Effects of vertebral mobilization and manipulation on kinematics of the thoracolumbar region

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Objective—To measure passive spinal movements induced during dorsoventral mobilization and evaluate effects of induced pain and spinal manipulative therapy (SMT) on passive vertebral mobility in standing horses.

Animals—10 healthy adult horses.

Procedures—Baseline vertical displacements, applied force, stiffness, and frequency of the oscillations were measured during dorsoventral spinal mobilization at 5 thoracolumbar intervertebral sites. As a model for back pain, fixation pins were temporarily implanted into the dorsal spinous processes of adjacent vertebrae at 2 of the intervertebral sites. Vertebral variables were recorded again after pin placement and treadmill locomotion. In a randomized crossover study, horses were allocated to control and treatment interventions, separated by a 7-day washout period. The SMT consisted of high-velocity, low-amplitude thrusts applied to the 3 non–pin-placement sites. Control horses received no treatment.

Results—The amplitudes of vertical displacement increased from cranial to caudal in the thoracolumbar portion of the vertebral column. Pin implantation caused no immediate changes at adjacent intervertebral sites, but treadmill exercise caused reductions in most variables. The SMT induced a 15% increase in displacement and a 20% increase in applied force, compared with control measurements.

Conclusions and Clinical Relevance—The passive vertical mobility of the trunk varied from cranial to caudal. At most sites, SMT increased the amplitudes of dorsoventral displacement and applied force, indicative of increased vertebral flexibility and increased tolerance to pressure in the thoracolumbar portion of the vertebral column. (Am J Vet Res 2007;68:508–516)

Back problems in horses are often characterized by signs of pain, stiffness, and reduced performance.1 Physical examination of the equine vertebral column requires detailed palpation of soft tissue and bony structures as well as assessment of segmental and regional spinal mobility.2 Unfortunately, the clinical assessment of back pain and stiffness is mostly subjective. Objective methods are needed for functional assessment of the vertebral column and evaluation of the therapeutic efficacy of rehabilitative approaches used to treat back problems in horses. Kinematic tools that quantify vertebral mobility or stiffness have the potential to improve the diagnosis and management of vertebral injuries.

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Abbreviation

| SMT | Spinal manipulative therapy |

The equine vertebral column is typically modeled as a bowstring bridge with fore and hind cantilevers representing the head and neck (cranially) and sacrum and tail (caudally).3 The structural and functional relationships of a segmental 3-point bending model suggest that maximal vertical displacements occur at the central portion and are reduced near the supports at either end. Findings of increased regional spinal mobility at T6-T13 in in vitro4–6 and in vivo7–9 studies support this hypothesis. However, the lumbosacral junction is also cited as the single intervertebral articulation with the highest amplitude of flexion and extension in the thoracolumbar portion of the vertebral column.10–12 To validate a proposed model of vertebral mobility in standing horses, we were interested in measuring peak vertical displacement at 5 intervertebral sites in the thoracolumbar portion of the vertebral column.

Spinal manipulative therapy involves the application of manually applied forces with the intent of reducing pain and promoting joint mobility.11,12 Spinal manipulative therapy is being used with increased frequency for the conservative management of back pain in horses.13–14 Biomechanical assessment and quantification of manipulative techniques are critical to understanding the mechanical events that occur during a manipulative thrust.13 Presently, there is limited objective evidence of the mechanical effects of SMT in horses.14–15
Few studies have evaluated the effects of induced back pain or stiffness on vertebral kinematics in horses. Injection of lactic acid into the longissimus muscles of horses undergoing treadmill exercise caused an increase in thoracolumbar stiffness and an inability to perform at fast speeds. Reduced flexion-extension and asymmetric lateral bending have been reported in horses with naturally occurring back problems. Pin implantation into the dorsal spinous processes has been used as a back pain model and validated with pressure algometry.

The objectives of the present study were to determine regional differences in vertical mobility and stiffness in the thoracolumbar portion of the vertebral column in standing horses and assess the effects of induced pain and SMT in a randomized crossover study. We hypothesized that dorsoventral displacement would be significantly reduced after pin implantation into the dorsal spinous processes and that SMT would increase vertebral flexibility in horses with induced back pain.

