (DME group) for 7 weeks.

DME	Initial		Final		Increase (%)	P
	Mean	SD	Mean	SD		
Localization						
T12	9.39	0.70	10.75	1.39	12.67	.012
T16	9.28	0.95	9.96	1.56	6.82	.161
L2	7.74	0.97	9.79	2.43	20.92	.025
Side						
Left	8.81	1.21	10.33	1.66	14.71	.002
Right	8.80	1.12	10.00	2.03	12.06	.042

Assumptions of normality and homoscedasticity were checked. The level of significance was set at $P < .050$ for all comparisons. IBM SPSS. 20 for Windows version 10 was used for data analysis.

3. Results

The *multifidus m.* CSA was measured, either at the start of the DME and NMES therapy and after the end of both treatments, to assess the change over the duration of the two treatments types. The intraclass correlation coefficient (IC) was 0.98 (95% IC 0.97–0.99; $P < .001$), what was defined in substantial agreement according to Fleiss' kappa scale. There were no missing data.

The *multifidus m.* area was increased after treatments in both groups, from an average CSA of 10.45 ± 2.32 to 12.84 ± 3.20 cm^2 (mean ± SD) in the NMES group and from 8.80 ± 1.14 to 10.17 ± 1.82 cm^2 (mean ± SD) after the DME therapy. These data represented an increase of 18.65% and 13.41% of the muscle size after NMES and DME treatments, respectively. Significant increases ($P < .001$) of the *multifidus m.* CSA between the initial and the final treatment periods, both in NMES and DME, were obtained (Table 1).

A significant increase in CSA was detected at the right and left sides of T12 and L2 ($P < .05$) in both treatments (Tables 2 and 3).

4. Discussion

This is the first report, to the best of our knowledge, that compares the efficacy of NMES and DME in increasing the cross-sectional area of the *multifidus m.* in horses. Our results indicate that both treatments induce an increase in the area of the *multifidus m.* when applied for a 7-week period, suggesting either a return toward a normal size in a previously atrophied muscle or hypertrophy of a normal muscle. Interestingly, these findings were significantly more evident in T12 and L2. Muscle CSA at T16 was enlarged at a lesser extent. This result might probably be influenced by the sample size, or by the presence of some occult pathological changes not clinically evidenced.

The findings observed with the **DME** group are in agreement with previous reports following a 3 months mobilization therapy [16,23]. Nevertheless, studies in Thoroughbred horses in full racing training [24] concluded that these mobilization exercises failed to show any improvement in the *multifidus m.* area when applied beyond 6 weeks, suggesting that maximal potential to hypertrophy of *multifidus m.* occurs during this initial period of time. Although results in our study have shown an increase in CSA at T12 and L2 spine levels, it remains uncertain, therefore, if additional sessions to the completed 7 weeks could have induce greater changes in muscle size at T16 level when applying DME manipulation.

Spinal flexion and extension are induced at different levels during DME, as well as rotation and back movements along T6 thought to S2, especially in exercises were the chin is moved caudally to the hip and tarsus [4,16]. This movement highly activates the *multifidus m.*, producing an extension force to balance the unwanted flexion. Interestingly, the highest muscle augmentation identified at L2 in the DME group could indicate a greater muscular activity required at this point, representing a reinforcement and strengthening of the core musculature to stabilize the horse's back at this level.

Results arisen from **NMES** therapy were unpredictable, as reported outcomes in human and equine research differ. Some publications have presented conflicting information regarding the time needed and the protocol used to achieve muscle hypertrophy after electrostimulation. Neither a 6-weeks period of therapy in human patients with back pain nor 12 weeks of NMES treatment in the *quadriceps m.* of old people have achieved any clinical benefit, increase strength or muscle CSA changes [25,26]. Similarly, nor histological or size muscle modifications were obtained in the equine *multifidus m.* after 4 weeks of electrical treatment [22]; moreover, 3 months of NMES training was unsuccessful to increase the thickness of the *rectus abdominis m.* in horses, although an improvement in muscle force and fatigue resistance measured by surface electromyography was evident [27]. The reason for the lack of response to NMES therapy in some studies remains unidentified, but it has been hypothesized that neural changes before structural modifications and muscle hypertrophy could occur [28]; hence, longer treatments could be needed to produce these adaptations. Otherwise, there is also a considerable divergence between patient features, muscle groups stimulated, number of NMES sessions performed and current parameters used in the published literature, so results are difficult to be homogenized.

