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Kinematics of the equine thoracolumbar spine

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Summary

At least three types of movement take place in the joint complexes of the equine thoracolumbar spine: dorsoventral flexion and extension, axial rotation and lateral bending. Using the standard right-handed Cartesian coordinate system, these movements may be defined as rotation about the x, y and z axes respectively. Except in cases of intervertebral fusion, all three types of movement occur in each joint complex of the equine back. The greatest amount of dorsoventral movement takes place at the lumbosacral and the first thoracic intervertebral joints. The greatest amount of axial rotation and lateral bending was measured in the mid-thoracolumbar spine at the level of the 11th or 12th thoracic intervertebral joints. The caudal thoracic and the lumbar spine is the least mobile region of the equine back. In the mid-thoracic spine, lateral bending was always accompanied by a "coupled" axial rotation. The presence of the rib cage stabilised the cranial thoracic vertebrae against axial rotation.

Introduction

RECENT reports indicate that back pain and related lameness are important problems in the horse and that there may be a relationship between these conditions and the mechanics of the thoracolumbar spine (Jeffcott 1975, 1979). Little is known about the biomechanics of the equine spine. Horses are believed to have relatively inflexible backs (Jeffcott and Dalin 1980) and of the movement that does occur, most is thought to be dorsoventral movement of the lumbosacral articulation (Slijper 1946; Hildebrand 1959; Gambaryan 1974). Dorsoventral movement and lateral bending cranial to the lumbosacral joint have also been reported (Slijper 1946; Jeffcott and Dalin 1980) but further information about the mechanical properties of the thoracolumbar spine is required to understand equine back lameness (Jeffcott and Whitwell 1976; Jeffcott 1979).

Biomechanics is the application of mechanical laws to living structures (Dorland's 1967) and spinal kinematics, a sub-discipline of biomechanics, is the study of the kind and amount of motion the spine undergoes during its normal movements (White and Panjabi 1978). The various methods of measuring movement in mammalian spines have been reviewed (White 1969; Ten Have and Eulderink 1980) and sophisticated radiographic techniques have been developed for the study of spinal motion (Olin, Olson, Selwick and Willner 1976; White and Panjabi 1978; Frymoyer, Frymoyer, Wilder and Pope 1979). However, because of the size of the equine vertebral column, radiographic techniques are of limited use in the study of its movement and the development of other techniques for this purpose is required.

A great deal has been learned about the biomechanics of the human spine through the study of individual motion segments obtained from human cadavers (White 1969; Panjabi, Brand and White 1976; Panjabi 1977; White and Panjabi 1978). Six types of movement (Fig 1) can theoretically take place in any intervertebral joint (Gray 1944; Badoux 1975; Panjabi 1977). These are: (1) longitudinal bending in a vertical plane which tends to flex or extend the back (dorsoventral flexion and extension); (2) transverse bending in a horizontal plane that tends to curve the trunk to the right or the left side (lateral bending); (3) torsion about a longitudinal, horizontal axis, rotating adjacent vertebrae (axial rotation); (4) transverse shearing; (5) longitudinal compression or tension of the axial skeleton; and (6) vertical shearing. The amount of motion occurring with shearing, compression and extension in the human spine is very small (White and Panjabi 1978).

The purposes of the present study were: (1) to develop a technique for measuring intervertebral joint movement of intact thoracolumbar spines taken from horses shortly after

