



Extracorporeal shockwave therapy raises mechanical nociceptive threshold in horses with thoracolumbar pain

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Summary

Background: Although extracorporeal shockwave therapy (ESWT) is a common treatment for horses with back pain, effects on mechanical nociceptive threshold (MNT) and *multifidus* muscle cross sectional area (CSA) in the spine are unknown.

Objectives: To evaluate effects of ESWT on spinal MNT and *multifidus* muscle CSA in horses with thoracolumbar pain.

Study design: Non-randomised trial.

Methods: Thoracolumbar spines of 12 horses with thoracolumbar pain were radiographed to document existing pathology. Each horse received three ESWT treatments, 2 weeks apart (days 0, 14, 28). Palpation scores were documented (days 0, 45 and 65). Ultrasonographic CSA of left and right *multifidus* muscles was recorded at T12, T14, T16, T18, L3 and L5 (days 0, 45 and 65). MNT was measured at the same spinal sites every 7 days (day 0–56).

Results: Mechanical nociceptive threshold in 10/12 horses (83%) was greater at each time point compared with day 0 ($P < 0.05$). Mechanical nociceptive threshold increased at all time points at six sites in 2/12 (16%), at five sites in 3/12 (25%), at four sites in 4/12 (33%) and at one site in 1/12 (8%; $P < 0.05$). Mechanical nociceptive threshold average per cent increase from day 0 to 56 was 64% for the thoracic region (T12–T18) and 29% for the lumbar region (L3–L5). There was no statistical difference in MNT from day 35 to 56 ($P = 0.25$). A bimodal analgesic trend was observed following ESWT. Degree of radiographic change was not associated with response to treatment. No significant change in *multifidus* muscle CSA was observed.

Main limitations: Small study size and lack of control group.

Conclusions: Three treatments of ESWT 2 weeks apart raised MNT over a 56-day period in horses with back pain, but did not influence change in CSA of the *multifidus* muscle. While ESWT appears justifiable for analgesia, physiotherapeutic techniques may be necessary in conjunction for concurrent muscle rehabilitation.

Keywords: horse; back pain; extracorporeal shockwave therapy; multifidus; mechanical nociceptive threshold

Introduction

Back pain is frequently diagnosed and treated in the horse [1,2]. Affected horses present with axial skeleton stiffness or pain, lameness, poor performance or avoidance behaviours under saddle [1–3]. Impingement of the spinous processes at thoracic vertebrae T12–T18 and osteoarthritis of the articular facets at lumbar vertebrae L3–L5 are the most commonly reported osseous pathologies in the thoracolumbar spine [4,5]. Atrophy of the epaxial musculature, including the *iliocostalis*, *longissimus* and *spinalis* muscles, is recognised in conjunction with back pain [2,6]. Recently, rehabilitation of the spinalis *multifidus* muscle, a deep spinal stabiliser, has become a focus of targeted physiotherapy due to documented atrophy ipsilateral to osseous spinal pathology [6–9].

Horses with back pain resent palpation and dorsiflexion of spinal structures (bone, muscle and soft tissue). Assessment of the degree of pain is subjective due to individual interpretation and palpation technique. Pressure algometry is a validated, objective and repeatable measure of axial skeleton mechanical nociceptive threshold (MNT), defined as the minimum pressure required to induce a pain response [10–13]. Horses with experimentally induced back pain have demonstrated decreased MNT over localised areas of induced pain, but not at distant sites [10], a correlation that suggests utility for monitoring MNT in response to treatment.

Due to challenges quantifying back pain, it is common to treat empirically and assess response to therapy. Medical and surgical treatments include extracorporeal shockwave therapy (ESWT), corticosteroid injection, mesotherapy, acupuncture, chiropractic adjustment, physiotherapy, interspinous ligament desmotomy and partial spinous process resection [1,5,14–17]. There is limited research documenting the efficacy of these treatments in horses.

Extracorporeal shockwave therapy is a noninvasive, well-tolerated treatment for back pain [1,14]. Extracorporeal shockwaves are focused, high-velocity acoustic waves that exert direct and indirect mechanical forces on bone, soft tissue and muscle [18]. Effects include increased perfusion, osteogenesis, fibroblastic stimulation and analgesia [18,19]. Despite popularity for treatment of back pain, there is no research documenting effects of ESWT on equine spinal MNT or *multifidus* CSA. The objective of this study was to evaluate the effects of ESWT on MNT and *multifidus* CSA in horses with thoracolumbar pain. We hypothesised that ESWT would exert an analgesic effect reflected by increased MNT and increased CSA of the *multifidus*.

