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Dynamic mobilisations in cervical flexion: Effects on intervertebral angulations

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Keywords: horse; physical therapy; rehabilitation; neck; back; kinematics

Summary

Reasons for performing study: **Based upon human data, it is probable that many conditions associated with neck pain in horses may benefit from performing mobilisation exercises as part of the rehabilitation protocol.**

Objectives: **To compare sagittal plane intervertebral angulations in a neutral standing position with the angulations at end range of motion in 3 dynamic mobility exercises performed in cervical flexion.**

Methods: **Sagittal plane motion of the head, neck and back were measured in 8 sound horses standing in a neutral position and in 3 end-of-range neck flexion positions: chin-to-chest, chin-between-carpi, and chin-between-fore fetlocks. Skin markers on the head, transverse processes of C1–C6, and dorsal spinous processes of T6, T8, T10, T16, L2, L6, S2 and S4 were tracked and adjacent markers connected to form rigid segments. Intersegmental angles, measured between segments on the ventral surface, in the 4 positions were compared using repeated measures ANOVA with Bonferroni *post hoc* tests ($P<0.05$).**

Results: **The largest angular differences involved the cranial and caudal cervical joints with smaller angular differences (<10°) in the mid-neck. The angle at C1 was significantly more extended for chin-between-carpi (98 ± 11°) and chin-between-fetlocks (132 ± 11°) than for the neutral position (86 ± 8°) or chin-to-chest (92 ± 8°) positions. The intersegmental angle at C6 indicated progressive lowering of the neck from neutral through chin-to-chest and chin-between-carpi to chin-between-fetlocks. The intersegmental angles from T6–L1 were more flexed by 3–7° in the cervical flexions compared with the neutral position with the differences being significant for at least one of the dynamic mobilisations at each vertebral level.**

Conclusions: **The articulations at the extremities of the cervical vertebral column are primarily responsible for sagittal plane position and orientation of the head and neck. Dynamic cervical flexion also flexes the thoracic intervertebral joints.**

Potential relevance: **The results indicate that dynamic mobilisation exercises performed in cervical flexion have applications in mobilising the cervical and thoracic intervertebral joints, which may have some clinical applications in rehabilitation.**

Introduction

Dynamic mobilisation exercises differ from passive stretches in that the movements are produced by concentric activation of the muscles, which alter the horse's posture, while the abdominal, epaxial and pelvic muscles act isometrically or eccentrically to stabilise the trunk and limbs. Thus, dynamic mobilisation exercises that target the cervical intervertebral joints may not only have a mobilisation effect on the cervical and thoracolumbar spine, they may also activate and strengthen the epaxial and hypaxial musculature throughout the cervical, thoracic and lumbar regions and may alter functional movement patterns and neuromotor control. Therapeutic exercises that move the joints through a wide range of motion and facilitate muscle activation have potential applications in flexibility training for athletic horses and in restoration of locomotor function following injury or immobilisation (Goff and Stubbs 2007). The therapeutic applications are relevant not only in horses that suffer from neck and/or back pain (Jeffcott 1979; Dyson 2003; Turner 2003) but also in lame horses due to the mechanical interaction between the vertebral column and the limbs; subtle lameness is associated with changes in spinal kinematics (Gómez Álvarez *et al.* 2007a, 2008) and induced back pain alters limb kinematics (Gómez Álvarez *et al.* 2007b). Consequently, dynamic mobilisation exercises that stimulate spinal flexion/extension and lateral bending may be appropriate in horses that are being rehabilitated following injury to the neck, back or limbs.