Materials and Methods

Horses—Ten horses from the Equine Research Park at Cornell University with a median age of 9 years (range, 6 to 16 years) and mean ± SD body weight of 553 ± 63 kg were used in this study. Horses included 7 females and 3 castrated males and 5 Thoroughbreds, 2 Standardbreds, 2 Quarter Horse crosses, and 1 Morgan. The horses did not have current histories of acute back problems or lameness and were judged as clinically sound during in-hand gait evaluation and treadmill locomotion. To examine possible relationships between height and back length with vertebral mobility, the height at the top of the shoulders (ie, withers), highest point of the croup (ie, tubera sacrale), and length of the thoracolumbar portion of the vertebral column from the dorsocranial apex of the third thoracic spinous process to the dorsocranial apices of the tubera sacrale were measured. Horses were handled in accordance with approved Animal Care and Use Protocols at Cornell University.

Study design—Baseline values of vertical displacement, applied force, stiffness, and frequency of the oscillations were measured during dorsoventral SMT at 5 thoracolumbar intervertebral sites (Figure 1). A concurrent study required attachment of a vertebral kinematic transducer via fixation pins temporarily implanted into the dorsal spinous processes of adjacent vertebrae at 2 of the intervertebral sites. For this study, the fixation pins were used as a model for the induction of acute back pain. The vertebral variables were recorded again after pin placement and treadmill locomotion. In the randomized crossover study, horses were allocated to control and treatment interventions, separated by a 7-day washout period (Figure 2). Treatment consisted of high-velocity, low-amplitude thrusts applied to the
Measurement of vertical displacements—All horses were restrained quietly in stocks with cross-ties and were required to stand squarely. The examiner stood on a mounting block positioned beside the stocks to enable the application of a consistent vertical force perpendicular to the dorsal midline over the intervertebral site of interest. The amplitude and frequency of vertical vertebral displacements were measured with a calibrated cable extensometer attached to a mobile overhead rail in the stocks that allowed cranial-caudal and medial-lateral positioning (Figure 1). The distal end of the cable extensometer was attached to the examiner’s hand, which was placed on the horse’s back and used to manually induce cyclic loading and unloading of the vertebral column (ie, passive spinal mobilization). A cyclic load was applied beginning cranially at T14-15 and continuing caudally at the T17-18, L1-2, L3-4, and L5-6 intervertebral sites in an effort to induce maximal ventral displacement (ie, extension). Force was applied until firm resistance to the induced motion was felt (end-range of motion in extension) or a local avoidance reaction was detected. The applied force was immediately released to allow the vertebral column to passively rebound dorsally (passive flexion). If a local avoidance reaction was detected, the amount of force was reduced until the avoidance reaction was no longer induced by the mobilization. Adverse reactions to the applied pressure included local muscular contractions, active vertebral movements (induced lordosis), or stepping away from the applied pressure. If the horse stepped away from the applied force or did not stand squarely on all 4 limbs, SMT was repeated at that site. Each intervertebral site was cyclically loaded for approximately 5 seconds prior to data collection in an effort to condition the horse and the corresponding intervertebral segment to the induced motion. The voltage output of the cable extensometer was recorded at 100 Hz for 10 seconds.

Measurement of the applied forces—The force applied during each cyclic displacement was simultaneously measured by use of a calibrated pressure mat with an overall area of 122.94 cm² and a pressure sensitive range of 0 to 1,036 kPa. The pressure sensor was laminated with a thin layer of self-adhesive film to improve durability and reduce artifacts. Prior to use, the sensor was equilibrated at 18, 107, and 196 kPa, and a 2-point calibration protocol that used dead weights at 29% (71 kPa) and 80% (196 kPa) of expected maximum load was completed according to manufacturer’s recommendations. The pressure sensor was triggered and sampled simultaneously with the cable extensometer at 100 Hz for 10 seconds. The amount of force applied during each spinal oscillation was calculated from the pressure and contact area measured by the sensor. The typical contact area during peak force was approximately 47.63 cm².

Data analysis—At each intervertebral site, the mean amplitude of displacement (millimeters), applied force (newtons [kg/(m X s²)]), and frequency (hertz) of each cycle of spinal oscillation were computed for over 10 seconds. The velocity of the induced vertebral displacements (ie, slope of the displacement-time curves) during the loading and unloading phases was also calculated. Visual inspection was used to assess rapid or gross changes in the pattern, amplitude, or frequency of the typically sinusoidal displacement or force signals. Segments of the displacement or force data that had aberrant or inconsistent signals were discarded and not included in the analysis. For each intervertebral site, data from a mean (± SD) of 18 (± 4) vertebral oscillations were used to calculate the final vertebral variables. To determine stiffness, a single loading cycle was randomly chosen in the last 10% of each data collection period. The slope of the linear region in the load-displacement curve was used to calculate stiffness (N/mm) at each intervertebral site.