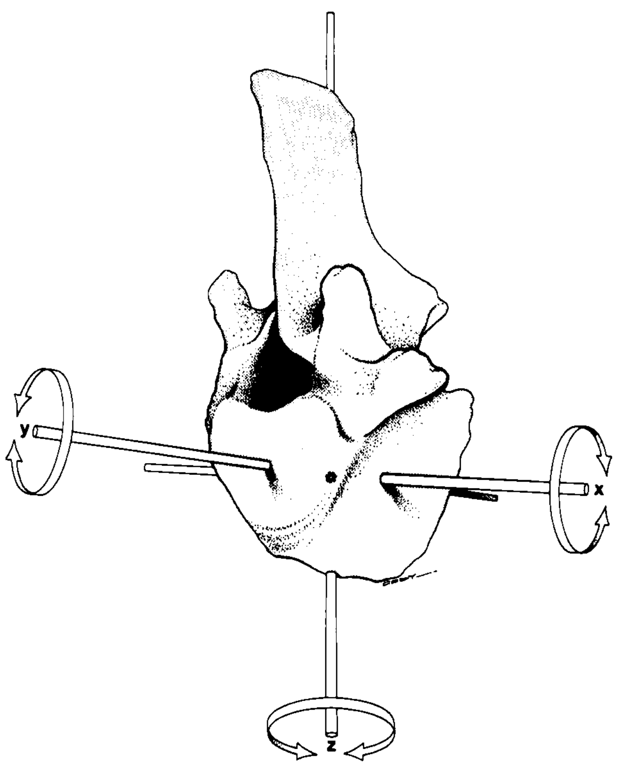

Fig 1. The left lateral aspect of a 17th equine thoracic vertebra with the right-hand Cartesian coordinate system applied to it. Rotation about x -dorsoventral flexion and extension; rotation about y - axial rotation; rotation about z - lateral bending; translation or movement along x -transverse shearing; translation along y - longitudinal compression or tension; translation along z - vertical shearing. The three axes intersect at a point within the vertebral body (*)

death; (2) to determine the type and magnitude of movement that can take place at each intervertebral joint; (3) to determine the effect of the rib cage on spinal mobility; and (4) to develop a model of equine spinal kinematics.

Materials and methods

Eighteen thoracolumbar spines were obtained from routine submissions of horses to the necropsy room of the Western College of Veterinary Medicine. All of these animals had died of natural causes or were killed at the college for reasons other than conditions related to the spinal column. The age, sex and breed of each horse, and the manipulation performed with each spine, are shown in Table 1.

After completion of a routine necropsy, the thoracolumbar and sacral spine were dissected from each carcase, being careful not to damage the associated ligaments, joint capsules and intervertebral discs. The spinal cord was left in the spinal canal. Only specimens comprised of 18 thoracic and six lumbar vertebrae were included in the study.

The dissection and manipulation of each spine were completed within 24 h of the death of the animal and, except during these procedures, the specimens were kept in a refrigerated room to reduce the rate of post mortem change.

After completion of the dissection, threaded, stainless steel Steinmann pins (300 mm × 3.18 mm) were drilled into the geometric centre of the ventral surface of each vertebral body. The pins were oriented perpendicular to the long axis of the spinal column and the transverse processes. In the same manner, a reference pin was placed in the ventral surface of the first sacral vertebra. The sacrum was clamped in a vice and then, by applying manual pressure to the first thoracic vertebra, the entire thoracolumbar spine was alternately flexed and extended (Fig 2).

A 35 mm camera, equipped with a 135 mm lens and a flash, was placed 7.5 m from, and at right angles to, the long axis of the spine and when the estimated point of maximum flexion or extension was reached, a photograph was taken. Each manipulation was performed twice.

TABLE 1: Age, sex, breed, length of spine and manipulations performed with and without the rib cage attached, on 18 horse spines

Spine number	Age (years)	Sex	Breed	Length* (cm)	Manipulation Rot	DV	Lat	Rib cage On	Off
1	8	MC	TB	124	–	P	P	–	X
2	28	M	TB	ND	–	P	P	–	X
3	4	MC	QH	123	–	P	P	–	X
4	10	MC	TB	118	–	P	P	–	X
5	8	F	QH	116	–	P	P	–	X
6	4	F	TB	110	P	P	P	–	X
7	5	MC	TB	117	P	P	P	X	X
8	3	M	G	108	P	P	P	X	X
9	5	MC	QH	113	P	P	P	X	X
10	5	MC	TB	122	P	P	P	X	X
11	8	F	G	114	P	P	P	–	X
12	25	F	TB	ND	P	P	P	X	X
13	7	F	TB	116	P	P	P	–	X
14	23	F	G	111	P	P	P	–	X
15	12	F	G	118	P	P	P	–	X
16	8	MC	AR	116	P	P	P	X	X
17	7	F	TB	118	P	P	P	X	X
18	4	F	TB	108	P	P	P	X	X