In the context of neuromotor control, one of the functions of the neck is to allow the animal to change the orientation of the head independently from that of the trunk. Proprioceptive, visual and vestibular input from the head that is required for control of postural orientation and stability can then be collected independent of trunk position (Dunbar *et al.* 2008). Human neck pain syndromes are associated with modifications in cervical motor control (Falla *et al.* 2004a; Jull *et al.* 2004), with one of the manifestations being that the cervical muscles show pain-induced inhibition when acting as agonists during voluntary contraction (Falla *et al.* 2007). Another key motor control feature is a reduction of the intervertebral stabilising function of the deep cervical flexors (*longus colli* and *longus capitis*) and extensors (*multifidus mm*) (Falla *et al.* 2004a,b). Specific exercise strategies to facilitate optimal motor control (stability with mobility) have been

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developed and advocated in the clinical management of human neck pain (Moffett and McLean 2006). These exercises focus on recruitment of both deep and superficial cervical flexor muscles (Falla 2004) using movements in different directions (Taimela *et al*. 2000). Based on the human data, equine physical therapy techniques that stimulate voluntary neck movements in different directions through a wide range of motion and postures are recommended to recruit and strengthen the cervical muscles that play a role in athletic performance. The potential benefits include maintaining or improving cervical range of motion; strengthening the cervical musculature and restoring normal motor control patterns and postural stability after cervical injury. Exercise therapy is beneficial in human subjects with osteoarthritis (Smidt *et al*. 2005) and it is probable that many conditions associated with neck pain in horses, such as osteoarthritis of the cervical spine, may also benefit from performing mobilisation exercises as part of the rehabilitation protocol provided spinal instability or nerve root compression are not a concern.

The study reported here is part of a broader research initiative directed towards developing rehabilitation techniques that can be used to maximise performance, reduce the risk of injury, and restore musculoskeletal function during rehabilitation after injury. The specific objective of this study was to measure and compare sagittal plane intervertebral angulations in a neutral standing position, with the angles at end range of motion in horses performing 3 dynamic mobilisation exercises (baited stretches) emphasising cervical flexion in order to determine which regions of the spine undergo significant angular changes in each exercise. The experimental hypothesis is that the cervical and thoracic intervertebral angulations differ significantly between the neutral standing position and the positions at end range of motion in the 3 dynamic mobilisation exercises in cervical flexion.

Materials and methods

The study was approved under protocol 02/08-020-00 by the Institutional Animal Care and Use Committee at Michigan State University.

Horses

The subjects were 8 sound Arabian horses (mean ± s.d. age: 13.4 ± 4.3 years; height: 149.1 ± 2.0 cm; mass 435.6 ± 19.5 kg) that were assessed by an experienced observer to show no overt signs of neck or back pain and to be serviceably sound at trot, which was defined for the purposes of this study as lameness *grade <1* on a 5 point lameness scale (Anon 1991). All horses had been turned out in paddocks without ridden exercise for the previous 3 months during which time they had performed a series of 10 dynamic mobilisation exercises in flexion, extension and lateral bending. Five repetitions of each exercise were performed daily in a single session on 5 days/week.

Prior to data collection, 34 reflective markers, 6 mm in size, were attached to the horse's skin using double-sided tape. Six markers were attached to the head: 2 on the dorsal midline and one each on the left and right temporal crest and facial crest. Multiple markers were necessary to facilitate reconstruction of the positions of markers that were obscured when the head passed between the forelimbs. Markers were attached bilaterally over the transverse processes of the following cervical (C) vertebrae: C1 (wings of the atlas), C2, C3, C4, C5 and C6, which was the most caudal vertebra that could be palpated reliably in all horses. Midline markers were attached overlying the dorsal spinous processes of the following thoracic (T), lumbar (L) and sacral (S) vertebrae: T6, T8, T10, T12, T14, T16, L2, L6, S2 and S4. Additional markers were attached bilaterally over the *tuber spinae scapulae* and the ventral part of the *tuber coxae* and to the lateral wall of each hoof.

