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Effects of a Bio-Electromagnetic Energy Regulation Blanket on Thoracolumbar Epaxial Muscle Pain in Horses

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ABSTRACT

Back pain and inflammation of the epaxial musculature is a significant problem in all equine athletes. Treatment of back pain can be challenging and often requires a multimodal approach. In humans, bio-electromagnetic energy regulation therapy (BEMER) has been reported to be effective in pain modulation. With its increased use in people comes a similar robust application in veterinary medicine unfortunately, there is unsubstantiated evidence for this type of therapy in horses.

Objectives of this study were to assess analgesic responses and biomechanical outcome variables using a bio-electromagnetic energy regulation therapy blanket, and to evaluate serum biomarkers as a method to monitor the treatment effects in horses with thoracolumbar epaxial muscle pain.

Cohort study of 8 horses treated for 3 consecutive days.

Horses with naturally-occurring thoracolumbar epaxial muscle pain were used in this study. Objective outcome variables were recorded daily for 5 days, which included spinal evaluation, mechanical nociceptive thresholds, electromyography, kinematics, kinetics, and serum biomarkers.

BEMER blanket therapy significantly improved thoracolumbar epaxial muscle nociceptive thresholds. Center of pressure displacement as a measure of postural stability was significantly improved as well as significant gains in spinal flexibility were demonstrated at study completion. A significant treatment effect was not appreciated in measures of muscle tone, ground reaction forces or serum biomarkers.

Limitations include the lack of a control group and a definitive structural diagnosis of thoracolumbar epaxial muscle pain.

The BEMER blanket produced significant clinical and biomechanical effects in horses with back pain.

1. Introduction

Back pain and inflammation of the epaxial musculature is a significant problem in all types of equine athletes, which results in poor performance, lost training days, and wastage [1]. Back pain is considered one of the most common and least understood clinical problems in horses with a reported prevalence ranging from 27% up to 100% in the ridden horse population [2]. The precise etiology of equine thoracolumbar pain is often poorly defined even after thorough clinical and diagnostic imaging evaluations. The myriad of possible mechanisms include poor saddle fit, weak abdominal musculature, epaxial muscle hypertonicity, appendicular lameness, and osseous pathology [3]. In addition, there is a dearth of reliable and objective measures to accurately and reliably diagnosis the presence and severity of thoracolumbar pain. Positive findings identified on radiography, ultrasonography and nuclear scintigraphy (bone scan) often do not correlate well with clinical signs of back pain [4]. Finally, the treatment of back pain can be challenging and often requires a multimodal approach. Recent research in human physiotherapy pain modulation approaches has demonstrated efficacious medication free solutions through the application of bio-electromagnetic energy regulation therapy [5].

Bio-electromagnetic energy regulation therapy, analogous to pulsed electromagnetic field (PEMF) therapy, is created when an electrical current is driven through a coiled wire that generates a magnetic field. The magnetic field creates small currents within the target tissue, resulting in various biologic effects. Distinctively unique from other forms of PEMF, bio-electromagnetic energy regulation therapy utilizes a low frequency and short phase duration, which results in a current generated within the tissues without heat production [6]. Well defined effects for this type of therapy have been reported in human patients to significantly increase microvessel vasomotion, arteriovenous pO_2 difference, number of

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open capillaries, arteriolar and venular flow volume, as well as enhance flow rate of red blood cells within the targeted microcirculatory area [7,8]. These changes in the microcirculation status were demonstrated by combining high-resolution intravital microscopy, computer image processing, and measurement of microflow rate using laser reflection spectroscopy [7,8]. The improvements in blood flow lead to increases in tissue perfusion, metabolic activity, and muscle relaxation thereby facilitating cellular repair and diminishing nociception. The precise biophysical and cellular mechanisms through which bio-electromagnetic energy regulation therapy influences tissues responses remains an ongoing area of research focus. However, a number of research studies have demonstrated that exposure to electromagnetic fields upregulates several signaling pathways related to metabolism, circulation, inflammation, and vascular tone [9]. In particular, various PEMF devices have identified a significant increase in the production of nitric oxide (NO) following treatment in human, canine and rodent in vivo studies [9–11]. In addition to its role in stimulating vasodilation, NO has been associated with reduced inflammatory gene expression, reduction in programmed cell death, and enhanced circulation [12,13]. These outcomes in tissue responses are consistent with reductions in pain, stiffness, and improved function that have been observed clinically in human patients treated specifically with bio-electromagnetic energy regulation therapy. [14–18].

Currently, there have not been any reported studies using bio-electromagnetic energy regulation therapy despite its widespread use within the equine industry. The aim of this study was to objectively assess analgesic responses and biomechanical outcome variables and to evaluate serum biomarkers as a method to monitor the treatment effects of a bio-electromagnetic energy regulation blanket in horses with naturally occurring thoracolumbar epaxial muscle pain. The authors hypothesize that bio-electromagnetic energy regulation blanket therapy will improve objective measures of back pain and dysfunction. This study will serve as a proof of concept for future controlled studies using bio-electromagnetic energy regulation therapy in horses.

2. Materials and Methods

2.1. Horses

Eight horses of mixed breeds and disciplines from 4–10 years of age and in consistent work 4–5 days per week, walk trot, canter at a minimum of 20 minutes per session were enrolled. Horses were selected from a single riding center following a musculoskeletal exam in which clinical signs of thoracolumbar pain and stiffness were demonstrated using manual palpation techniques that were confirmed with pressure algometry. Normative mechanical nociceptive thresholds from the thoracolumbar epaxial musculature were used to identify horses with back pain [19].

Pain on palpation of both bone and soft tissue sites were recorded as epaxial muscle fasciculations, tremors and evasion responses from the horse. Thoracolumbar stiffness was noted as restricted range of motion in dorsal/ventral excursion, lateral bending and axial rotation. Subjective lameness evaluations were used to exclude horses with greater than or equal to a grade 2 (AAEP scale) forelimb or hindlimb lameness. Horses were housed in 12′ x 12′ stalls in a climate-controlled barn for the duration of the 5-day study. Horses were restricted to their stalls and no ridden exercise was conducted during the study. The Institutional Animal Care and Use Committee (IACUC) approved the study protocol (19-8723A).