In both humans and horses, the muscles involved in the spine stabilization have a high content of type I fiber and muscle spindles, indicative of their complex role in neuromotor control. In horses, the *multifidus* fiber composition can slightly vary across breeds, but it appears to have an equal proportion of I and IIA fibers, indicating that it could have a role both in locomotion and spinal stabilization [29,30]. We were not able to distinguish if changes in the *multifidus m.* obtained in our investigation were related to any histological or fiber modification, since muscle biopsies were not performed during the experiment. Besides this, there is scarce knowledge on the effects of DME and NMES in horses at the single muscle fiber level. Few studies have intended to clarify this issue in horses [22,31] and people [32–34]. The recruitment pattern of activation of motor units under NMES stimulation is quite different from the "*size principle*" voluntary contraction [35]. Activation of fast and slow motor units (force-producing type II and type I muscle fibers, respectively) occurs synchronously during NMES therapy. The main consequence of this is the magnified metabolic cost, which could provoke greater and earlier onset of muscle fatigue [21]. This feature needs special considerations when applying this therapy to muscles with a great proportion of fast glycolytic II fibers [19,36].

Optimal NMES dosages and treatment characteristics for reducing muscle tension are still being identified. To maximize the effect of this therapy, it is strongly recommended to use biphasic rectangular pulses of short pulse duration to avoid fatigue [21], delivered at a stimulation frequency of 50 to 100 Hz [37], and at the highest tolerated current intensity [38]. However, longer pulse durations are advised when the anatomic structure to be stimulated is covered by the skin and subcutaneous fat tissue, as multifidus m. is [39,40]. The selected current protocol used in this study included these considerations and was set in order to generate the highest muscle workload, without causing serious discomfort to the patient. Skin irritation during NMES therapy has been described as similarly occurs with transcutaneous electrical nerve stimulation (TENS) [17]. We didn't find any apparent complaint during NMES treatment in any patient, and in general terms, it was well tolerated by horses.

The findings of this research have to be seen in light of some limitations. The first is the lack of a control group. Horses included in this study were turned out in a small paddock for 12 hours daily, however non were handwalked or received dedicated exercise. Although we assumed that their physical activity was insufficient to cause significant changes to *multifidus m* CSA, it would be advisable to include a control group to evaluate this effect in future investigations. The second limitation concerns the sample size. Significant T16 changes could have emerged with a larger sample of horses. However, pathology in the spine (i.e. spinous process impingement or articular facet remodeling) was not investigated in our equine population. Even in the absence of clinical evidence of back pain, pathologic change at T16 might have been a substantial consideration and could explain the lack of significant findings at this spine level. Nevertheless, despite the small population size, significant change in the *multifidus m.* was observed at T12 and L2, information which is useful for clinical practitioners.

5. Conclusions

In conclusion, our results suggest that a 7-week period of dynamic mobilization exercises and neuromuscular electrical stimulation are useful to increase CSA of the *multifidus m.* in horses, and hence, to improve the spine stabilization. These two therapies could be combined and implemented in conjunction during a back-rehabilitation program to ensure an optimal outcome or as an additional tool to enhance performance in horses.

Authors' Contributions

Raquel Gómez Lucas: Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision. Isabel Rodríguez Hurtado: Writing - review & editing, Supervision. Carla Troteaga Álvarez: Investigation, Writing - original draft. Gustavo Ortiz: Software, Formal analysis.

Financial disclosure

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jevs.2022.103934.