Materials and methods

Animals

Twelve horses from the Intercollegiate Equestrian Program were selected for inclusion based on the following criteria: 1) physical evidence of back pain with a combined thoracolumbar and epaxial muscle palpation and epaxial muscle atrophy score of ≥ 3 ; 2) no overt signs of lameness at the trot over firm ground; 3) no treatment for back pain within 6 months; 4) no concurrent nonsteroidal anti-inflammatory treatment and 5) in regular work ≥ 4 days/week.

Physical evidence of back pain was scored based on response to thoracolumbar and epaxial muscle palpation and presence or absence of epaxial muscle atrophy. Scoring systems were modified from previous methods [20]. Thoracolumbar palpation was performed on midline, directly over the spinous processes from the base of the withers to the tuber

sacrale. Response was scored: no obvious avoidance (0), avoidance characterised by lordosis of spine or movement away from pressure (1), avoidance plus tossing of head and/or tail swish (2), or violent avoidance characterised by kicking or biting (3). Epaxial muscle palpation was performed bilaterally 5 cm off midline, abaxial to the spinous processes. Response was scored: soft musculature with no avoidance (0), stiff musculature with no avoidance (1), stiff musculature with avoidance characterised by lordosis or movement away from pressure (2), or stiff musculature with violent avoidance characterised by kicking or biting (3). *Longissimus* epaxial muscle atrophy was visually assessed as present or absent and scored: no atrophy characterised by musculature flush with the spinous processes (0), atrophy in the thoracic or lumbar region (1), or atrophy in the thoracic and lumbar region (2).

Horses were housed in mixed gender turnout of 5–10 horses in approximately 3 acre fields and were ridden on the flat and over fences during scheduled lessons. All tack remained the same for each horse throughout the duration of the study.

Imaging

Prior to baseline recordings, lateromedial radiographs of the spinous processes and articular facets from T12 to L5 were obtained. Radiographs were evaluated by an ACVR board-certified radiologist (K.C.) for the presence of spinous process impingement at T12, T14, T16, T18, L3 and L5 and/or presence of articular facet pathology at T12, T14, T16, T18 and L3 using radiographic grading scales adapted from previous sources (Table 1) [21].

Ultrasonography (6.8–2.0 MHz convex probe, Sonoscape S9)^a of the left and right *multifidus* muscle at T12, T14, T16, T18, L3 and L5 was performed on days 0, 45 and 65. To determine spinal site locations, the articulation of the 18th rib with the 18th thoracic vertebral body was identified and marked with a 5 × 5 cm region of clipped hair on dorsal midline. The remaining sites were identified and clipped based on relationship to the 18th thoracic vertebral body. Clipped regions were maintained throughout the study to ensure consistency of data collection. Horses were restrained in a quiet grooming stall without sedation. The probe was oriented transversely (short axis), adjacent to dorsal midline at the level of the caudal articular facet of the respective vertebral body until the fascial border between the *multifidus* and *longissimus dorsi* muscles was clearly delineated (Fig 1) [8]. Images were obtained by the same experienced ultrasonographer (L.T.). *Multifidus* CSA was measured using Image J software^b. Blinded images were measured three times on three separate occasions by the same person (L.T.).

Pressure algometry

Horses were restrained in a quiet grooming stall without sedation. A pressure algometer (Force Dial FDK 20)^c with a 1 cm² rubber tip was slowly

applied perpendicular to dorsal midline until a local avoidance response (e.g. skin or muscle twitch, lordosis of the spine at the point of pressure or adverse response to pressure characterised by raised head, flattened ears and/or tail swish) was achieved [10,13]. Measurements were collected in triplicate at T12, T14, T16, T18, L3 and L5 with a 30 s break between each set. The same clipped regions were used to ensure consistency with data collection. A baseline recording was obtained on day 0. Subsequent recordings were obtained every 7 days until day 56. All measurements were performed by the same examiner (L.T.) who was blinded to the readings during the procedure and recorded in kg/cm² by an impartial observer.

Thoracolumbar palpation, epaxial muscle palpation and epaxial atrophy scores

Response to palpation and presence or absence of atrophy was scored in each horse on days 0, 45 and 65. Horses were restrained in a quiet grooming stall without sedation. The same examiner (L.T.) assessed each horse at all time points.

Extracorporeal shockwave therapy

Horses were sedated with detomidine hydrochloride^d (0.01 mg/kg bwt) and the skin from T12 to L5 was prepped with 70% isopropyl alcohol and gel (LithoClear®)^e. Extracorporeal shockwave therapy (Versatron®)^f was performed using an 80-mm trode at power setting E4 (penetration depth 113 mm, energy flux density 0.13 mJ/mm²; chosen based on ultrasonographic measurements of depth from skin surface to articular facets). The trode was orientated adjacent to midline and angled approximately 45 degrees towards the spine. Continuous movement of the trode from T12 to L5 was performed for 1500 pulses (750 pulses/side). Each horse received three treatments 2 weeks apart on days 0, 14 and 28. On days coinciding with pressure algometer readings, MNT was performed prior to sedation and ESWT. Post-ESWT, horses received 48 h of turnout with no work. All treatments were performed by the same examiner (L.T.).