Mobilisation exercises

Three dynamic mobilisation exercises were performed that involved different types of cervical flexion. The horses were enticed to take the chin to the desired position using bait (piece of carrot) with each position being maintained for 3–5 s. The 3 positions were: chin-to-chest in which the chin was moved as close as possible to the manubrium; chin-between-carpi in which the chin was moved as far caudally as possible with the dorsum of the nose at the level of the carpal joint; and chin-between-fore fetlocks in which the chin was taken as far ventrally and caudally as possible between the fore fetlocks (Fig 1). Each mobilisation was performed to end range of motion with the horse standing square and no movement of the feet.

Data collection

Kinematic data were collected using an automated motion analysis system[1] after calibration of the data collection volume (4 × 2.5 × 3 m) using a wand technique. The error in a linear measurement of 1.0 m within the calibrated volume was <0.8 mm. The horse stood in the calibrated volume so that the craniocaudal and mediolateral body axes were aligned with the longitudinal and transverse axes of the data collection volume. A recording of the horse standing with the head and neck in a neutral position was used to determine neutral joint angles. The 3 flexion exercises were performed by the same physical therapist (N.C.S.) in random order, for 5 trials per exercise.

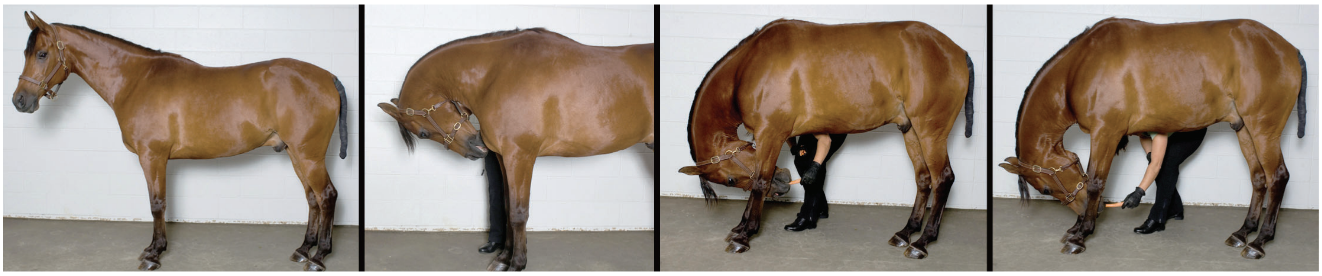

Fig 1: The 4 cervical positions in which measurements were made. Left to right: neutral position; chin-to-chest; chin-between-carpi; chin-between-fetlocks.

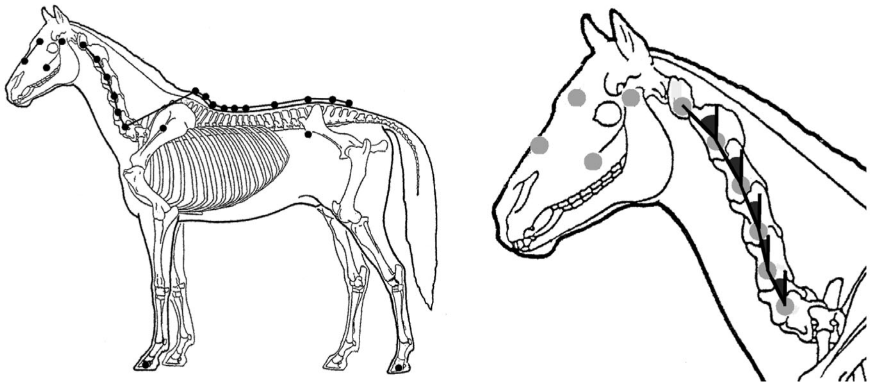

Fig 2: Skin markers and angles measured. Left: Locations of skin markers are shown as black circles on left side of head, neck and limbs and midline markers on head and trunk. Black lines connect successive vertebral markers to form segments. Joint angles are measured between segments on the ventral side. Right: Locations of skin markers (grey circles) on the left side of head and neck. The angle of each cervical segment relative to the vertical (black lines) is measured on the dorsal side of the segment in an anticlockwise direction when the horse faces to the left (angles shown in black).