2.2. Study Design

Baseline data was collected from all horses on Day 0 (Fig. 1). Active treatment with the bio-electromagnetic energy regulation blanket occurred twice daily (AM/PM sessions) on Days 1-3 with outcome measures collected immediately before and after each treatment session Table 1. Final data collection occurred on day 4, 24 hours after the last treatment session (Day 4).

2.3. Bio-Electromagnetic Energy Regulation Therapy

A single customized magnetic field equine blanket (BEMER Group USA[1]) was applied over the thoracolumbar and croup region (T5-cranial coccygeal vertebrae) of each horse twice a day (at 6-hour intervals) for 3 consecutive days with progressively increasing durations (i.e., Day 1 × 5 minutes; Day 2 × 10 minutes; and Day 3 × 15 minutes) (Fig. 2). A total magnetic flux density of 35-microTesla was delivered at each treatment session.

2.4. Spinal Evaluation

A single examiner (KS) boarded in sports medicine and rehabilitation with certification in equine chiropractic evaluated each horse at baseline prior to application of the blanket and at study completion. The examiner was not involved in study design or data collection and did not review the previous scores prior to performing the second assessment on day 4 in order to keep the second assessment scores as unbiased as possible. The detailed thoracolumbar evaluation included manual palpation for signs of inflammation (i.e., pain, heat, and swelling), muscle tone and development, regional stiffness and joint range of motion (dorsal ventral excursion and lateral bending). Each outcome parameter was scored on a 0-3 scale: absent, mild, moderate or severe (Supplemental File A).

2.5. Static Surface Electromyography (sEMG)

Surface electromyography was recorded wirelessly (Myovision[2]) from the epaxial musculature at C5, T11, T14, T18, L4, and S3 vertebral levels during quiet standing (Fig. 3). The sEMG values were recorded in μV with a threshold of $>10\mu$V used to define increased amplitudes of muscle activity or hyperactive tone.[14] Previous equine research using Myovision has determined that horses standing quietly have low resting epaxial muscle tone ($< 10\mu$V) [20].

2.6. Mechanical Nociceptive Thresholds (MNT)

A pressure algometer with a 1–cm^2 rubber plunger tip and a calibrated range from 0 – 30 kg/cm^2 was used to determine MNT values at standardized thoracolumbar spinous processes (SP) and bilateral epaxial musculature landmarks. Pressure was applied perpendicularly to predetermined thoracolumbar anatomic landmarks at a rate of approximately 10 kg/cm^2/sec over 2 to 3 seconds until a local avoidance reaction was observed. Avoidance reactions include skin twitching, local muscle fasciculation, or moving away from the applied pressure. When a reaction was observed, the applied pressure was discontinued immediately and the corresponding MNT value recorded. The single, trained examiner (MK) did not view the pressure gauge reading during application of pressure to limit potential bias. The instrument automatically records the highest applied pressure and resets to zero after each measurement. 3 consecutive measurements at 3-to-4 second intervals were recorded at each site and the mean value for each site reported. The MNT sites were marked with permanent lacquer to ensure consistent pressure algometry placement throughout the study (Fig. 3).

[1] BEMER Group, USA LLC, Carlsbad, CA
[2] Myovision, Seattle, WA

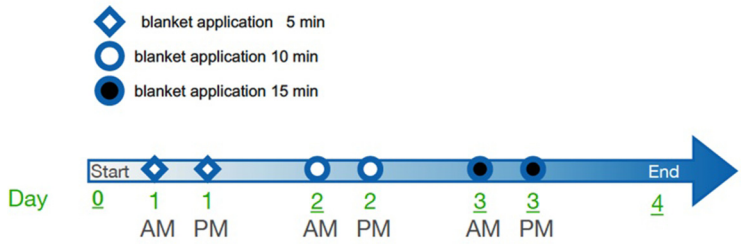

Fig. 1. Illustration of data collection time points and duration of treatment over the 5 day study period.

Table 1
List of outcome parameters and time points used for data collection. Data was collected on the green highlighted time points. Postural stability data was collected during BEMER blanket therapy on Days 1-3.

	Timepoints												
	Day 0	Day 1				Day 2				Day 3				Day 4
		AM		PM (+6 hours)		AM		PM (+6 hours)		AM		PM (+6 hours)		
Outcomes		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
EMG														
MNT														
Biomarkers														
Postural stability				During Therapy				During Therapy				During Therapy		
Inertial Sensor														
Kinetics														
Kinematics														

Fig. 2. Horse with BEMER blanket applied.

2.7. Serum Creatine Kinase and Aspartate Aminotransferase

Serum muscle isoenzymes, creatine kinase (CK) and aspartate aminotransferase (AST), were measured baseline and at serial time points throughout the study to assess for any indication of muscle injury or changes in muscle metabolism.

2.8. Blood Derived Biomarkers - Nuclear Magnetic Resonance (NMR) and Mass Spectrometry (MS)

Serum samples were prepared from peripheral blood collected in 10 mL red top tubes and stored on ice (for less than 1 hour) until processing. Blood samples were centrifuged at 2,000 g for 10 minutes at 4°C to separate the serum. The resulting serum was aliquoted (1.8 mL) into cryotubes for storage at -80°C until analysis. Plasma samples were prepared from blood collected in 10 mL dark green top BD Lithium-Heparin tubes and stored on ice until processing. Collection tubes were centrifuged at 2,800 g for 25 minutes at 4°C to separate the plasma and 1.8 mL plasma aliquots were pipetted into cryotubes for storage at -80°C until analysis. Further analysis of the NMR and MS data was conducted as previously described [21]. The resulting data was processed against an instrument customized library that provides the highest level of identification. Additional relative quantification was performed post classification in order to provide the highest level of confidence. Post data processing analysis was performed using custom data analytics procedures developed in-house.