Data analysis

The median of triplicate MNT measurements was used for downstream analyses. Normal probability plots showed that MNT data, MNT per cent change from baseline and *multifidus* CSA at all time points and locations followed a normal distribution. Data were summarised as mean (±s.d.). Per cent changes from baseline in MNT were analysed by mixed-model repeated-measures ANOVA followed by Tukey–Kramer's procedure for multiple comparisons. The linear model specified day, spinal site and the interaction between day and site as fixed factors with Kenward–Roger approximation as the denominator degrees of freedom. G-side variation in the data (the random effects) was modelled by specifying horse identification as a random effect while the R-side variation in the data (the errors) was modelled by specifying a first-order autoregressive covariance matrix. Spinous process impingement grades and articular facet scores were grouped by severity (grade 0, grades 1 and 2, or grades 3 and 4; and score 0–1 or score 2–3 respectively). Effects of spinous process impingement and articular facet scores and day on MNT were assessed using mixed-model repeated-measures ANOVA followed by Tukey–Kramer's procedure for multiple comparisons. The linear model specified spinous process impingement or articular facet score, day and interaction between spinous process impingement or articular facet score and day as fixed effects with Kenward–Roger approximation as the denominator degrees of freedom. G-side variation in the data was modelled by specifying horse identification and location as random effects while the R-side variation in the data was modelled by specifying a first-order autoregressive covariance matrix. *Multifidus* CSA was analysed by mixed-model repeated-measures ANOVA followed by Tukey–Kramer's procedure for multiple comparisons. The linear model specified day, spinal level and side plus all two-way interactions and a single three-way interaction as fixed factors with Kenward–Roger approximation as the denominator degrees of freedom. G-side variation in the data was modelled by specifying horse identification as a random effect while the R-side variation in the data was modelled by specifying a first-order autoregressive covariance matrix. The three-way interaction was further examined to

TABLE 1: Spinal pathology radiographic grading scales

Spinous process impingement	
0	No abnormalities noted
1	Narrowing of interspinous space (<4 mm), mild sclerosis of cortical margins
2	Loss of interspinous space, moderate sclerosis of cortical margins
3	Loss of interspinous space, severe sclerosis of cortical margins, osteolysis of spinous processes
4	Loss of interspinous space, severe sclerosis of cortical margins, osteolysis and cystic formation of spinous processes
Articular facet remodelling (cumulative score based on pathologies present)	
Asymmetry	Loss of clear joint space and/or double joint space
Opacity changes	Sclerosis or radiolucencies
Periarticular proliferation	Dorsal or ventral
Ankylosis	Dorsal bridging with loss of joint space
Fracture	Radiolucent line of the cranial/caudal articular facet

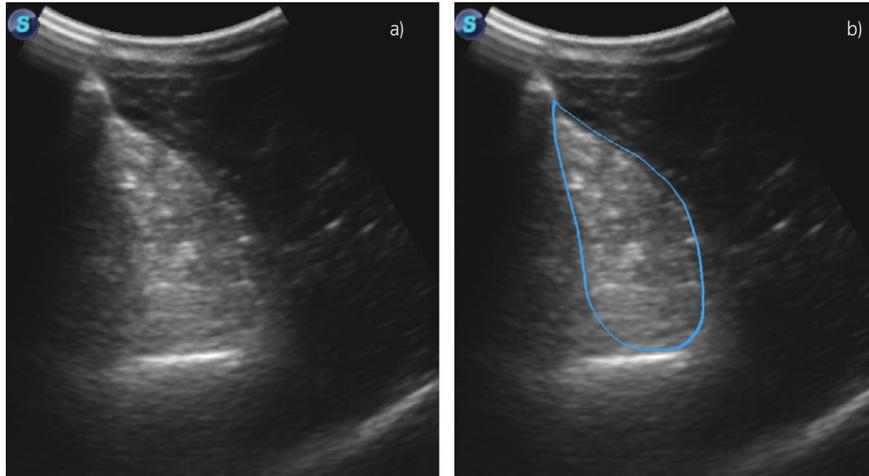


Fig 1: a) Representative transverse ultrasound image of the left *multifidus* muscle at T18 and b) *multifidus* outlined

compare sides within each combination of location and day. Significance threshold was set at $P < 0.05$. All analyses were performed using SAS[®] version 9.4.

Results

The study population consisted of nine geldings and three mares (median age 14.5 years; range 6–19 years). Breeds included Thoroughbred ($n = 5$), Hanoverian ($n = 2$), and Westphalian, Trakehner, Quarter Horse, Thoroughbred/Quarter Horse and Irish Sport Horse ($n = 1$ each). All horses completed all treatments and measurements and were consistently ridden 4–5 days per week, with the exception of Horse 9, who could not be ridden on days 26–32 due to a foot abscess.