TABLE 1: Mean ± s.d. sagittal plane angles (°) of cervical segments (C1–C6) and the vertical in 8 horses with the neck in a neutral position and at end range of motion in 3 dynamic mobilisation exercises performed in cervical flexion. Similar superscripts indicate variables that differ significantly within the same row (P<0.05)

Segment	Neutral	Chin-to-chest	Chin-between-carpi	Chin-between-fetlocks
C1–C2	59.7 ± 8.4^{abc}	186.5 ± 17.9^{ad}	194.1 ± 18.2^{b}	203.9 ± 10.2^{cd}
C2–C3	45.7 ± 8.0^{abc}	162.7 ± 17.6^{a}	174.6 ± 10.4^{bd}	183.7 ± 7.0^{cd}
C3–C4	49.1 ± 13.2^{abc}	157.2 ± 19.2^{ad}	169.1 ± 8.5^{be}	181.7 ± 7.3^{cde}
C4–C5	39.2 ± 11.8^{abc}	136.2 ± 17.3^{ad}	149.4 ± 9.5^{be}	167.4 ± 8.6^{cde}
C5–C6	39.0 ± 14.3^{abc}	125.9 ± 16.8^{ad}	143.4 ± 14.7^{be}	164.9 ± 13.5^{cde}

Data analysis

Proprietary software (Realtime 5.04)[2] was used to track the markers during the mobilisation exercises. Marker coordinate data were filtered using a Butterworth low pass digital filter with cut off frequency 15 Hz. A physical therapist (N.C.S.) viewed the stick figure reconstructions from different perspectives to evaluate the horse's position at end range of motion and eliminate trials in which the mobilisation exercises were performed incorrectly. Faults in performance that were a reason to eliminate trials included moving the chin ventral to the sternum in the chin-to-chest position, lateral bending or axial rotation of the neck, or movement of the limbs. After elimination of incorrect trials, the remaining trial with the most caudal (chin-to-chest, chin-between-carpi) or most ventral (chin-between-fetlocks) position of the chin was analysed in each horse. This trial was considered to give a better representation of the end range of motion for the purposes of this study than averaging the values over a number of trials with lesser ranges of motion.

The sagittal plane angle of the head was represented by a line connecting the 2 markers on the dorsal midline of the nose. If one of these markers was obscured by the forelimbs, it was reconstructed as a virtual marker from the visible head markers based on marker locations in the neutral file and assuming the head to be a rigid body.

For each cervical segment, a virtual midline marker was constructed midway between the markers on the left and right transverse processes. Adjacent midline markers were connected to form rigid segments. Segment angles between the line representing each cervical segment and the vertical were measured on the dorsal side of the segment (Fig 2) in the global coordinate system. Intersegmental angles between adjacent cervical segments were measured on the ventral (flexor) aspect (Fig 2). These measurements described both the orientation of the cervical segments and intersegmental angles. For the thoracolumbosacral spine, adjacent markers were connected to form rigid segments and the sagittal plane angles between segments were measured on the ventral aspect.

Statistical analysis

Statistical software[2] was used to calculate descriptive statistics for the angular measurements in the 4 cervical positions (neutral, chin-to-chest, chin-between-carpi, chin-between-fetlocks). The measured variables were found to be normally distributed using the Shapiro-Wilks test. Differences in angulations between the 4 positions were sought using repeated measures ANOVA with Bonferroni *post hoc* tests (P<0.05).

Results

The segment angles differed significantly between the 3 flexed positions and the neutral standing position for all segments from C1–C6 (Table 1). The orientation of C6 changed by >85° from the neutral position to the chin-to-chest position, with further smaller increases in flexion in the chin-between-carpi and chin-between-fetlocks positions. Since segment angles to the vertical are cumulative from C6–C1, the angular changes increase in magnitude from the caudal to the cranial segments.