Induced back pain—As part of a concurrent study requiring attachment of a vertebral kinematic transducer, all horses were instrumented with 2 fixation half pins (2.4-mm shank diameter, 101-mm overall length, 25-mm positive threads, and 3.2-mm thread diameter) implanted in the dorsal spinous processes of 2 adjacent vertebrae (T17-18 and L3-4) by use of described techniques. The half pins were implanted after sedation via IV administration to effect with xylazine (200 to 300 mg) and detomidine hydrochloride (3 to 8 mg) and via local SC infiltration with lidocaine (6 mL). Stab incisions were made through the skin and underlying supraspinous ligament with a No. 15 scalpel blade, which allowed for cranial-caudal skin and ligament displacement around the implanted pins. The T14-15, L1-2, and L5-6 intervertebral sites were considered non-pain sites, whereas T17-18 and L3-4 were considered pain sites because of pin implantation. After pin placement, the spinal variables could not be measured at the T17-18 and L3-4 sites because of the implanted pins and spinal transducers. The pins were removed after approximately 4 hours. Skin staples were used to close the skin, and betadine ointment was applied locally to seal the skin wounds. The skin wounds were monitored for signs of inflammation or infection throughout the course of the study. Pin implantation and removal were repeated at the same sites during study day 2, 1 week later. Immediately after each study day, horses were treated with orally administered sulfamethoxazole and trimethoprim (15 tablets, q 12 h, for 14 days) and phenylbutazone (1 g, q 12 h, for 3 to 7 days), as needed to control inflammation.

Treadmill exercise—Horses were positioned on a treadmill to assess spinal kinematics at a walk (1.8 m/s), trot (4.0 m/s), and canter (8.0 m/s), and walk again for approximately 1-minute intervals during level and 5% incline locomotion. A final treadmill exercise session was repeated after each control and treatment control period (Figure 2). Vertebral variables at the non-pin-placement sites were measured after each treadmill session.

SMT—We hypothesized that pin placement into the dorsal spinous processes would induce back pain and stiffness. The primary purpose of the crossover study was to assess the effects of SMT on vertebral flexibility, compared with a control session in the
same horse. During the treatment sessions, vertebral variables were recorded after SMT, which consisted of high-force, high-velocity, low-amplitude, dorso-ventral thrusts applied by use of a reinforced hypothenar contact and a body-centered, body-drop technique (Figure 1). In an effort to apply treatment consistently among all horses, SMT was applied at the following 4 intervertebral locations, irrespective of clinical signs of pain, muscle hypertonicity, or joint stiffness: dorsal spinous processes at T14-15, the left and then right articular processes at L1-2, and dorsal spinous processes at L5-6. All treatments were applied by the same nonblinded investigator (KKH). In the control portion of the study, horses did not receive treatment but were required to stand quietly for 10 minutes to simulate the time required to apply SMT in the treatment portion of the study.

**Statistical analysis**—The signalment, morphometric, and vertebral variable data were assessed for normality by use of Komolgorov-Smirnov tests. For statistical purposes, horse breeds were categorized into Thoroughbred (n = 5) and non-Thoroughbreds (5). Baseline values of displacement, velocity, force, frequency, and stiffness were compared across sites by use of ANOVA followed by the Tukey honest significant difference test. Correlations among the signalment, morphometric, and baseline vertebral variables were assessed by use of the Pearson correlation coefficient. Age was not normally distributed; therefore, the Spearman rank correlation was used to assess correlations between age and other variables. The percentage change from baseline values of pre- and posttreatment values was calculated during the crossover portion of the study. Initial values for study day 2 were used as baseline values for calculating the percentage change in those sessions. To assess any crossover effects (ie, washout period) from study days 1 to 2, baseline values were compared by use of paired t tests. Paired t tests (2 tailed) were also used to assess in-horse comparisons. Significance was set at P > 0.05. Data are expressed as mean ± SD.