MC Male castrate or gelding
M Male
F Female
TB Thoroughbred
QH Quarterhorse
G Grade or mixed breed
AR Arabian
ND Not done
Rot Axial rotation
DV Dorsoventral flexion and extension
Lat Lateral bending
On Ribs and sternum attached
Off Ribs and sternum removed
* Length measured from cranial T1 to caudal L6
P Performed
X Performed "On" or "Off"

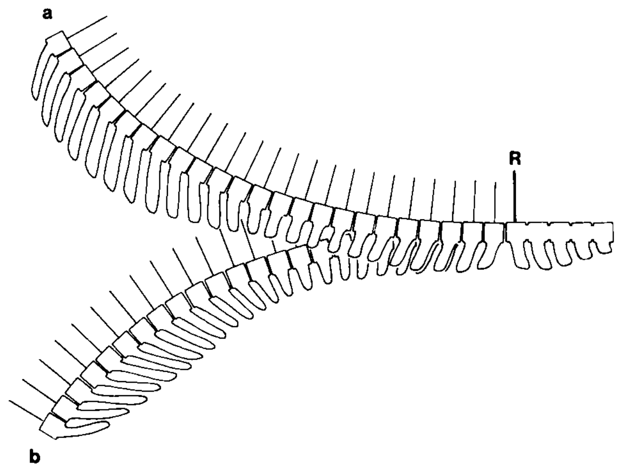

Fig 2. Schematic representation of the method of producing and measuring dorsoventral flexion (a) and extension (b) of an equine thoracolumbar spine. R Reference pin in sacrum

To record rotation about the longitudinal axis of the spine, a steel rod 9 mm in diameter and 150 cm in length was inserted into the spinal canal from the first thoracic vertebra, down to the level of the lumbosacral junction. The free, cranial end of the rod was inserted into a metal sleeve, the height of which was adjusted so that the vertebral column was parallel to the surface of the floor. The specimen was orientated so that the view of the camera was down the length of the spine. Rotational strain was produced by grasping the first thoracic vertebra firmly and applying a torque in either a clockwise or anticlockwise direction with the operator applying as much pressure as he could (Fig 3). The procedure was performed twice in each direction and the angulation of the Steinmann pins was recorded with a photograph in each case.

The study of lateral bending was carried out in a manner similar to that used for assessing dorsoventral movement with pins placed in the left, lateral surface of each vertebral body at right angles to the dorsal spinous processes (Fig 4).

In eight instances animals were submitted under circumstances that allowed the removal of the spinal column with the rib cage intact. These specimens were used to assess the effect of the sternum and ribs on the movement of the vertebrae.

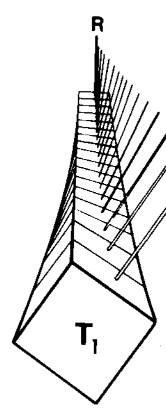

Fig 3. Schematic representation of the method of producing and measuring axial rotation. R Reference pin in sacrum; T1 First thoracic vertebra