Comparison of the joint angles in the 4 positions indicated that the largest angular changes occurred at the poll (C1: 47° extension in chin-between-fetlocks) and the base (C6: 91° flexion in chin-between-fetlocks) of the neck (Table 2). The intersegmental angle at C1 was most flexed in the neutral position; this joint was

TABLE 2: Sagittal plane joint angles between adjacent vertebral segments measured on the ventral aspect in 8 horses with the neck in a neutral position and at end range of motion for 3 dynamic mobilisations in flexion. The joint is named according to the vertebra about which the angle is measured. Values are mean ± s.d. Similar superscripts indicate variables that differ significantly within the same row (P<0.05)

	Neutral (deg)	Chin-to-chest (deg)	Chin-between-carpi (deg)	Chin-between-fetlocks (deg)
C1	85.7 ± 8.1^{ab}	91.9 ± 8.2^{c}	97.9 ± 11.3^{ad}	132.4 ± 10.6^{bcd}
C2	166.0 ± 9.0^{a}	156.2 ± 9.9^{a}	160.4 ± 14.0	159.8 ± 10.0
C3	183.4 ± 7.3^{ab}	174.5 ± 9.3^{a}	174.5 ± 8.7^{b}	178.0 ± 11.9
C4	170.1 ± 6.9^{abc}	159.0 ± 8.1^{ad}	160.3 ± 7.9^{be}	165.7 ± 7.9^{cde}
C5	179.8 ± 7.6^{a}	169.7 ± 7.9^{a}	174.1 ± 10.4	177.5 ± 11.3
C6	253.2 ± 11.1^{abc}	192.1 ± 14.0^{ad}	179.2 ± 15.7^{be}	161.7 ± 16.4^{cde}
T6	129.3 ± 4.9^{ab}	120.3 ± 3.6^{acd}	124.2 ± 2.5^{bc}	125.6 ± 2.9^{d}
T8	193.5 ± 4.7^{a}	186.9 ± 4.1^{ab}	188.7 ± 5.4	189.2 ± 5.2^{b}
T10	191.6 ± 2.2^{ab}	188.4 ± 3.7	187.2 ± 3.7^{a}	187.0 ± 3.4^{b}
T12	186.0 ± 2.2^{a}	182.7 ± 2.9	182.0 ± 2.6^{a}	181.7 ± 3.7
T14	183.5 ± 1.1^{abc}	178.6 ± 1.2^{a}	177.8 ± 1.3^{b}	177.9 ± 1.7^{c}
T16	184.7 ± 1.9^{abc}	179.7 ± 3.3^{a}	177.9 ± 1.9^{b}	177.2 ± 2.3^{c}
L1	180.5 ± 1.5^{a}	177.6 ± 2.5	176.7 ± 1.6^{a}	176.0 ± 3.2
L3	179.8 ± 1.4	178.4 ± 1.9	177.9 ± 2.3	177.7 ± 3.7
L5	175.0 ± 2.9	174.3 ± 2.6	174.4 ± 2.9	173.7 ± 2.5
S2	165.6 ± 4.3	165.7 ± 3.0	165.0 ± 4.7	163.6 ± 3.9

progressively more extended in the chin-to-chest and chin-between-carpi, and considerably more extended in the chin-between-fetlocks positions. In contrast the intersegmental angle at C6 was most extended in the neutral position and showed significantly more flexion in all 3 mobilisation exercises with the largest change in the chin-between-fetlocks position. In general, the joints in the mid-neck (C2–C5) were more flexed by 9–11° in the chin-to-chest position compared with the neutral position and showed progressively less flexion in the chin-between-carpi and chin-between-fetlocks positions.

The thoracic intersegmental angles were more flexed by 3–7° at the end range of motion in the 3 dynamic mobilisations compared with the neutral standing position (Table 2). Flexion increased most at T6 and T8 in the chin-to-chest position, whereas the joints from T10–T16 showed most flexion in the chin-between-fetlocks mobilisation. Angular changes from the neutral position were most apparent at T14 and T16 where the joint angles at end range of motion were significantly more flexed in all 3 mobilisation exercises compared with the neutral standing position. The lumbar angles did not differ significantly between positions.