**Results**

**Signalment and vertebral mobility**—Age, weight, sex, and breed were not correlated with most baseline vertebral variables. The exceptions were a positive correlation between age and peak applied force at the T14-15 and L5-6 intervertebral sites (r > 0.68; P < 0.04), indicating older horses could tolerate increased loads, and a negative correlation between displacement at L1-2 and body weight (r = –0.77; P = 0.04), indicating increased flexibility at L1-2 in lighter horses.

**Conformation and spinal mobility**—The horses had a mean ± SD wither height of 161 ± 7 cm, croup height of 160 ± 7 cm, and thoracolumbar vertebral length of 96 ± 6 cm measured from the dorsocranial apex of the third thoracic spinous process to the dorsocranial apices of the tubera sacræ. All height and vertebral morphometric variables were positively correlated (r > 0.85; P < 0.001). Back length was 40.9 ± 2.3% of wither height and 40.6 ± 2.0% of croup height. Longer back length was positively correlated with heavier body weight (r = 0.89; P = 0.008). There was no significant correlation between back length and displacement at any of the intervertebral sites (r < 0.33 and > –0.33; P > 0.35), indicating no significant relationship between back length and vertebral flexibility. However, a negative correlation was found between displacement at L1-2 and height at the withers (r = –0.81; P = 0.03) and croup (r = –0.78; P = 0.04), which implied that taller horses had less flexibility at L1-2.

**Baseline values**—Vertical displacement progressively increased in a cranial-to-caudal direction among intervertebral sites (Table 1). The loading and unloading velocities also varied from cranial to caudal. The maximum applied force was measured at the L5-6 intervertebral site. No significant differences in stiffness or the frequency of oscillations were found among intervertebral sites. A slight phase shift caused the peak force to precede the peak displacement, which is characteristic of loading viscoelastic tissues. At maximal loading, the peak-applied force preceded the point of maximal displacement by approximately 69 ± 12 milliseconds. During unloading, the point of minimum force preceded the point of minimal displacement by 39 ± 13 milliseconds.

**Crossover period**—In comparison to baseline values at study days 1 and 2, a significant reduction in force was detected at most intervertebral sites and significant increases in frequency of the oscillations were detected.

**Table 1**—Mean ± SD baseline values measured during dorsoventral SMT at 5 intervertebral disk sites in 10 horses.

<table>
<thead>
<tr>
<th>Variable</th>
<th>T14-15</th>
<th>T17-18</th>
<th>L1-2</th>
<th>L3-4</th>
<th>L5-6</th>
<th>ANOVA P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (mm)</td>
<td>18.0 ± 2.9^a</td>
<td>21.0 ± 2.4^b</td>
<td>22.8 ± 3.7^c</td>
<td>24.7 ± 2.6^c</td>
<td>25.4 ± 4.4^c</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Loading velocity (mm/s)</td>
<td>88 ± 13^a</td>
<td>99 ± 8^b</td>
<td>106 ± 17^c</td>
<td>117 ± 13^c</td>
<td>114 ± 17^c</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Unloading velocity (mm/s)</td>
<td>–83 ± 12^a</td>
<td>93 ± 10^a</td>
<td>–104 ± 17^c</td>
<td>–119 ± 11^d</td>
<td>–126 ± 21^e</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Force (N)</td>
<td>466 ± 105^a</td>
<td>442 ± 116^b</td>
<td>467 ± 85^c</td>
<td>498 ± 95^a</td>
<td>625 ± 139^a</td>
<td>0.004</td>
</tr>
<tr>
<td>Stiffness (N/mm)</td>
<td>77 ± 23</td>
<td>68 ± 15</td>
<td>69 ± 20</td>
<td>55 ± 15</td>
<td>64 ± 15</td>
<td>0.135</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>2.37 ± 0.13</td>
<td>2.35 ± 0.10</td>
<td>2.35 ± 0.12</td>
<td>2.37 ± 0.12</td>
<td>2.36 ± 0.12</td>
<td>0.991</td>
</tr>
</tbody>
</table>

^a,bValues with different superscript letters within a row indicate significant (P < 0.05) differences among intervertebral sites.