Group pressure algometry data

Intraobserver algometry measurements were consistent across all time points and sites (Coefficient of variation median 9.4, interquartile ratio [IQR] 5.9–13.6). A total of 216 MNT readings over 56 days were obtained. Of those, 72 median MNT were calculated for statistical analysis. Baseline average MNT was $4.84 \pm 0.23 \text{ kg/cm}^2$ for T12–T18 and $6.05 \pm 0.09 \text{ kg/cm}^2$ for L3–L5. By day 56 average MNT was $7.63 \pm 0.23 \text{ kg/cm}^2$ for T12–T18 and $7.72 \pm 0.13 \text{ kg/cm}^2$ for L3–L5.

As a group, the majority of MNT increased 7 days post-ESWT (Fig 2). The exception was following the first treatment, where MNT of only the thoracic sites increased. Seven days after the second and third treatments, MNT at all sites had increased. Contrary to this, the majority of MNT decreased 14 days post-ESWT (Fig 2). The exception was again following

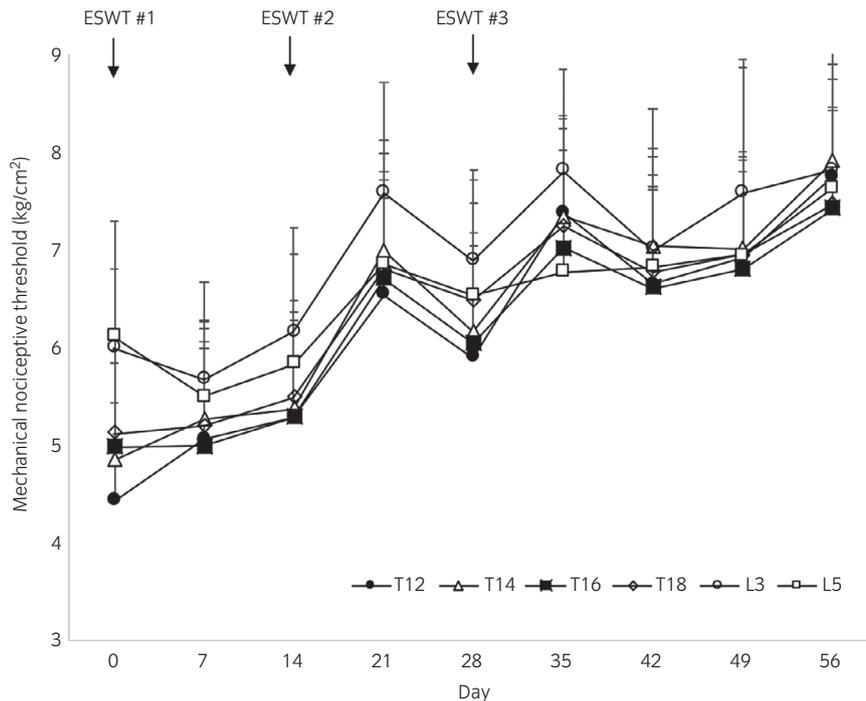


Fig 2: Average median mechanical nociceptive threshold (\pm s.d.) by spinal site from day 0 to 56, $n = 12$ horses. ESWT treatments are noted on days 0, 14, 28. Mechanical nociceptive threshold was performed prior to sedation and ESWT.

the first treatment, where thoracic and lumbar MNT increased instead of decreased.

Average per cent change in MNT increased by 64% at T12–T18 and by 29% at L3–L5 from day 0 to 56 (Table 2). The first significant change in MNT from baseline was at T12 on day 7. By day 21, MNT per cent change at T12–L3 was significantly increased from baseline. A significant increase in MNT per cent change at L5 was not observed until day 56. There was no significant difference in per cent change at any spinal site between days 35 and 56 ($P = 0.250$).

Individual pressure algometry data

For each combination of horse and location, linear and nonlinear relationships between MNT (outcome) and day (predictor) were determined at each time point. The linear relationship between individual time points was statistically significant in 44/72 (61%) of the models ($P < 0.05$), while 28/72 (39%) of the models showed a nonlinear relationship ($P > 0.05$). Among individual horses, MNT increased at all time points in 10/12 (83%) at ≥ 1 site in comparison to baseline ($P < 0.05$). MNT increased at all time points in 2/12 horses (16%) at six spinal sites, in 3/12 horses (25%) at five spinal sites, in 4/12 horses (33%) at four spinal sites and in 1/12 horses (8%) at one spinal site (Table 3). In 2/12 horses (16%), MNT did not change at any spinal site. Of the 10 horses that responded to ESWT, MNT increased at T14, T16 and T18 in eight horses (80%), at T12 and L3 in seven horses (70%), and at L5 in five horses (50%) ($P < 0.05$).