Discussion

This study confirmed that when horses performed dynamic mobilisation exercises in cervical flexion, the majority of movement involved the cranial and caudal joints of the cervical spine with smaller movements in the mid-cervical and mid to caudal thoracic regions. The entire neck was raised and lowered from its base with relatively small contributions from the mid-cervical articulations and the position of the head relative to the neck in the sagittal plane was adjusted by changing the angulation at C1. In general, our findings support the experimental hypothesis that intersegmental angles differ significantly between the neutral standing position and the positions at end range of motion for the 3 mobilisation exercises, although angular differences were not significant at every cervical joint for all 3 mobilisations.

The equine neck behaves as a loaded beam (Slipjer 1946) with the cervicothoracic junction acting as a fulcrum for sagittal plane rotations (Townsend and Leach 1984). In the standing position there is an S-shaped curvature with a dorsal convexity at the poll and a ventral convexity at the base of the neck. The latter puts the caudal cervical joints, represented in our study by the angle at C6, into extension in neutral stance and allows it to undergo a large range of motion in flexion. Preservation of the range of motion at the base of the neck is necessary for everyday activities, such as grazing and self-grooming. Lame horses use the mobility at the base of the neck in a dynamic mechanism that creates a torque around the cervicothoracic junction to change the fore-hind load distribution (Vorstenbosch *et al.* 1997). Mobilisation exercises that lower the neck, especially chin-between-fetlocks, are particularly effective in preserving the range of motion at the base of the neck.

The articulations at C1 and C2 are highly specialised for allowing 3D movements of the head required for visual, vestibular and proprioceptive input. The angle measured at C1, representing the atlanto-occipital joint, has a hinge-like action that allows considerable flexion and extension (Getty 1975). It can be moved through approximately 88° from maximal flexion to maximal extension *in vitro* (Clayton and Townsend 1989a). In the neutral position, the joint angle at C1 was already quite strongly flexed (86°) and did not become more flexed in any of the mobilisation exercises. The C1 intersegmental angle in the chin-to-chest position was not significantly different from the angle in the neutral standing position, which is perhaps not intuitively obvious from the shape of the neck. In the mobilisations that involved lowering the neck, the joint at C1 became significantly more extended with the angle changing by 47° from the neutral position to the chin-between-fetlocks position.

The intersegmental angle at C2, which represents the atlanto-axial joint, is a trochoid or pivot joint. The atlas rotates axially around the peg-like dens that projects cranially from the body of the axis, which allows the head to twist around the longitudinal axis of the neck. Flexion of this joint is limited primarily by the short, strong longitudinal ligament of the dens anchoring its dorsal surface inside the ventral arch of C1 (Getty 1975), which prevents the dens protruding into the spinal canal and compressing the spinal cord. The joint at C2 was significantly more flexed only in the chin-to-chest mobilisation. *In vitro*, the joint at C2 has a relatively small amount of flexion-extension in the adult horse (16°) but has a significantly larger range of motion in foals (39°) (Clayton and Townsend 1989b) in which a large range of motion in all directions is needed to position the head for suckling.

The intersegmental angles in the mid neck (C3–C5), which are aligned close to 180° in the neutral position, became significantly more flexed in the chin-to-chest position but, as the neck was lowered, these joints extended, i.e. returned closer to the neutral angles. *In vitro* studies (Clayton and Townsend 1989a) indicate that the range of motion in flexion-extension is 20° for the joint at C3 increasing to around 30° at C5 (Clayton and Townsend 1989a). The strongest band of the nuchal ligament attaches to the dorsal spinous process of C2 (Gellman and Bertram 2002) making the position of C2 particularly influential in applying tension via this ligament to the thoracic spines.