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at most sites during study day 2 (Figure 3). For the study day 2 baseline, displacement was reduced, compared with study day 1 baseline at the pin implantation sites of T17-18 and L3-4, which indicated a strong carryover effect from study day 1 (ie, washout period between study days 1 and 2 was too brief). The carryover effect was similar in the control and treatment portions of the crossover study (Figure 4). Applied force was significantly reduced at 2 sites in the second control group, compared with the first control group. Stiffness was significantly reduced at 3 sites, and displacement and force were both reduced at L3-4 in the second treatment group, compared with the first treatment group.

Compared with baseline values, pin implantation did not significantly affect most vertebral variables (Figure 5). The exceptions were significant reductions in stiffness at L1-2 (−30%) and L5-6 (−24%) in the control portion of the crossover study. Compared with post-pin-placement measurements, the initial treadmill locomotion (with implanted pins) induced significant reductions in most displacement and force values in the control and treatment portions of the study (Figure 5). Mean change in displacement was −22% (range, −30% to −15%) in the control sessions and −17% (range, −30% to 7%) in the treatment sessions. Mean change in force was −19% (range, −20% to −19%) in the control sessions and −15% (range, −22% to −2%) in the treatment sessions. There were also significant reductions in frequency at L1-2 in the control (−4%) and treatment (−4%) portions of the crossover study.

Compared with the initial treadmill measurements, the control intervention induced no significant changes in any of the variables (Figure 5). Conversely, SMT induced significant increases in displacement and applied force at the T14-15 and L1-2 intervertebral sites. Mean increase in displacement was 15% (range, 7% to 25%) after SMT, compared with 0% (range, −4% to 7%) after the control intervention in the control sessions. Mean increase in force was 18% (range, 10% to 27%) after SMT, compared with −2% (range, −7% to 5%) after the control intervention in the control session.

Compared with the control measurements, there were no significant effects of the final treadmill exercise in the control portion of the crossover study (Figure 5). In the treatment sessions, there were significant reductions in displacement at the T14-15 (−16%) and L1-2
Figure 5—Percentage changes from baseline values of vertebral variables associated with different interventions in 10 horses during a crossover period. A—Displacement during control session (left panel) and treatment session (right panel). B—Force during control session (left panel) and treatment session (right panel). C—Stiffness during control session (left panel) and treatment session (right panel). D—Frequency during control session (left panel) and treatment session (right panel). *Significantly (P ≤ 0.05) different from preintervention values. See Figure 2 for remainder of key.
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use and the sensors were not regularly recalibrated. The
pressure sensor has been reported to consistently un
Derestimate applied loads by 15% to 20%; therefore, it
is likely that the reported forces in the present study
were underestimated.

A previous study of induced dorsoventral verte
bral movements in standing horses revealed maximal
vertical displacement of 13.6 cm (9.6 cm flexion and
4.0 cm extension) at T16; however, the painful stimuli
used to induce extension were applied only to that re
gion of the vertebral column. Vertical forces or painful
stimuli applied near the lumbosacral junction often in
duce maximal extension at the lumbosacral joint.15 In
the present study, lower amplitudes of vertical displace
ment were reported because spinal end-range of motion
was assessed only in extension and painful stimuli were
not used to induce the spinal movements. Induced spi
nal range of motion is also typically less during cyclic
versus static loading.21 In humans, posterior-to-anterior
spinal displacements are typically < 4 mm during mo
bilization23 and from 6 to 13 mm during SMT; however,
human patients often lie prone on tables, which re
stricts spinal extension.24-26 In the present study, higher
displacements were measured in standing quadrupeds
because extension movements were not restricted by
external factors.

A mean peak mobilization force of approximately
470 N was measured in the present study, which is
higher than the median force of approximately 200 N
(range, 100 to 330 N) recorded during mobilization
of the lumbar portion of the vertebral column in hu
mans.22,27 Because of body mass differences, the force
required to mobilize the trunk of a horse would be ex
pected to be higher than that of humans. Joint mobil
ization consists of passive cyclic graded movements
of controlled depth and rate in the physiologic range
of joint motion, whereas manipulation involves mov
ing an articulation past its passive end-range of motion
without exceeding the anatomic limit of the joint.19
Therefore, higher forces and larger ranges of joint mo
tion are typically associated with spinal manipulation,
compared with mobilization.11,13

In vitro dorsoventral stiffness in extension has been
reported to be 2.9 ± 0.9 N/mm (range, 0.9 to 4.8 N/
mm) in the equine T2-L5 thoracolumbar portion of the
vertebral column.28 In the present in vivo study, stiff
ness was higher by an order of magnitude, up to 55 to
77 N/mm, at the different thoracolumbar intervertebral
levels, which is expected given the added mass and sup
port provided by an intact rib cage, trunk muscles, and
viscera in a live horse. Other methodologic differences
included use of a dorsoventral force applied at the T12
dorsal spinous process until a ± 4-cm displacement
occurred, compared with the present in vivo study, in
which a dorsoventral force was applied at 5 interverte
ral sites (T14-15, T17-18, L1-2, L3-4, and L5-6) until
spinal joint end-range of motion was detected.