Imaging

Radiographic pathology: There was no statistical relationship between the grade of spinous process impingement or cumulative articular facet score and MNT response at any site or time point. Of the 72 spinous

processes imaged, 43% were grade 0, 29% were grade 1, 4% were grade 2, 11% were grade 3 and 12% were grade 4 (Table 3). The majority of grade 0 had a lumbar distribution, while the majority of grade 1–4 had a thoracic distribution (Fig 3, Table 3). Of the 60 articular facets imaged, 8% had a cumulative score of 0, 40% a score of 1, 30% a score of 2 and 22% a score of 3 (Fig 4, Table 3). None had a cumulative score of ≥ 4 . Pathologies included asymmetry, opacity changes and/or periarticular proliferation. Due to obstruction by the ilium, L5 was unable to be imaged radiographically.

Multifidus muscle cross-sectional area: Compared with baseline, there was no significant change in left or right *multifidus* muscle CSA at any site or time point ($P \geq 0.05$). Left and right CSA of the *multifidus* at L3 was statistically smaller at all time points in comparison to other spinal sites (left T12, $P < 0.003$; left T14, $P < 0.001$; right T12, T14, T16, T18 and L5, $P < 0.001$).

Palpation and muscle atrophy scores

Thoracolumbar palpation scores improved at all time points in all horses (range 1–3) except Horse 3 (Supplementary Item 1). Epaxial muscle palpation scores improved at all time points in all horses (range 1–2; Supplementary Item 1). Epaxial muscle atrophy scores improved by 1° in 5/12 horses at all time points, while the remaining six horses exhibited no degree of improvement (Supplementary Item 1).

Discussion

This is the first clinical study to document MNT response (an objective quantification of response to treatment) in horses with back pain before and after a series of ESWT. Extracorporeal shockwave therapy

TABLE 2: Mechanical nociceptive threshold average per cent change from day 0

Day	T12		T14		T16		T18		L3		L5	
	% Δ	P value										
7	19 \pm 0.3	0.03	12 \pm 0.3	0.2	2 \pm 0.2	0.8	6 \pm 0.3	0.5	-5 \pm 0.2	0.6	-8 \pm 0.1	0.4
14	23 \pm 0.4	0.005	15 \pm 0.2	0.1	8 \pm 0.2	0.4	10 \pm 0.2	0.2	4 \pm 0.2	0.7	-3 \pm 0.2	0.7
21	56 \pm 0.5	<0.001	49 \pm 0.3	<0.001	40 \pm 0.3	<0.001	39 \pm 0.4	<0.001	28 \pm 0.2	0.002	14 \pm 0.2	0.1
28	41 \pm 0.5	<0.001	32 \pm 0.3	0.004	25 \pm 0.3	0.005	29 \pm 0.4	<0.001	17 \pm 0.2	0.06	10 \pm 0.3	0.3
35	77 \pm 0.5	<0.001	56 \pm 0.3	<0.001	45 \pm 0.3	<0.001	47 \pm 0.4	<0.001	32 \pm 0.2	<0.001	13 \pm 0.3	0.1
42	59 \pm 0.5	<0.001	49 \pm 0.3	<0.001	37 \pm 0.3	<0.001	37 \pm 0.3	<0.001	18 \pm 0.2	0.040	12 \pm 0.2	0.2
49	65 \pm 0.5	<0.001	49 \pm 0.3	<0.001	39 \pm 0.3	<0.001	39 \pm 0.3	<0.001	28 \pm 0.2	0.002	13 \pm 0.2	0.1
56	84 \pm 0.5	<0.001	70 \pm 0.4	<0.001	51 \pm 0.3	<0.001	51 \pm 0.3	<0.001	32 \pm 0.2	<0.001	26 \pm 0.2	0.004

% Δ , % change from day 0 (\pm s.d.).

TABLE 3: Distribution of radiographic spinous process impingement (SP) and articular facet (AF) pathology