References

[1] Clayton HM. Core training and rehabilitation in horses. Vet Clin North Am - Equine Pract 2016;32:49–71. doi:10.1016/j.cveq.2015.12.009.
[2] Valberg SJ. Spinal muscle pathology. Vet Clin North Am Equine Pract 1999;15:87–96. doi:10.1016/S0749-0739(17)30165-7.
[3] Stubbs NC, Hodges PW, Jeffcott LB, Cowin G, Hodgson DR, Mcgowan CM. Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse. Equine Vet J 2006;38:393–9. doi:10.1111/j.2042-3306.2006.tb05575.x.
[4] Clayton HM, Kaiser LAJ, Lavagnino M, Stubbs NC. Evaluation of intersegmental vertebral motion during performance of dynamic mobilization exercises in cervical lateral bending in horses. Am J Vet Res 2012;73:1153–9. doi:10.2460/ajvr.73.8.1153.
[5] Cottriall S, Ritruechai P, Wakeling J. The effects of training aids on the longissimus dorsi in the equine back. Comp Exerc Physiol 2008;5:111–14.
[6] Wakeling JM, Ritruechai P, Dalton S, Nankervis K. Segmental variation in the activity and function of the equine longissimus dorsi muscle during walk and trot. Equine Comp Exerc Physiol 2007;4:95–103. doi:10.1017/s1478061507812126.
[7] Van weeren PR, Mcgowan C, Haussler KK. Science overview: development of a structural and functional understanding of the equine back. Equine Vet J 2010;42:393–400.
[8] Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. Spine (Phila Pa 1976) 2001;26:E243–8. doi:10.1097/00007632-200106010-00004.
[9] Clayton HM. Equine back pain reviewed from a motor control perspective. Comp Exerc Physiol 2012;8:145–52. doi:10.3920/CEP12023.
[10] Kavcic N, Grenier S, McGill SM. Determining the stabilizing role of individual torso muscles during rehabilitation exercises. Spine (Phila Pa 1976) 2004;29:1254–65. doi:10.1097/00007632-200406010-00016.
[11] Riccio B, Fraschetto C, Villanueva J, Cantatore F, Bertuglia A. Two multicenter surveys on equine back-pain 10 years a part. Front Vet Sci 2018;5. doi:10.3389/fvets.2018.00195.
[12] Stubbs NC, Riggs CM, Hodges PW, Jeffcott LB, Hodgson DR, Clayton HM, et al. Osseous spinal pathology and epaxial muscle ultrasonography in Thoroughbred racehorses. Equine Vet J 2010;42:654–61. doi:10.1111/j.2042-3306.2010.00258.x.
[13] Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine (Phila Pa 1976) 1996;21:2763–9. doi:10.1097/00007632-199612010-00011.
[14] Hides J, Gilmore C, Stanton W, Bohlscheid E. Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. Man Ther 2008;13:43–9. doi:10.1016/j.math.2006.07.017.
[15] McGowan CM, Stubbs NC, Jull GA. Equine physiotherapy: a comparative view of the science underlying the profession. Equine Vet J 2007;39:90–4. doi:10.2746/042516407x163245.
[16] Stubbs NC, Kaiser LJ, Hauptman J, Clayton HM. Dynamic mobilisation exercises increase cross sectional area of musculus multifidus. Equine Vet J 2011;43:522–9. doi:10.1111/j.2042-3306.2010.00322.x.
[17] Schlachter C, Lewis C. Electrophysical therapies for the equine athlete. Vet Clin North Am - Equine Pract 2016;32:127–47. doi:10.1016/j.cveq.2015.12.011.
[18] Hong DZ, Sui M, Zhuang Liu H, Zheng X, Cai C JD. Effectiveness of neuromuscular electrical stimulation on lower limbs of patients with hemiplegia after chronic stroke: a systematic review. Arch Phys Med Rehabil 2018;99:1011–22.
[19] Maffiuletti NA. Physiological and methodological considerations for the use of neuromuscular electrical stimulation. Eur J Appl Physiol 2010;110:223–34. doi:10.1007/s00421-010-1502-y.
[20] Kaigle AM, Holm SH HT. Experimental instability in the lumbar spine. Spine (Phila Pa 1976) 1995;20:421–30.
[21] Doucet BM, Lam A, Griffin L. Neuromuscular electrical stimulation for skeletal muscle function. Yale J Biol Med 2012;85:201–15.
[22] Bergh A, Nordlöf H, Essén-Gustavsson B. Evaluation of neuromuscular electrical stimulation on fibre characteristics and oxidative capacity in equine skeletal muscles. Equine Vet J 2010;42:671–5. doi:10.1111/j.2042-3306.2010.00180.x.
[23] de Oliveira K, Soutello RVG, da Fonseca R, Costa C, Paulo PR, Fachiolli DF, et al. Gymnastic training and dynamic mobilization exercises improve stride quality and increase epaxial muscle size in therapy horses. J Equine Vet Sci 2015;35:888–93. doi:10.1016/j.jevs.2015.08.006.
[24] Tabor G. The effect of dynamic mobilisation exercises on the equine multifidus muscle and thoracic profile [MS thesis]. Plymouth, UK: Plymouth University; 2015.
[25] Alrwaily M, Schneider M, Sowa G, Timko M, Whitney SL, Delitto A. Stabilization exercises combined with neuromuscular electrical stimulation for patients with chronic low back pain: a randomized controlled trial. Brazilian J Phys Ther 2019;23:506–15. doi:10.1016/j.bjpt.2018.10.003.
[26] Suetta C, Aagaard P, Rosted A, Jakobsen AK, Duus B, Kjaer M, et al. Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. J Appl Physiol 2004;97:1954–61. doi:10.1152/japplphysiol.01307.2003.