Lowering the neck tenses the nuchal ligament and the contiguous supraspinous ligament pulling the dorsal spinous processes of the withers into a more vertical orientation (Denoix 1999). This, in turn, applies tension to the erector spinae to elevate the caudal thoracic region. The increases in thoracic flexion that accompanied lowering of the neck may have been a consequence of this passive process. The amount of flexion at the thoracic intervertebral joints in conjunction with lowering of the neck was well within the range of motion recorded for maximal range of flexion-extension *in vitro* (Townsend *et al.* 1983). Thoracic range of motion during the cervical mobilisation exercises was similar in magnitude to the range of flexion-extension that occurs during trotting on a treadmill with the head and neck in a neutral position (Audigié *et al.* 1999; Rhodin *et al.* 2005) but appears to be less than that induced by chiropractic manipulations of the caudal thoracic and lumbar vertebrae (Haussler *et al.* 1999). The fact that dynamic mobilisation exercises flex the thoracic spine suggests that they may be beneficial in horses with impinging or over-riding dorsal spinous processes (kissing spines) since thoracic flexion separates the spines. In this context, the chin-to-chest mobilisation appears to be most effective in flexing the intersegmental angles from T6–T10 in the withers region, whereas chin-between-carpi and chin-between-fetlocks are more effective for flexing the caudal thoracic spine.

In general, there is less intervertebral motion in the thoracolumbar than the cervical region (Townsend *et al.* 1983). Flexion-extension from T2–T18 is limited by the supraspinous and interspinous ligaments and by the tangential orientation of the thoracic articular facets (Getty 1975; Townsend and Leach 1984). The only joints in the thoracolumbar spine that have a relatively large range of motion in flexion-extension are located cranially between C7 and T1 and caudally at the lumbosacral joint (Slipjer 1946; Townsend *et al.* 1983; Stubbs *et al.* 2006).

There are several potential sources of errors in our measurements. The segment from C6–T6 was represented by a line connecting markers on the transverse processes of C6 and the dorsal spinous process of T6. This segment spanned several joints and does not represent a rigid anatomical segment. Conformational differences in the height of the withers affect the slope of the C6–T6 segment and affect the neutral angles at C6 and T6 in opposite directions. Thus high withers are associated with a larger intersegmental angle on the ventral side of C6 and a smaller intersegmental angle on the ventral side of T6. Furthermore, extreme cervical flexion displaces the skin over the withers in a cranial direction so that a marker placed over T6 when the horse is standing in the neutral position moves forward to the T5–T6 intervertebral space when the neck is flexed. The skin over T8 also moves cranially but by a lesser amount (Rhodin 2008). These movements affect angular measurements in the cranial thoracic region when the neck is flexed. The use of skin markers over the thoracolumbar dorsal spinous processes is a valid technique for measuring thoracolumbar flexion-extension angles at walk and trot (Faber *et al.* 2001) but skin displacement relative to the underlying cervical vertebrae has not been quantified and correction algorithms are not available. As in the limbs (van Weeren *et al.* 1992), kinematic data from the cervical region that have not been corrected for skin displacement may be adequate for repeated measures comparisons as in this study but the absolute values should be regarded as approximations. Other researchers have represented changes in head and neck position using the horizontal and vertical distances between a marker overlying T6, which is regarded as a relatively stable point, and a marker on the wing of the atlas (Rhodin *et al.* 2009). The addition of markers over the cervical transverse processes in the study reported here provides further information about the relative movements of the cervical intervertebral joints when the neck is in different positions.