In humans, in vivo posterior-to-anterior spinal
stiffness has been reported to be from 10 to 27 N/mm,
which is lower than that in the present equine study,20-31
In humans performing maximal voluntary contractions
of their spinal extensor muscles, stiffness increased to a
range of 25 to 108 N/mm. In horses with signs of back
pain and concurrent epaxial muscle hypertonicity, simi
lar increases in spinal stiffness would be expected; how
ever, there were no clearly defined differences in stiff
ness at the pain versus non–pain sites in the crossover
period. In some instances, the estimate of stiffness was
actually reduced after induced pain, possibly because of
reductions in the applied force.

The increasing cranial-to-caudal gradient in dis
placement in standing horses is most likely related to
alterations in articular facet orientation and the in
creased amplitudes of flexion and extension at the lum
bosacral joint.3,10 Rotation of the pelvis about the hip
joint is an underappreciated but major contributor to
doorsal spinal mobility. Flexion and extension at the
lumbosacral joint require movement between the last
umbar vertebra and the sacrum, which is firmly at
ached to the pelvis via strong sacroiliac and sacciostat
ic ligaments. The middle gluteal muscle (dorsally) and
the iliopsoas muscles (ventrally) are major contributors
to flexion and extension of the lumbosacral joint. These
muscles also have a primary function at the hip joint of
inducing retraction and protraction of the pelvic limb
during locomotion.

Modeling of the vertebral column as a bow and
string or suspension bridge anchored at the thoracic
and pelvic limbs may provide a starting point for static
modeling in the standing horse, but it is an oversimpli
fication for dynamic modeling of spinal mobility in
either standing or moving horses. Findings of increased
spinal mobility at T13-T16 in both in vitro7 and in vivo
studies support the notion that the thoracolumbar ver
tebral column has maximal vertical or lateral bending
mobility in its central portion. However, when segmental
intervertebral joint motion is considered, the am
plitude of flexion-extension at the lumbosacral joint
often far exceeds those found at the other thoracolumbar
articulations.4,9,10 Incorporating the potential contribu
tions of the highly mobile lumbosacral and hip joints
provides a more realistic and useful static and dynamic model of the equine thoracolumbar vertebral column.

Previous in vitro\textsuperscript{28} and in vivo\textsuperscript{29} studies evaluating dorsoventral mobility and stiffness of the equine thoracolumbar vertebral column detected no significant relationship between age and the amplitude of vertebral movements, which is similar to our results. Another study\textsuperscript{30} found a negative correlation between age and dorsoventral mobility at the trot, but not at the walk. Presumably, older horses have more vertebral disease and subsequently have reduced vertebral mobility.\textsuperscript{1,14} Future studies need to explore the direct relationships between signalment, documented vertebral disease, and kinematics.

On the basis of results of the present study, horses with longer backs did not have increased dorsoventral vertebral flexibility, and conversely, horses with short backs did not have reduced vertebral mobility. This finding is contrary to commonly held beliefs about the relationship between back length and the prevalence of back problems.\textsuperscript{3} An in vitro study\textsuperscript{28} reported that longer vertebral columns are stiffer, and an in vivo study\textsuperscript{29} reported a lack of correlation between the overall length of the thoracolumbar portion of the vertebral column and most vertebral kinematic variables in horses during locomotion. Additional factors such as the use and ability of the horse, fitness level, flexibility, muscle balance and strength, weight and ability of the rider, proper saddle fit, and lameness are more likely to play important roles in the predisposition to back problems.\textsuperscript{31,32}