2.9. Inertial Sensor Gait Analysis

An inertial sensor system (Equinosis Q[3]) was applied to each horse as a method to objectively assess limb lameness. Horses

[3] Equinosis Q with Lameness Locator, LLC, Columbia, MO

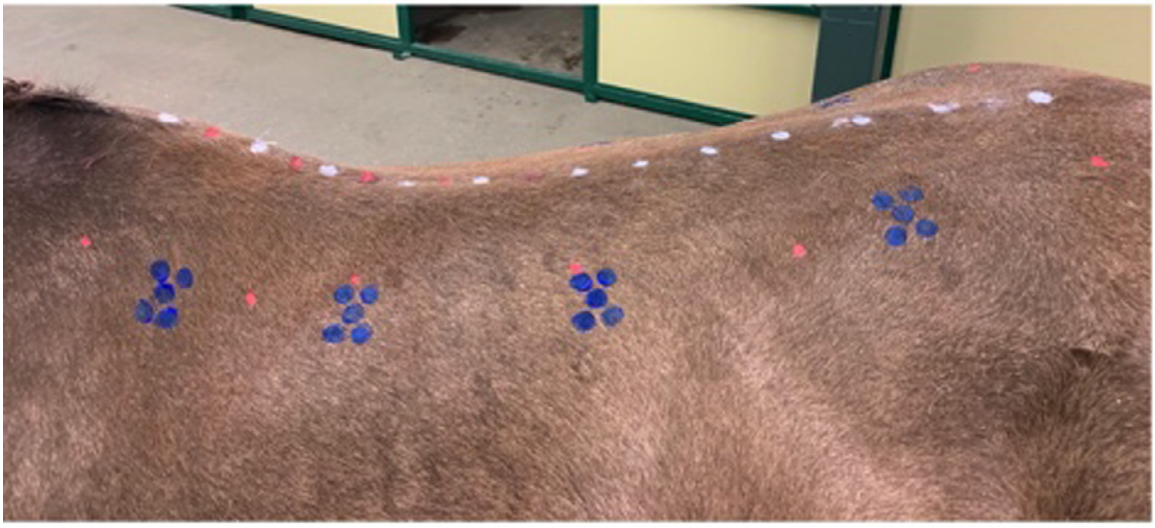

Fig. 3. Photograph of the dorsal aspect of the thoracolumbar region of a horse with anatomic landmarks indicated with permanent lacquer. The orange dots indicate the spinous process and epaxial musculature landmarks used for pressure algometry. The blue dots indicate sites for surface EMG electrodes. The white dots indicate sites of retro-reflective marker placement over spinous processes used for evaluation of spinal kinematics.

were evaluated in a straight line for a minimum of 25 strides on an asphalt surface. The system consists of 2 uniaxial accelerometers: 1 mounted on the poll with a head-bumper attached to the headpiece of the halter and the other located on midline between the tuber sacrale. A uniaxial gyroscope was mounted to the dorsal aspect of the right front pastern. The inertial sensor data was collected and analyzed using proprietary software. Outcome variables included head movement asymmetry (HMA), maximum head position (HMax), minimum head position (HMin), maximum pelvic position (PMax), minimum pelvic position (PMin). The variables were averaged across horses for each time point.

2.10. Biomechanical Assessment

Ground reactions forces (GRF), center of pressure (COP) displacement (i.e., postural sway), and spinal and limb kinematics, were assessed to evaluate for signs of lameness, postural stability, and spinal motion patterns. Kinetic, kinematic, and inertial sensor data were collected simultaneously from each horse at baseline (Day 0), on Day 3 before and after the PM therapy session and at study conclusion (Day 4). For gait data collection, horses were trotted in hand at a self-selected uniform velocity (2.8-3.4 m/s). Forward velocity was measured using a series of 5 infrared emitters and corresponding reflective sensors spaced at 2-meter intervals. Each horse was maintained within 10% of its initial average baseline velocity.

2.10.1. Kinetic Analysis

GRFs from all 4 limbs was recorded to objectively measure changes in load distribution using 2 strain-gauge based force platforms (60 × 90-cm) mounted sequentially in an isolated concrete base in the center of a 25-m runway. A kinetic trial was considered successful when ipsilateral thoracic and pelvic limb pairs contact the center of a single force platform. 5 valid trials were collected during each time point. Orthogonal GRF data was sampled at 2000 Hz; however, only the vertical and craniocaudal GRFs were analyzed for this study. The following kinetic parameters were calculated from each trial: stance duration, peak vertical, braking and propulsive forces and impulses and vertical loading rates. Kinetic variables were averaged across the 5 trials, normalized to subject body mass, and expressed as N/kg or Ns/kg.

2.10.2. Postural Stability

Postural stability was assessed by measures of displacement of the center of pressure (COP) within each horse while quietly standing on dual force platforms. Postural sway data was collected daily during the 5 day study. On Days 1-3 data was collected during the PM treatment sessions (i.e., COP was measured with horses standing on the forces platforms during the afternoon blanket therapy sessions on days 1-3). The COP accuracy for each force platform was ± 2 mm, and the static resolution for the system was ± 1 N. Postural stability variables were calculated from the net COP displacement during active treatment. Craniocaudal sway (mm) was calculated as the range of COP displacements in a craniocaudal direction (COPy) relative to the horse, where positive values indicated movements in the cranial direction. Mediolateral sway (mm) was calculated as the range of COP displacements in a mediolateral direction (COPx), where positive values indicated movements toward the right side. COP area (mm2) was calculated as the extreme bounds of the COP movement in both craniocaudal and mediolateral directions. The COP velocity (mm/sec) was defined by the direction and amplitude of COM displacement in the immediately following time instant. The average velocity was calculated by summing the resultant distance between 2 consecutive COP data points divided by time. The 3 dimensional (3-D) transformed orthogonal coordinates of the reflective markers were used to determine the following hoof morphometric measurements; cranial caudal length, medial to lateral width and base of support as previously described [21]. Head height was calculated as the mean vertical distance between the reflective markers located on the forehead and the left front hoof. Prior to statistical analysis the postural sway variables were normalized to the corresponding morphometric measurements and reported as a normalized percent value. Normalization was used to remove the dependence of the postural sway variables on each individual horse's morphometric factors.