	Signalment	T12		T14		T16		T18		L3		L5		Total # sites responding
		SP	AF	SP	AF	SP	AF	SP	AF	SP	AF			
Horse 1	9y, ISH, M	0*	3*	1*	2*	1*	1*	2*	1*	0*	3*	1*	NR*	6
Horse 2	14y, Han, M	1	1	4	1	4	2	3	3	0	3	0	NR	0
Horse 3	16y, TB, G	0*	1*	1*	1*	0*	1*	0	3	0*	3*	0	NR	4
Horse 4	19y, TB, G	1*	1*	3*	2*	4*	2*	3*	2*	0*	2*	1*	NR*	6
Horse 5	15y, TB, G	1*	0*	4	1	4*	2*	4*	2*	1*	3*	2	NR	4
Horse 6	11y, Han, G	1	1	1	1	1	2	0	3	0	3	0	NR	0
Horse 7	14y, TB/QH, G	1	1	3	1	3*	0*	3	0	0	2	0	NR	1
Horse 8	6y, Trak, M	0*	1*	0*	1*	0	1	0*	2*	1	3	0*	NR*	4
Horse 9	17y, QH, G	0	0	1*	0*	1*	1*	0*	1*	0*	2*	0*	NR*	5
Horse 10	16y, West, G	0*	1*	1*	2*	3*	2*	0*	3*	0*	1*	1	NR	5
Horse 11	10y, TB, G	3*	3*	4*	2*	4	1	4*	2*	2	3	0*	NR*	4
Horse 12	8y, TB, G	1	1	0*	1*	1*	2*	1*	2*	0*	1*	0*	NR*	5
Average		0.8	1.2	1.9	1.3	2.2	1.4	1.7	2	0.3	2.4	0.4	NR	3.6

+, significant change in MNT post-ESWT; NR, not recorded; ISH, Irish Sport Horse; Han, Hanoverian; TB, Thoroughbred; QH, Quarter Horse; Trak, Trakehner; West, Westphalian.

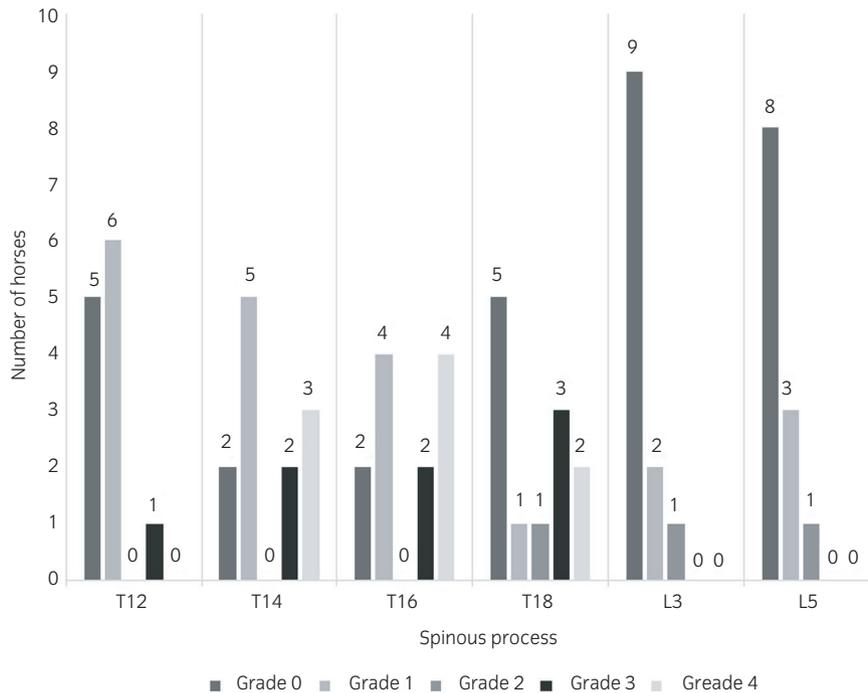


Fig 3: Distribution of radiographic spinous process impingement grades by spinal site (n = 12 horses)

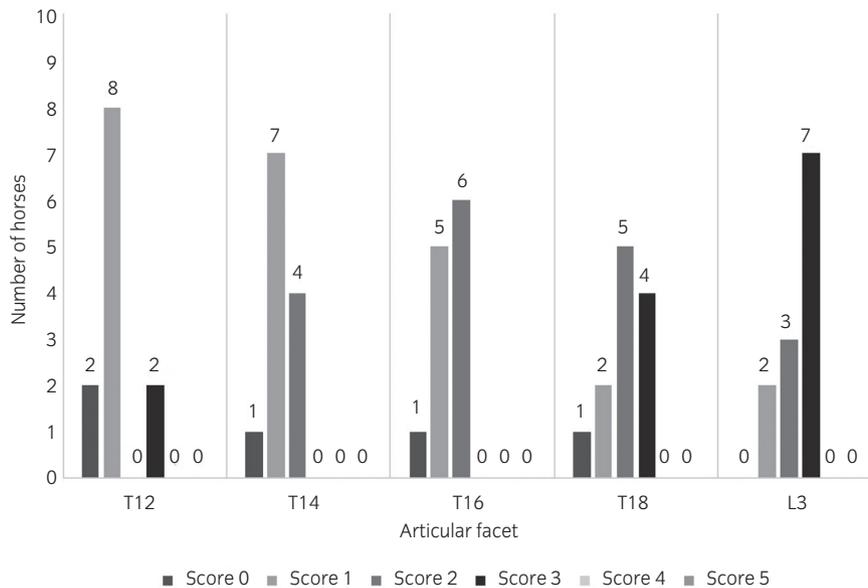


Fig 4: Distribution of articular facet cumulative scores by spinal site (n = 12 horses).