The effects of different head and neck positions on thoracolumbar kinematics have been studied during locomotion in the unridden horse (Rhodin *et al.* 2005; Gómez Álvarez *et al.* 2006). These studies evaluated a free neck position that is similar to the neutral position described here and a low position that is similar to, but less extreme than, our chin-to-chest position. The chin-between-carpi and chin-between-fetlocks positions are not compatible with locomotion. When horses trotted with the head and neck restrained in a low position there was increased flexion in the cranial thoracic region and increased extension in the caudal thoracic and lumbar regions compared with the free position (Gómez Álvarez *et al.* 2006). The chin-to-chest mobilisation exercises were also associated with increased cranial thoracic flexion. Angular changes in the lumbar region did not reach statistical significance but showed a trend towards increased flexion rather than extension in the chin-to-chest position. The difference is probably due to gravitational and inertial effects that tend to extend the lumbar spine during the stance phase at trot under the control of the abdominal muscles which act eccentrically to stabilise the spine in gaits that have a suspension phase (Robert *et al.* 1998). In contrast to the situation during locomotion, in the dynamic mobilisation exercises the horse is stationary and is weightbearing on all limbs. This may facilitate activity of the thoracic sling muscles, especially *serratus ventralis thoracis*, that raise the withers; the abdominal muscles that flex the thoracolumbar spine; and *gluteus medius* that can be recruited to lift the back when the coxofemoral joints are flexed.

The chin-to-chest position is somewhat similar to that used in the training technique of neck hyperflexion (rollkur). The results presented here indicate that the joints in the middle and lower neck show the greatest amount of flexion in the chin-to-chest position. Flexion at C1 may be limited *in vivo* by compression of anatomical structures ventral to the cervical vertebrae, such as the larynx, trachea, salivary glands and hypaxial musculature, which may cause airway compression resulting in increased intrathoracic airflow resistance (Sleutjens *et al.* 2009). During training the increase in cranial thoracic flexion in the hyperflexed position might be construed as being advantageous in that it implies rounding of the back but this must be weighed against the possibility of respiratory compromise and proprioceptive difficulty due to the abnormal position of the head and vestibular apparatus, which are of greater concern during exercise than in the standing horse.

Osteoarthritis of the cervical articular facet articulations is common, particularly from C5 caudally (Ricardi and Dyson 1993). Controlled motion of the affected area and range of motion exercises are beneficial in treating human osteoarthritis (Minor 1999). In horses, dynamic mobilisation exercises may be a useful adjunct to manual therapy and the conventional pharmacological treatments including nonsteroidal anti-inflammatory drugs, intra-articular steroids, viscosupplementation and chondroprotectants (Goodrich and Nixon 2006). When performing dynamic mobilisation exercises, the horse controls the range of motion, which is in contrast to passive stretches that may move the joint outside the comfort zone. Performance of the mobilisation exercises facilitates a more normal neuromotor control pattern by stimulating the musculature that moves and stabilises the affected joint(s). Based on the results presented here, it is recommended to start with the chin-between fetlocks then chin-between carpi exercises and progress to the chin-to-chest mobilisation when using these exercises therapeutically in horses with osteoarthritic cervical facet joints to allow gradual strengthening of the muscles that are used to achieve the progressively more flexed positions in the mid-cervical region. The use of cervical dynamic mobilisations in flexion may be contraindicated in horses with osteoarthritic changes that compress the spinal cord or spinal nerves and in horses that have dynamic spinal cord compression or instability of the intervertebral joints with a risk of spinal cord compression when the neck is flexed (Rush 2003).

In conclusion, when horses perform dynamic mobilisation exercises in cervical flexion, the largest changes in intersegmental angles occur at the upper and lower joints, which are represented by the angles at C1 and C6 in our study. The chin-to-chest position induced significant flexions at all cervical joints. Lowering the neck in the chin-between-fetlocks mobilisation induced the greatest flexion at C6 combined with the greatest extension at C1. The findings also confirm that flexion and lowering of the neck are associated with flexion of the thoracic segments from T6–T16 in the standing horse *in vivo*.

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Conflicts of interest

The authors declare no potential conflicts.

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[1]Motion Analysis Corporation, Santa Rosa, California, USA.
[2]SPSS Inc., Chicago, Illinois, USA.

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