2.10.3. Kinematic Analysis

A series of ten Oqus 7, Qualysis[4] 3-D motion capture cameras centered around the capture volume containing the force platforms were used to assess full-body evaluation of spinal and limb movement. For data collection and analysis, 12.7 mm retroreflec-

[4] Qualysis, Gothenburg, Sweden

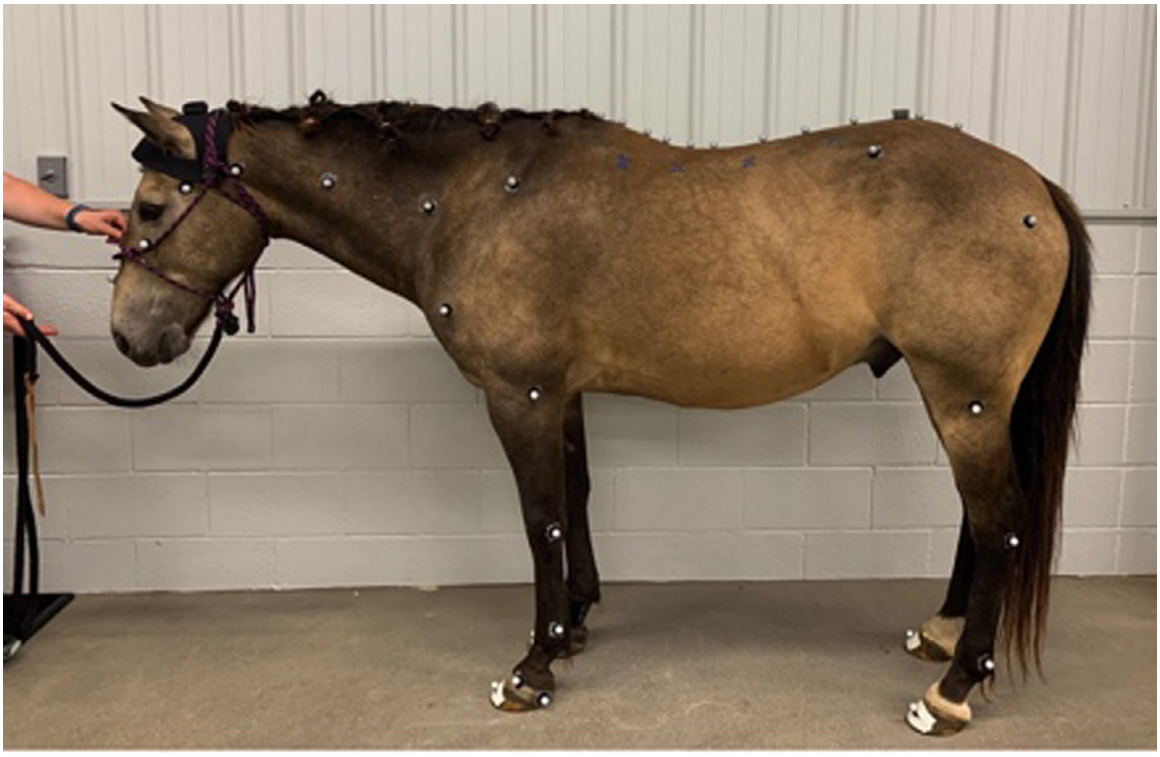

Fig. 4. Lateral photograph showing the location of retro-reflective markers on the skin overlying anatomic landmarks within the axial and appendicular skeleton.

tive markers were adhered to the skin overlying anatomic landmarks of the axial dorsal spinous processes (T6, T8, T10, T12, T14, T16, L1, L3, L6, cranial aspect of tuber sacrale, S3) and appendicular skeleton (centers of joint rotation for the thoracic and pelvic limbs) (Fig. 4). Motion of the thoracolumbar vertebrae was described as flexion-extension (in the sagittal plane), lateral bending (in the horizontal plane) and axial rotation (in the transverse plane). Flexion-extension and lateral bending curvature of the thoracolumbar spine was determined during induced spinal motion, which included sternal elevation reflexes and baited carrot stretches: muzzle to between forelimb fetlocks (cervical flexion), and muzzle to left or right tuber coxae (lateral bending). Raw coordinate data was filtered with a low-pass fourth-order recursive Butterworth filter at 12 Hz. Kinematic variables calculated for each trial included angular displacement (spinal curvature) between T6 and L6 during spinal motion tasks, distance of bridge of nose marker to right and left tuber coxae during left and right lateral bending, and height of thoracolumbar markers in relation to the spine of the sixth thoracic vertebrae (T6) during sternal elevation and cervical flexion tasks.

2.12. Statistical Analysis

The continuous data were found to be normally distributed based on visual inspection of diagnostic plots. Studentized residual plots were used to demonstrate the absence of outliers for the spinal evaluation ordinal data. A mixed-model analysis of variance (ANOVA) with repeated measures was fit separately for each response variable using SAS software (SAS Institute Inc[5].) with significance set at $P \leq .05$. The fixed effects are day, time point and day x time point. Interactions, as well as main effects, were considered. Horse was included as a random effect to account for repeated measures. Significant results were reported as means and standard error with 95% confidence intervals.

[5] SAS Institue Inc, Carey, NC

3. Results

3.1. Horses

All 8 horses enrolled in the study participated in western performance disciplines and were consistently ridden up until the start of the study. The horses included 4 geldings and 4 mares with a mean age of 6.5 ± 2.1 years, a mean weight of 440 ± 51.5 kg, with a mean height at the withers of 157.48 ± 2.54 cm.