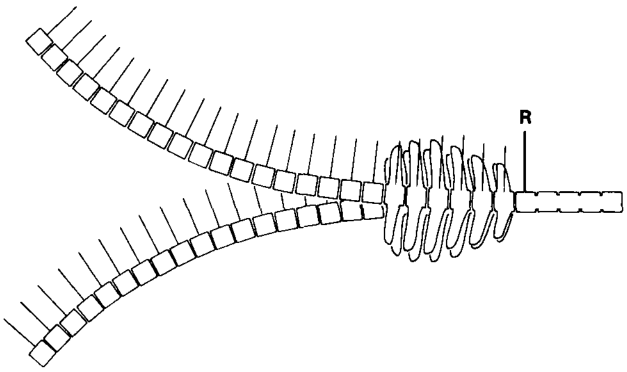

Fig 4. Schematic representation of the method of producing and measuring lateral bending. R Reference pin in sacrum

Preparation of these specimens was similar to that already described except that the rib cage, with all the soft tissues removed, was left intact.

The presence of the rib cage made it impossible to place the Steinmann pins in the mid-ventral line of the vertebral bodies. Accordingly, the pins were inserted into the dorsal spinous processes for the dorsoventral and rotation studies. For the study of lateral bending, the pins were placed in the bases of the dorsal spinous processes, in the geometric centre of the vertebrae and at right angles to the dorsal spinous processes. After completion of these studies, the ribs and sternum were removed by transecting the ribs just distal to their articulation with the spine and the procedure for spines without ribs was completed.

The photographic negatives of each procedure were developed and projected on to flat, white paper using a photographic enlarger (Omega Enlarger; Simmon Bros Inc, Woodside, New York, USA). The image of each Steinmann pin was traced on the paper and a clear plastic protractor used to measure the total change in the angle of each pin as compared to the reference pin in the sacrum.

One-way analysis of variance (Snedecor and Cochrane 1969) ($P<0.01$) was used to detect differences in the amount of each type of movement occurring in groups of joint complexes. Two-way analysis of variance (Snedecor and Cochrane 1969) ($P<0.01$) was used to detect differences in the mobility resulting from the removal of the rib cage and to detect interactions between joint complex mobility and the presence or absence of the rib cage. Groups of joint complexes were separated into non-overlapping subsets using Duncan's multiple range test (Snedecor and Cochrane 1969) (significance $P<0.05$).

Results

The average amount of dorsoventral movement, axial rotation and lateral bending occurring at each intervertebral joint with the rib cage intact and removed are shown in Figs 5, 6 and 7 respectively. A significant difference in the average amount of dorsoventral movement was detected between groups of joint complexes and these can be divided into three significantly different subsets. The lumbosacral joint had the greatest range of dorsoventral movement, followed by the first thoracic joint. The least movement took place in the joint complexes between T2 and L6. The removal of the ribs and sternum did not significantly change the average amount of dorsoventral movement in the joint complexes of the thoracolumbar spine.

A significant difference in the average amount of axial rotation was detected between groups of joint complexes. Before the removal of the rib cage, significantly more rotation

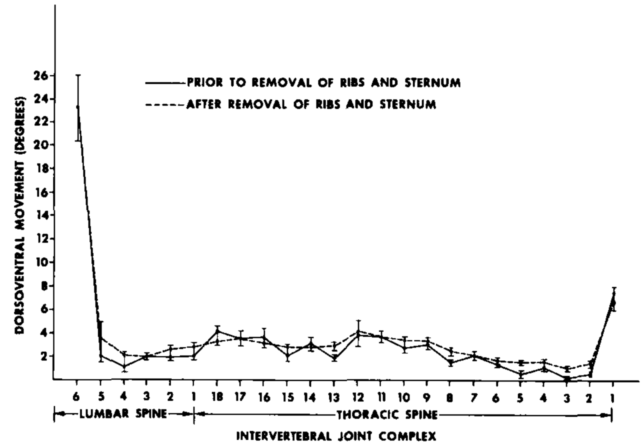

Fig 5. Comparison of dorsoventral movement between joint complexes of eight equine thoracolumbar spines before removal of the ribs and sternum and 18 thoracolumbar spines after removal of the ribs and sternum (± se of the mean). The connecting lines are drawn to increase clarity and do not represent intermediate values