[27] Hernández-Fernández T, Gutiérrez-Cepeda L, López-Sanromán J, Manso-Díaz G, Cediel R. Electromyographic and ultrasonographic evaluation of neuromuscular electrical stimulation training on the equine rectus abdominis muscle. Comp Exerc Physiol 2020;16:87–100. doi:10.3920/cep190004.

[28] Gondin J, Guette M, Ballay Y, Martin A. Electromyostimulation training effects on neural drive and muscle architecture. Med Sci Sports Exerc 2005;37:1291–9. doi:10.1249/01.mss.0000175090.49048.41.

[29] Hyytiäinen HK, Mykkänen AK, Hielm-Björkman AK, Stubbs NC, McGowan CM. Muscle fibre type distribution of the thoracolumbar and hindlimb regions of horses: relating fibre type and functional role. Acta Vet Scand 2014;56:8. doi:10.1186/1751-0147-56-8.

[30] García Liñeiro JA, Graziotti GH, Rodríguez Menéndez JM, Ríos CM, Affricano NO, Victorica CL. Structural and functional characteristics of the thoracolumbar multifidus muscle in horses. J Anat 2017;230:398–406. doi:10.1111/joa.12564.

[31] Serrano AL, Quiroz-Rothe E, Rivero JLL. Early and long-term changes of equine skeletal muscle in response to endurance training and detraining. Pflugers Arch Eur J Physiol 2000;441:263–74. doi:10.1007/s004240000408.

[32] Dal Corso S, Nápolis L, Malaguti C, Gimenes AC, Albuquerque A, Nogueira CR, et al. Skeletal muscle structure and function in response to electrical stimulation in moderately impaired COPD patients. Respir Med 2007;101:1236–43. doi:10.1016/j.rmed.2006.10.023.

[33] Pérez M, Lucia A, Rivero JLL, Serrano AL, Calbet JAL, Delgado MA, et al. Effects of transcutaneous short-term electrical stimulation on M. vastus lateralis characteristics of healthy young men. Pflugers Arch Eur J Physiol 2002;443:866–74. doi:10.1007/s00424-001-0769-6.

[34] Nuhr MJ, Pette D, Berger R, Quittan M, Crevenna R, Huelsman M, et al. Beneficial effects of chronic low-frequency stimulation of thigh muscles in patients with advanced chronic heart failure. Eur Heart J 2004;25:136–43. doi:10.1016/j.ehj.2003.09.027.

[35] Delitto A, Snyder-Mackler L. Two theories of muscle strength augmentation using percutaneous electrical stimulation. Phys Ther 1990;70:158–64. doi:10.1093/ptj/70.3.158.

[36] Maffiuletti N. The use of electrostimulation exercise in competitive sport. Int J Sports Physiol Perform 2007;1:406–7. doi:10.1123/ijspp.1.4.406.

[37] Vanderthommen M, Duchateau J. Electrical stimulation as a modality to improve performance of the neuromuscular system. Exerc Sport Sci Rev 2007;35:180–5. doi:10.1097/jes.0b013e318156e785.

[38] Lake DA. Neuromuscular electrical stimulation. Sport Med 1992;13:320–36. doi:10.2165/00007256-199213050-00003.

[39] Vanderthommen M, Depresseux JC, Dauchat L, Degueldre C, Croisier JL, Crielaard JM. Spatial distribution of blood flow in electrically stimulated human muscle: a positron emission tomography study. Muscle Nerve 2000;23:482–9. doi:10.1002/(SICI)1097-4598(200004)23:4⟨482::AID-MUS5⟩3.0.CO;2-I.

[40] Bracciano AG MK. Physical agent modalities developing a framework for clinical application in occupational therapy practice. OT Pract 2009;14:CE1–7.