3.2. Spinal Evaluation

Spinal assessment of muscle tone was significantly different ($P = .031$) at day 4 (end of study) compared to baseline scoring. Muscle tone was graded significantly higher (grade 1.1 ± 0.2, 95% CI = 0.6-1.7) at baseline indicating mild muscle hypertonicity and a moderate withdrawal reflex readily elicited with firm digital pressure. In comparison, at study completion, the average epaxial and middle gluteal muscle tone was graded lower (0.6 ± 0.2, 95% CI = 0.07-1.1), indicating no palpable muscle hypertonicity; no increase in muscle tone elicited with firm digital pressure. Similarly, baseline epaxial and middle gluteal muscle pain was graded significantly ($P = .02$) higher with an average score of (1.3 ± 0.3, 95% CI = 0.6-1.9), indicating a mild pain response, mild withdrawal elicited with firm digital pressure compared to study completion with an average score of (0.4 ± 0.3, 95% CI = -0.3-1.0), indicating no pain response or withdrawal reflex elicited with firm digital pressure. No significant differences were appreciated in regional stiffness or joint range of motion assessment.

Table 2
Mean ± standard error and 95% confidence intervals for all MNT values (kg/cm^2) measured at predetermined epaxial muscle and spinous process landmarks.

Left epaxial muscle	AM PRE (95% CI)	AM POST(95% CI)	PM PRE(95% CI)	PM POST(95% CI)
T9	13 ± 0.6^c(11-14)	14 ± 0.6^b(13-15)	14 ± 0.6^b(12-15)	15 ± 0.6^a(14-16)
T13	13 ± 0.7^b(11-14)	14 ± 0.7^a(13-16)	13 ± 0.7^b(12-15)	15 ± 0.7^a(13-16)
T18	13 ± 0.8^b(11-15)	14 ± 0.8^a(12-16)	12 ± 0.8^b(11-14)	14 ± 0.8^a(12-16)
L3	13 ± 0.8^b(11-15)	15 ± 0.8^a(13-17)	14 ± 0.8^b(12-16)	16 ± 0.8^a(14-18)
L6	15 ± 0.9^b(13-17)	16 ± 0.9^a(14-18)	15 ± 0.9^b(13-17)	17 ± 0.9^a(15-19)
S2	17 ± 1.0^b(15-19)	19 ± 1.0^a(16-21)	17 ± 1.0^b(15-20)	19 ± 1.0^a(17-21)
Right epaxial muscle	AM PRE (95% CI)	AM POST(95% CI)	PM PRE(95% CI)	PM POST(95% CI)
T9	13 ± 0.7^c(11-15)	15 ± 0.7^b(13-16)	13 ± 0.7^c(12-15)	16 ± 0.7^a(14-18)
T13	13 ± 0.6^c(12-15)	15 ± 0.6^b(14-17)	14 ± 0.6^b(13-16)	16 ± 0.6^a(14-17)
T18	14 ± 0.8^b(12-16)	16 ± 0.8^a(14-18)	14 ± 0.8^b(12-16)	17 ± 0.8^a(15-18)
L3	15 ± 0.8^b(14-17)	17 ± 0.8^a(15-18)	15 ± 0.8^b(13-17)	17 ± 0.8^a(16-19)
L6	17 ± 0.8^b(15-19)	18 ± 0.8^a(16-20)	17 ± 0.8^b(15-19)	19 ± 0.8^a(17-21)
S2	18 ± 1.1^b(15-20)	19 ± 1.1^a(17-22)	18 ± 1.1^b(15-21)	20 ± 1.1^a(17-22)
Spinous Process	AM PRE (95% CI)	AM POST(95% CI)	PM PRE(95% CI)	PM POST(95% CI)
T4	20 ± 0.8^a(18-22)	21 ± 0.8^a(19-23)	20 ± 0.8^a(18-22)	19 ± 0.8^a(18-21)
T11	16 ± 0.6^a(15-17)	16 ± 0.6^a(15-18)	16 ± 0.6^a(15-17)	17 ± 0.6^a(15-18)
T15	15 ± 0.6^a(14-17)	15 ± 0.6^a(13-16)	15 ± 0.6^a(13-16)	15 ± 0.6^a(14-17)
T18	15 ± 0.5^a(14-16)	15 ± 0.5^a(13-16)	15 ± 0.5^a(14-16)	15 ± 0.5^a(14-16)
L3	16 ± 0.8^a(14-18)	16 ± 0.8^a(14-17)	16 ± 0.8^a(14-17)	16 ± 0.8^a(14-18)
L6	20 ± 1.0^a(17-22)	20 ± 1.0^a(17-22)	19 ± 1.0^a(17-21)	20 ± 1.0^a(18-22)
S2	22 ± 1.0^a(20-24)	21 ± 1.0^a(19-24)	22 ± 1.0^a(19-24)	22 ± 1.0^a(20-24)

This table represents the significant main effect of time point on the MNT values, excluding the effects of day. Within rows, different letters indicate significant ($P < .05$) differences between the time points within each muscle site.

3.3. Static Surface Electromyography (sEMG)

There was no significant treatment effect on muscle activity or muscle tone at any of epaxial muscle sites at any time point.

3.4. Mechanical Nociceptive Thresholds

For the AM and PM timepoints, the pre blanket application MNT values were significantly ($P < .0001$) lower (more painful) than the post-blanket application MNT values at all epaxial muscle sites tested Table 2. The significantly higher MNT values following blanket therapy indicate improvements in nociception.

Similarly, when comparing baseline (Day 0) MNT values to end of study (Day 4) there was significantly ($P < .0001$) higher MNT values measured on Day 4 at all epaxial muscle sites tested. 18th thoracic vertebrae (T18) dorsal spinous process was the only significant bone site tested Table 3.

3.5. Serum Creatine Kinase (CK) and Aspartate Aminotransferase (AST)

There were no significant changes in muscle isoenzymes at any time point.

3.6. Serum Biomarker Analysis

3.6.1. NMR Data Analysis

No significant changes were found for any of the metabolites isolated at any of the time points.