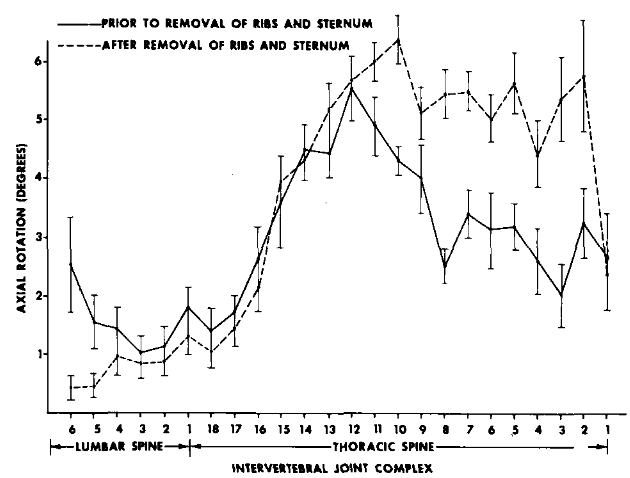

Fig 6. Comparison of axial rotation between joint complexes of eight equine thoracolumbar spines before removal of the ribs and sternum and 13 thoracolumbar spines after removal of the ribs and sternum (± se of the mean). The connecting lines do not represent intermediate values

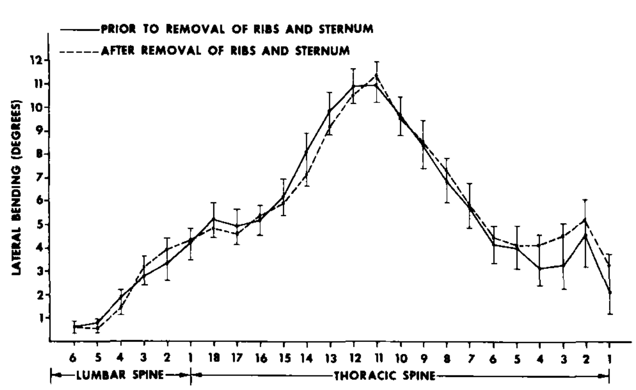

Fig 7. Comparison of lateral bending between joint complexes of eight equine thoracolumbar spines before removal of the ribs and sternum with 18 thoracolumbar spines after removal of the ribs and sternum (± se of the mean). The connecting lines do not represent intermediate values

took place in those subsets composed of T9 to T14 than in those composed of T1 to T8 and T15 to L6. The removal of the ribs and sternum significantly changed the average amount of rotational movement that occurred in the joint complexes of the spinal column and a significant interaction occurred between movement of groups of individual joint complexes and the presence or absence of the rib cage. The differences created by the removal of the ribs and sternum occurred in the caudal region of the lumbar spine and in the cranial region of the thoracic spine (Fig 6).

A significant difference in the average amount of lateral movement was detected between joint complexes. The data can be divided into non-overlapping subsets to indicate that significantly more lateral movement took place in the joint complexes centred around T11 and T12 than in those at either extreme of the thoracolumbar spine. The least lateral movement took place in the caudal lumbar spine.

The removal of the ribs and sternum did not significantly change the average amount of lateral movement in the joint complexes and no significant interaction occurred between movement of individual joint complexes and the presence or absence of the rib cage.

Although the system used in this study can only be used to measure movement in one plane at a time, it was consistently observed that lateral bending of all specimens resulted in a concomitant axial rotation in the thoracic spine that was most easily appreciated in the joints centred around T11 and T12. In every case, lateral bending of the vertebral column to one side produced a coupled, axial rotation in which the dorsal spinous processes went towards the opposite side.

Discussion

The traditional unit of study in spinal kinematics is the "motion segment" or "intervertebral joint complex", composed of two adjacent vertebrae and their intervening soft tissues (White 1971; White and Panjabi 1978). In this study, each motion segment was numbered according to the most cranial of the two contiguous vertebrae of which it was comprised (eg, the first motion segment of the thoracolumbar spine is referred to either as T1-2 or simply the T1 motion segment).