raised spinal MNT at all time points in 83% of horses in our study, regardless of the degree of spinous process or articular facet pathology. Not surprisingly, individual horses responded differently, with 50% responding at five or more sites and 90% responding at four or more sites. Timing of ESWT corresponded to MNT response and spinal sites responded differently. First to respond significantly was T12 by day 7, followed by all thoracic and one lumbar (L3) site by day 21. L5 was last to respond on day 56. In our study, a single ESWT was insufficient to raise MNT. A series of three ESWT was required to raise MNT at all thoracolumbar sites. Furthermore, MNT per cent change did

not differ from day 35 to 56, suggesting a lasting 21-day effect following the third ESWT.

A bimodal pattern of analgesia post-ESWT has been described in human subjects with an immediate decrease in pain for 3–4 days, a recurrence of pain and a second, gradual decrease in pain over 3–4 weeks [22]. Initial analgesia is likely related to direct effects of ESWT on the nociceptive response, while delayed effects are thought to be related to angiogenesis and tissue matrix remodelling associated with tissue healing [23–25]. In our study, a similar pattern was observed for the majority of spinal sites post-ESWT. After the second and third treatments, an increase in MNT was

observed at 7 days with a decrease at 14 days. This response was not consistently observed following the first treatment, with MNT of only the thoracic sites increasing at day 7 and all sites increasing at day 14.

The reason for this difference in MNT response following the first treatment is unknown; however, early response of thoracic and delayed response of the lumbar spinal sites could be related to spinal kinematics. Maximal intervertebral motion in the equine spine occurs in the caudal lumbar region and lumbosacral junction [26]. Kinematic evaluation of horses with back dysfunction has demonstrated that range of motion of the caudal thoracic and cranial lumbar spine is reduced, as evidenced by decreased dorsoventral flexion-extension of T13–17 at the walk and T17–L1 at the trot, significantly shorter stride length and decreased axial rotation of the pelvis [27]. Furthermore, horses with back pain will compensate with postural changes, such as stiffening of the epaxial musculature presumably to limit dorsoventral range of motion. These guarding mechanisms help explain the adverse response to a saddle and weight of the rider, which encourages an overall increase in extension of the spine [28] that is often seen from horses with back pain. It has been hypothesised that kinematic differences in the thoracic and lumbar spine result from altered neuromuscular control and proprioception to compensate for pain [27], possibly explaining differences in MNT response after the first ESWT. Additional investigation is warranted to determine if the kinematics in horses with back pain change following ESWT.

Analgesia in the horse following ESWT has also been observed and is consistent with our study findings. One study described decreased sensory nerve conduction velocity of the medial and lateral palmar digital nerves at 3 and 7 days post-ESWT [29]. Histologic findings indicated myelin nerve sheath separation and disruption of the treated nerves, thus a rationale for decreased nerve conduction due to impaired nerve function [29]. Another study reported decreased vertical ground reaction forces in horses with unilateral forelimb lameness localised to the foot, fetlock or carpus for up to 48 h following ESWT [30].

Assessment of pain in the thoracolumbar spine was quantified objectively with pressure algometry and subjectively by response to palpation and assessment of muscle atrophy. Overall, palpation and atrophy scores improved throughout the study. Thoracolumbar and epaxial palpation scores improved the most, while minimal change in visual assessment of *longissimus* epaxial atrophy was noted. These findings are helpful for practitioners with regard to tracking progress during treatment.

Previous studies in human and veterinary literature have validated pressure algometry as a repeatable measure for musculoskeletal pain, with readings equivalent to force plate measurements and with minimal adaptation and sensitisation [10,13,31]. Pressure algometry can also be considered for objectively screening horses with back pain. Median MNT in asymptomatic horses have been reported for thoracic (12 kg/cm²) and lumbar (13 kg/cm²) regions [13]. In our study, baseline MNT was not only lower than those in asymptomatic horses (4.84 ± 0.23 and 6.05 ± 0.09 kg/cm² for thoracic and lumbar regions, respectively), but lower than those reported in a population of horses with back pain (thoracic 7.2 kg/cm² and lumbar 8.1 kg/cm²) [32], as well as MNT in horses with surgically induced back pain [10].

Distribution of radiographic pathology in our study was similar to previous reports [2,5]. There is conflicting information in the current literature as to the clinical significance of presence of radiographic pathology in the thoracolumbar spine. Although the severity of the radiographic change has been correlated to the degree of pain and muscle atrophy in horses with back pain [33–35], radiographic pathology has also been documented in asymptomatic horses [6,36]. In our study, the degree of radiographic severity of spinous process impingement or articular facet remodelling was not associated with response to ESWT. Our findings suggest that response to ESWT cannot be predicted by the degree of radiographic pathology alone and emphasises the importance of clinical evidence of thoracolumbar pain with regard to identification of candidate horses expected to respond best to therapy.