3.6.2. MS Data Analysis

No significant changes in mass spectrometry measures were found for any tested metabolites at any time points.

3.7. Inertial Sensor Data

No significant effect of treatment was found in any parameter at any time point.

3.8. Biomechanical Outcome Variables

3.8.1. Kinetics

No significant effect of treatment was found in any parameter at any time point. Treatment did not significantly influence the peak vertical, braking, or propulsion force, nor did it influence the vertical, braking, or propulsion impulse of any fore or hindlimb at any time point.

The application of blanket therapy did not significantly influence stance duration or stride length of any fore or hindlimb at any time point.

The velocity at which each horse traveled remained consistent (2.93-3.03 m/s) between trials and did not significantly differ between horses or trials.

3.8.2. Postural Stability

A significant treatment ($P = .03$) effect was found for head height. The head height was significantly lower (1.54 ± 0.03m, 95% CI = 1.46-1.61m) during therapy on day 3 compared to day 1 (1.61 ± 0.03m, 95% CI = 1.53-1.68m) and day 2 (1.61 ± 0.03m, 95% CI = 1.53-1.68m) respectively.

A significant treatment effect was found in the normalized COP area. The normalized COP area was significantly ($P = .04$) smaller (more stable) on day 3 (32.8 ± 9.6, 95% CI = 11.6-53.9) compared to day 1 (55.4 ± 9.6, 95% CI = 34.3-76.6) which indicated improved postural stability during the 15 minute therapy session compared to day 1of 5 minutes of therapy (Fig. 5).

3.8.3. Kinematic Analysis

Sternal elevation thoracolumbar angular displacement – Treatment did not significantly influence the angular displacement (dorsal flexion angle) during a sternal lift exercise at any time point (baseline, day 3 pre/post blanket therapy or end of study). Treatment did not significantly affect the height of T6 compared to T12, T14, T16, L1, L3, or L6 at any time point.

Cervical flexion (muzzle between forelimb fetlocks) thoracolumbar angular displacement - Blanket therapy did significantly ($P = .003$) increase the dorsal flexion angle of the spine when comparing baseline values (167° ± 1.13, 95% CI = 164-169°) to end of study

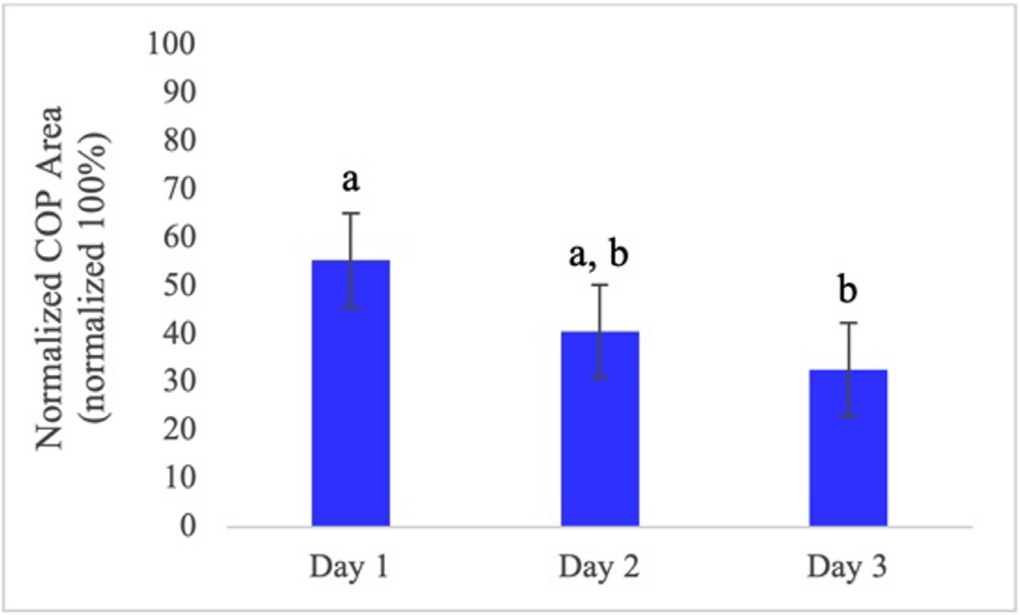

Fig. 5. Graph of normalized amplitudes of the COP area measured during treatment on days 1-3. Different letters indicate significant ($P < .05$) differences between treatment applications.

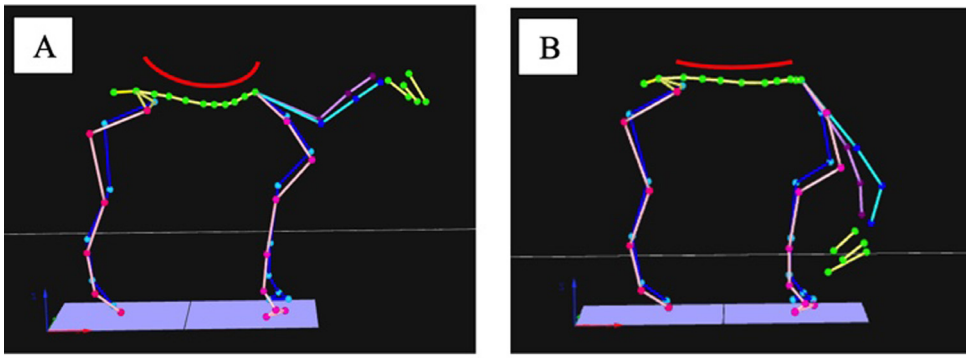

Fig. 6. Illustrates the sagittal kinematic computer generated stick figure. Image A demonstrates thoracolumbar curvature (red line) in a square stance position. Image B demonstrates thoracolumbar curvature (red line) during induced cervical flexion. The green dots (also on head) represent the retroreflective markers placed over the thoracolumbar spinous process.

values (172° ± 1.13, 95% CI = 169-174°) (Fig. 6). Treatment did significantly ($P = .002$) decrease the height difference between T6 baseline values and all other measured vertebral sites compared to end of study values, indicating improved lifting of the thoracolumbar spine at study conclusion Table 4 [1–29].