The right-handed orthogenal (Cartesian) coordinate system has been recommended for use in human spinal kinematics studies (White and Panjabi 1978). It can be easily adapted to quadrupeds (Olin *et al* 1976) and consists of three mutually perpendicular straight lines intersecting at a point (Fig 1). The lines are the axes and the point is the origin of the coordinate system (Panjabi 1977).

With the application of a right-hand Cartesian coordinate system to the motion segment, movement is seen to result from deformation occurring as either translation along a coordinate or as a rotation about a coordinate. Using this system, dorsoventral bending is defined as vertebral rotation about the x axis of the coordinate system. Axial rotation or rotation about the longitudinal axis of the vertebral column is vertebral rotation occuring about the y axis and the lateral bending occurs as a result of rotation about the z axis.

In order to describe clearly spinal movement in the horse, three additional definitions are required. "Flexion" of the spine is the dorsoventral movement that increases or tends to increase the normal curvature of the spine (arching of the back). "Extension" is the dorsoventral movement that tends to straighten or decrease the normal curvature of the spine (dipping of the back). "Coupling" is the term applied to motion in which rotation or translation of a rigid body about or along one axis is consistently associated with rotation or translation of the same rigid body about or along another axis. It is a phenomenon that is inherently present in the mechanics of the spine (Panjabi 1977).

In using isolated thoracolumbar spines from cadavers in this study of equine spinal kinematics, a number of important assumptions were made: (1) that, based upon the fact that none of the spines were obtained from animals reported to be suffering from back pain and upon the results of examination of the vertebrae at necropsy, the spines used in this study were considered functionally normal; (2) that the relative mobility of each individual joint complex, as compared to the entire mobility of the spine, in horses three years of age and older was not influenced by age, breed, sex or size of the animal from which it was obtained (Evans and Lissner 1959; White 1969; Braund, Taylor, Gosh and Sherwood 1977; Ten Have and Eulderink 1980); (3) that the relative mobility of each joint complex of the spine did not substantially change post mortem and, therefore, any changes that did occur in the strength and elasticity of the intervertebral discs and ligaments affected all the joints equally (Evans and Lissner 1959); (4) that the method of manipulation of the spine approximated the full range of motion of each joint complex (Ten Have and Eulderink 1980); (5) that at the limits of the full range of motion of the specimen, a torque applied to T1 was distributed to all the joint complexes of the spine; and (6) that this model can be used to make useful predictions regarding *in vivo* spinal kinematics, even though the effects of isolation of the spine upon the characteristics of mobility are not known (Andriacchi, Shultz, Belytschko and Galante 1974; Panjabi *et al* 1976; White and Panjabi 1978).

The results of this study confirm that at least three types of movement (dorsoventral flexion and extension, axial rotation and lateral bending) can take place at each joint complex of the equine thoracolumbar spine, provided that the joints are not fused. Significant differences were measured in the amount of movement taking place in various regions of the spine.

The greatest amount of movement observed during the study was the dorsoventral movement measured in the lumbosacral joint. Significantly more dorsoventral movement occurred in this joint than in any other joint complex of the thoracolumbar spine and this finding is consistent with previous studies of live horses (Hildebrand 1959; Jeffcott 1977; Jeffcott and Dalin 1980). It is probable that dorsoventral movement of the lumbosacral joint makes an important contribution to stride length, particularly during the canter and gallop which are asymmetric gaits.

A relatively wide range of dorsoventral movement also occurs in the first thoracic joint (T1-T2) and the results of the present study clearly indicate that this joint has greater dorsoventral mobility than any other intervertebral joint of the thoracic spine. The wide dorsoventral arc through which the horse is capable of moving its head and neck has previously been attributed to movement occurring in the cervical (Jeffcott 1979; Jeffcott and Dalin 1980) and cranial thoracic spine (Slijper 1946) but the importance of the mobility of the first thoracic joint complex has not been previously recognised. It is also probable that the remaining complexes of the cranial thoracic spine make a contribution to the total dorsoventral movement of the head.