It is possible that the lack of a sufficiently long washout period affected the interpretation of the crossover comparisons. The changes in vertebral variables were likely underestimated if compared with a situation in which no carryover effects from study day 1 were present; however, displacement at the non–pain sites served as a monitor of the direction and amplitude of changes in the study. It was also likely that phenylbutazone administration had effects on the study variables during the washout period. Phenylbutazone was used to reduce inflammation after pin placement, but it appeared that it was not completely effective in reducing or eliminating pain in the given washout period because of the measured reductions in displacement and force at baseline for study day 2. The use of phenylbutazone during the washout period likely helped to normalize the study day 2 baseline values more than if no anti-inflammatory drugs were used. The individual effects of pin placement and phenylbutazone administration were not specifically evaluated in our study and are unknown; however, the effects were expected to be similar for treatment and control sessions in the crossover study. It is likely that our results provided a more conservative estimate of vertebral effects than if the washout period was adequate.

Pin implantation alone caused few immediate changes in the vertebral variables when they were measured at the adjacent intervertebral sites. It is possible that longer-term evaluation would provide a better assessment of pin placement into the dorsal spinous processes as a method of inducing back pain.\textsuperscript{38} It is also possible that the chosen vertebral variables of this study are poor indicators of back pain in horses; however, back stiffness is one of the primary clinical indicators of vertebral dysfunction.\textsuperscript{17} Another possible explanation is that there were residual analgesic effects of the local anesthetic or xylazine-detomidine combination used during pin implantation approximately 1.2 hours earlier.\textsuperscript{39} A prior study\textsuperscript{31} revealed substantial reductions in mechanical nociceptive thresholds at sites of pin implantation and gradual normalization of values at adjacent nonimplanted dorsal spinous processes, which is possibly attributable to segmental spinal innervation.

Treadmill exercise, in combination with implanted pins, resulted in significant reductions in displacement and force at the adjacent intervertebral sites, which may have been related to differences in the induced vertebral mobility. Treadmill exercise after SMT caused significant reductions in displacement, which indicated that the combined effect of SMT and induced exercise in association with acute pain or inflammation may be detrimental to vertebral flexibility. Measuring the effects of pin implantation required only passive vertebral mobilization associated with data collection. In contrast, treadmill exercise required active vertebral mobility, which may have caused more local irritation and pain adjacent to the pin implantation sites. Another possibility is that any analgesic present during the pin-placement measurements may have been metabolized after treadmill exercise. Pin implantation into the dorsal spinous processes is well tolerated immediately after implantation in most studies.\textsuperscript{28} Another treadmill study\textsuperscript{37} that compared equine vertebral kinematics measured with and without pin implantation into the dorsal spinous processes revealed no significant immediate or short-term differences in the amplitudes or patterns of flexion and extension. With pin implantation, it typically takes 1 or 2 days for local pain and an inflammatory reaction to develop. Once present, marked reductions in the mechanical nociceptive thresholds can be detected over the pin-implantation sites with pressure algometry.\textsuperscript{40} The present study used a more direct assessment of the effects of pin implantation by evaluating segmental stiffness rather than measuring regional vertebral mobility, as in another study.\textsuperscript{31,32}

The increases in dorsoventral vertebral mobility and the amount of applied pressure to the back after SMT were consistent with the first author's clinical experience, whereby horses with back pain and deemed unsuitable for riding begin to tolerate the weight of the rider in the saddle immediately or soon after treatment. Future studies need to investigate the effects of the frequency and sites of SMT applied to groups of horses with and without signs of back pain.

The control procedure was not a true nonintervention because the process of measuring the maximum amplitudes of displacement and force required vertebral mobilization, which is considered a form of treatment that is distinct from SMT.\textsuperscript{19} Therefore, treatment not only consisted of SMT, but also included vertebral mobilization that was required during measurement of the vertebral variables. A true control comparison would require assessment of vertebral biomechanics without physical human contact, which is possible with current video kinematic systems.\textsuperscript{13,37} In the present study, we were interested in assessing passive vertebral end-range

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of motion, which is not possible with video kinematic systems that measure active motion only. Cadaveric vertebral kinematic studies do measure passive vertebral mobility, but with the obvious limitations of assessing joint range of motion in osseous-ligamentous specimens without intact muscles or neural input. Results of the present study indicated some of the immediate beneficial effects of SMT on vertebral mobility in horses. Objective evaluation of back flexibility or stiffness and the response to untested treatment modalities can provide a basis for the development of appropriate management strategies of horses with acute signs of back pain.

References

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