Left lateral bending distance of nose to tuber coxae - Treatment did not significantly influence the distance of the nose from the tuber coxae during a left lateral bending exercise at any time point

Right lateral bending distance of nose to tuber coxae – Blanket therapy did significantly ($P = .04$) decrease the distance (improved lateral bending) between the bridge of the nose marker and the tuber coxae marker when comparing day 3 pre blanket therapy (767.1 ± 58.5mm, 95% CI = 637.3 – 897.1mm) and day 3 post blanket therapy (677.2 ± 58.5mm, 95% CI = 547.3 – 807.2mm).

4. Discussion

Bio-electromagnetic energy regulation therapy is a technology using low pulsed-electromagnetic frequency at a flux density of 35-microTesla in a bio-rhythmic format [22]. The application of BEMER therapy is frequently used for therapeutic purposes in horses with limited objective data to support its use in clinical cases. The purpose of this study was to evaluate the effects of bio-electromagnetic energy regulation blanket therapy on measures of back pain, stiffness and function in horses with naturally occurring thoracolumbar epaxial muscle pain. The outcomes of this study demonstrated that BEMER blanket therapy significantly improves static balance control, enhances spinal flexibility and modulates pain in horses, which is fundamental to providing foundational evidence-based support for bio-electromagnetic energy regulation therapy for the management of thoracolumbar epaxial muscle pain.

Back pain is considered one of the most common and least understood clinical problems in horses. Most horses used for athletic performance are ridden, therefore back pain can cause significant and potentially negative influences on musculoskeletal health. Overt clinical signs of back pain are infrequent and more often horses present with suboptimal performance or behavioral issues that may lead to rider falls, rehoming or increased expenses due to ineffective treatments. Often the localization of the primary source of pain can be difficult due to increased nociceptive plasticity (i.e., behavioral and cellular modifications produced by activation of nociceptors) causing radiating and referred pain.

Table 3
Mean ± standard error and 95% confidence intervals for all MNT values (kg/cm^2) at baseline and day 4. Within rows, different letters indicate significant ($P < .05$) differences between the days.

Landmarks Spinous process	Baseline (Day 0)(95% CI)	Study End (Day 4)(95% CI)
T4	21 ± 1.4^a(18-24)	21 ± 1.4^a(18-24)
T11	16 ± 0.9^a(14-18)	17 ± 0.9^a(15-19)
T15	15 ± 0.8^a(13-17)	16 ± 0.8^a(14-17)
T18	14 ± 0.8^b(12-16)	17 ± 0.8^a(15-18)
L3	17 ± 0.9^a(15-19)	17 ± 0.9^a(15-19)
L6	21 ± 0.8^a(19-23)	21 ± 0.8^a(19-23)
S2	23 ± 0.7^a(22-25)	24 ± 0.7^a(23-26)
Left epaxial muscle	Baseline (Day 0)(95% CI)	Study End (Day 4)(95% CI)
T9	11 ± 0.7^b(9-12)	16 ± 0.7^a(15-18)
T13	11 ± 0.7^b(9-12)	17 ± 0.7^a(16-19)
T18	11 ± 1.0^b(8-13)	16 ± 1.0^a(14-19)
L3	12 ± 0.7^b(10-14)	17 ± 0.7^a(15-19)
L6	15 ± 0.7^b(14-16)	18 ± 0.7^a(16-19)
S2	17 ± 1.2^b(14-20)	20 ± 1.2^a(17-22)
Right epaxial muscle	Baseline (Day 0)(95% CI)	Study End (Day 4)(95% CI)
T9	12 ± 0.9^b(10-14)	17 ± 0.9^a(15-19)
T13	11 ± 0.7^b(10-13)	18 ± 0.7^a(16-19)
T18	13 ± 0.8^b(11-15)	17 ± 0.8^a(15-19)
L3	14 ± 0.9^b(12-16)	19 ± 0.9^a(17-21)
L6	17 ± 0.9^b(15-19)	19 ± 0.9^a(17-21)
S2	19 ± 1.2^a(16-21)	20 ± 1.2^a(17-23)

Table 4
Dorsoventral displacement (mm) of spinous process markers (relative to T6) during induced cervical flexion (muzzle between front fetlocks). A negative value indicates the marker moved upward, compared to T6. Within rows, different letters indicate significant ($P < .05$) differences between the days within sites.

Landmark Spinous Process	Baseline (Day 0)(95% CI)	Study End (Day 4)(95% CI)
T6-T12	38.2 ± 5.4^a(26-50)	18.5 ± 5.4^b(7-30)
T6-T14	39.5 ± 5.4^a(28-51)	15.3 ± 5.4^b(4-27)
T6-T16	33.8 ± 5.6^a(22-46)	6.4 ± 5.6^b(-5-18)
T6-L1	17.9 ± 5.9^a(6-30)	-10.4 ± 5.9^b(-23-2)
T6-L3	4.3 ± 5.8^a(-8-16)	-25.3 ± 5.8^b(-37- -13)
T6-L6	-4.8 ± 5.9^a(-17-7)	-29.1 ± 5.9^b(-41- -17)