Although epaxial palpation and atrophy scores improved throughout the study, *multifidus* muscle CSA did not significantly change in response to ESWT. Previous reports have demonstrated neovascularisation and muscle fibre recruitment post-ESWT [23,37]. Recruitment of angiogenesis-related markers and a significant increase in neovascularisation was described in an Achilles tendon rabbit model at 4 weeks post-ESWT for up to 12 weeks

[23]. Additionally, recruitment of satellite cells for regrowth and regeneration of muscle tissue was reported 4–7 days post-cardiotoxin-induced muscle damage in rats [37]. It is possible that similar muscle effects to those observed by aforementioned reports were occurring on a cellular level, however, not reflected by an appreciable change in muscle CSA. It is also possible that the addition of physiotherapy during the study period as well as a longer treatment duration may have influenced CSA of the *multifidus*. Recent studies in horses have demonstrated an increase in *multifidus* CSA over a period of 60 and 90 days [8,9]. In both, either dynamic mobilisation [8] or whole body vibration therapy [9] was performed throughout the study duration. Although our final ultrasound was performed on day 65 in our study, the treatment period was only 35 days.

Another possible explanation for lack of statistically appreciable *multifidus* response could relate to the method of ESWT. Therapeutic effects of ESWT are suspected to occur where acoustic waves encounter resistance. This acoustic impedance depends on the density of the tissue; thus bone-soft tissue interfaces are prime therapeutic targets [22]. In our study, to maximise peak therapeutic effects, ESWT was directed over the epaxial muscles towards the spinous processes and articular facets in an attempt to maximise acoustic impedance effects at the bone-soft tissue interface. Future ESWT research should focus on the most advantageous

approach to target deep muscles, such as the *multifidus*. It is also possible that the epaxial muscles that benefited most from the ESWT were the more superficial muscles, such as the *longissimus*. An interesting follow-up to this study would be to assess ultrasonographic changes in *longissimus* CSA in response to ESWT.

Ultimately, MNT response did not statistically change in 2/12 horses throughout the study period. Coincidentally, both of these horses had cumulative articular facet scores of 3 at T18 and L3, a finding that was only present in one other horse. Although our results suggest that there is not a statistical association between the degree of radiographic pathology and the response to ESWT, it is logical that severity of pathology affects kinematic motion of the spine, especially in the caudal thoracic and cranial lumbar region. It is possible that this explains the lack of response in these two horses, however, additional investigation into correlation between kinematic function and radiographic pathology is warranted.

Limitations of the study include the lack of a control population and relatively small sample size. It would have been ideal to have a larger number of horses with back pain and a separate control group. However, it was important for us to have horses from a closed, controlled herd that were housed, fed and exercised on the same schedule, free of additional medication or orthopaedic treatments. This population of 12 horses was identified as the best candidate population. As such, baseline MNT and images for each horse were used as controls to maximise the number of horses included in the treatment protocol.

In conclusion, our findings indicate that three treatments of ESWT 2 weeks apart increases mechanical nociceptive threshold of the thoracolumbar spine in horses with clinical evidence of back pain. Our findings suggest that response to ESWT in horses with back pain cannot be predicted by the degree of radiographic pathology of the spinous processes or articular facets, as horses with both lesser and greater degrees of pathology responded equally. Although ESWT improved epaxial muscle palpation and atrophy scores, *multifidus* CSA did not statistically change within the designated study timeframe from ESWT alone. Our findings support three treatments of ESWT 2 weeks apart for treatment of horses with back pain. The lack of *multifidus* muscle response in our study suggests that physiotherapeutic techniques for concurrent muscle rehabilitation may be necessary in conjunction with ESWT.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

This study was approved by the Institutional Animal Care and Use Committee of Virginia Polytechnic Institute and State University (VT).

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Owner informed consent

The Director of the Intercollegiate Equestrian Program, responsible for the enrolled horses, gave consent for their inclusion.

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Authorship

All authors assisted with design of the experimental protocol, grant submission and manuscript preparation. L. Trager developed the hypothesis, collected all data and performed all data analysis; K. Clapp evaluated all images; S. Werre performed all statistical analysis.

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^aUniversal Solutions Inc., Bedford Hills, New York, USA.

^bImage J, NIH, Bethesda, Maryland, USA.

^cWagner Instruments, Greenwich, Connecticut, USA.

^dZoetis, Parsippany, New Jersey, USA.

^eNEXT Medical Products Company, Somerville, New Jersey, USA.

^fPulse Veterinary Technologies LLC, Alpharetta, Georgia, USA.

^gSAS Institute, Cary, North Carolina, USA.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Item 1: Palpation and atrophy scores from day 0 to 65.