Mechanical nociceptive threshold (MNT) assessment has been investigated in numerous human clinical studies [23] and more recently used to establish normal reference values in the horse [19], as well as assessing equine axial and appendicular musculoskeletal pain [24,25]. Use of the pressure algometer to assess MNT's provides a repeatable, objective quantification of pain, allowing changes in stimulus intensity to be compared [23]. Human studies have demonstrated that MNTs are not only decreased over the injured region, but that lower thresholds are often found over sites remote to the primary source of pain [23]. Similarly, experimentally-induced OA in the equine carpus resulted in lower MNT values recorded from sites tested directly in the region of the carpus, as well as decreased values in sites both distal and proximal to the osteoarthritic joint [25]. However, pressure algometry is often subject to criticism for use in research studies due to the concerns of habituation and/or sensitization. These concepts have been tested extensively in multiple equine pressure algometry studies and have reported a prevalence of 14% habituation, 15% sensitization and a 71% no consistent change to 3 consecutive measures [26]. In the current study, there were no significant differences between the AM pre-treatment and PM pre-treatment MNT values for a majority of sites tested, indicating no evidence of sequential increasing MNT values over repeated measures. MNT testing can be used to quantify the degree of pain associated with the primary injury, to identify and localize referred musculoskeletal pain, and may assess nociceptive changes related to rehabilitative therapies. In the present study, mechanical nociceptive thresholds were significantly higher (improved pain modulation) over both bone and epaxial muscle sites tested immediately after therapy and at study completion. In addition, blinded chiropractic evaluation demonstrated significant improvements in muscle tone and pain to palpation at the end of the study compared to baseline. These improvements in pain assessment demonstrate the influence of BEMER blanket therapy to modulate pain immediately following treatment, as well as the ability to maintain improvements in nociception within a 24-hour period following therapy.

The presence of back pain often coincides with epaxial muscle hypertonicity, muscle spasms, and restricted range of motion. The application of bio-electromagnetic energy regulation therapy in human patients with chronic low back pain has demonstrated significant improvements in functional activities, fatigue and sleep quality [27,28]. When therapeutic exercises were combined with bio-electromagnetic energy regulation therapy an additive effect was appreciated. Patients with low back pain that received standard physiotherapy and additional bio-electromagnetic energy regulation therapy displayed significant improvements in exercise scores, fatigue intensity, and pain modulation compared to those patients that received physiotherapy alone [9]. Similarly, the horses enrolled in this study demonstrated significant improvements in spinal motion and flexibility during various challenging range of motion exercises following bio-electromagnetic energy regulation blanket therapy. Horses demonstrated enhanced spinal flexibility in both spinal flexion and right lateral bending. The lack of significance to the sternal elevation exercise may be due to the measurement technique assessing only sagittal plane movement and not assessing out of plane motion. In addition, these exercises were novel to this group of horses and horses were not acclimated to the exercises prior to initiating the study. Furthermore, the exercises were only conducted on the scheduled data collection days in order to minimize a learned response. Although, we cannot rule out that some horses simply improved based on repeating the exercises alone. During ventral cervical flexion, horses were not allowed to "cheat" by knuckling at the carpus and the position of the treat was maintained at the level of the dorsal fetlock. Interestingly, spinal flexibility in lateral bending improved to the right but did not show any significant differences to the left. As a whole the horses were more comfortable lateral bending to the left with smaller distances appreciated between the bridge of nose and tuber coxae. This may be due to the fact horses are mostly handled from their left side and thus may be more supple moving to the left. Maintaining symmetrical flexibility through the thoracolumbar spine allows the horse to regulate movement more efficiently and effectively during sports specific tasks. A flexible spine provides pain free range of motion, enhances neuromotor control, and effectively improves strength gains in muscle. Although the exact mechanism of action for improvements in spinal motion is not fully understood, the potential improvements in microcirculation may have increased tissue perfusion and oxygenation thereby decreasing muscle spasms, hypertonicity, and pain.

Further improvements in neuromotor control were demonstrated in this group of horses through enhanced postural stability during quiet standing. During blanket therapy, the normalized COP area was significantly smaller on day 3 (15 minute therapy) compared to day 1 (5 minute therapy), indicating that bio-electromagnetic energy regulation blanket therapy increased proprioceptive acuity and thus postural control during 15 minutes of therapy compared to the shorter duration. In addition, during treatment the head height was significantly lower of day 3 compared to day 1, potentially indicating a relaxing effect during 15 minutes of therapy compared to the shorter duration therapy applications. Balance control in people can be significantly impaired by structural disorders, movement-strategy deterioration, periph-

eral neuropathies, and altered biomechanics. It is possible that the magnetic signals enhance the ability of the central nervous system to integrate available proprioceptive information and improve postural control. Diabetic patients with peripheral neuropathy have significant improvement in postural stability following pulsed electromagnetic therapy due to improvements in peripheral nerve function, motor neuron conduction velocity and increased sensory afferent fiber tactile stimulation [29].

5. Limitations

Given the complexity and variety of causes of back pain it is often difficult to determine the underlying cause and thus develop a targeted treatment approach. A limitation of the current study was the lack of establishing a definitive structural diagnosis for the identified thoracolumbar epaxial muscle pain of horses enrolled in the study. The inclusion of diagnostic imaging of the thoracolumbar region may have provided additional clinical information; however, poor correlations have been reported between radiographic findings and clinical signs of back pain, which greatly limit the utility of diagnostic imaging to confirm the presence and to localize the site of back pain, muscle hypertonicity or restricted range of motion in affected horses.[4] Because the common goal in the treatment of affected horses aims to alleviate discomfort, muscles spasms and stiffness associated with back pain regardless of the specific diagnosis we felt the current design was appropriate.

Further, limitations of the current study include the lack of a control group and lack of blinding all examiners responsible for data collection. This was a proof on concept study with a limited number of horses with naturally occurring thoracolumbar epaxial muscle pain. With evidence of beneficial outcomes further investigations involving a larger randomized placebo controlled trial is indicated to confirm the results of this project.

6. Conclusion

The results of this study validate the use of BEMER blanket therapy as a prospective method for modulating thoracolumbar epaxial muscle pain and for improving neuromotor control, and spinal flexibility. This emerging technology provides the equine practitioner with a medication free bio-solution to modulate thoracolumbar epaxial muscle pain in horses.

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Declaration of Competing Interest

None.

Acknowledgements

Declaration of ethics: All protocols were approved by the Colorado State University Animal Care and Use Committee (ACUC Study Number: 19-8723A) The authors have adhered to the Principles of Veterinary Medical Ethis of the AVMA.

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