The fact that no significant difference was detected in the relatively small amounts of dorsoventral movement measured in the joint complexes from T2 to L6 is not consistent with an earlier study in which Jeffcott and Dalin (1980) examined dorsoventral movement between T10 and L2 and concluded that detectable differences did occur between joint complexes in this region. However, dorsoventral flexion was induced in their study by suspending the thoracolumbar spine from beneath at T13. Extension was produced by supporting the spines at their cranial and caudal extremities and suspending a 10 kg weight from the mid-point of the back (T12-13).

Intervertebral joint movement in the region T10-L2 was estimated by measuring the change in distance between the dorsal spinous processes at a variable distance from the point of rotation within the joint complex. These methods would not have induced a full range of dorsoventral movement in all of the intervertebral joints and do not account for the effect of the variation in the distance between the points of measurement and the instantaneous axis of rotation within each joint complex (Cossette, Farfan, Robertson and Wells 1971; Badoux 1975; White and Panjabi 1978). Further, the effect of the distance of each joint complex from the point of suspension during flexion of the specimens was not considered. The effect of these variables would have increased the magnitude of the readings in the cranial aspect of the specimens, where the spinous processes are long, and decreased the readings in the lumbar region where the spinous processes are shorter and the strain placed on the joint complexes during flexion is less, because of their distance from the point of suspension.

Axial rotation and lateral bending were observed throughout the TL spine and the most mobile region was the mid-back. The greatest axial, rotational mobility was observed in the joint complexes T9-T14 and the greatest degree of lateral bending was measured in the region centered around T11 and T12. These results also differ from those of Jeffcott and Dalin (1980) who concluded that lateral bending does not occur caudal to T13 and that no appreciable axial rotation occurs caudal to T11. Their conclusions were based upon manipulation of three isolated thoracolumbar spines. The joint complexes at which movement occurred were determined by visual observations only. During the present study it was found that it is difficult to determine precisely where spinal movement occurs using this method and that the results of such observations are not reliable.

Lateral bending of the specimens in one direction was always accompanied by a coupled axial rotation of the joint complexes of the mid-back. This phenomenon has been observed as a consistent finding in the movement of the human spine (Panjabi 1977) and is caused by the presence, shape, size and orientation of the articular facets.

As removal of the rib cage resulted in a significant increase in the amount of axial rotation measured in the cranial thoracic spine, it appears that the presence of the ribs and sternum is an important factor in the rotational stability of the cranial thoracic spine in the living horse. The finding that the rib cage stabilises the cranial joint complexes only correlates with the presence of fixed or sternal ribs in this region. Caudal to T9, the ribs are described as being asternal because they do not articulate directly with the sternum and their cartilages (Sisson and Grossman 1967).

It was also observed that removal of the rib cage was accompanied by a decrease in the amount of axial rotation in the caudal lumbar spine. This finding is not consistent with the predicted results based upon anatomical studies of the region (Townsend 1981) and remains unexplained at this time.

Little is known about the movement of the thoracolumbar spine in the normal horse during various activities. Because these movements are relatively small and because of the mass of the epaxial muscles of the vertebral column, movement of the thoracolumbar spine in the living horse can be difficult to appreciate. However, observable movement does occur in the vertebral column between T2 and L6 (Jeffcott 1975). Jeffcott (1975) has described methods of stimulating flexion, extension and lateral bending of the thoracolumbar spine. Horses often dip (extend) the back when the saddle girth is tightened and many horses extend or flex the vertebral column when the rider mounts. Undoubtedly the occurrence of dorsoventral movement in the lumbosacral joint accounts for much of this movement but careful observation of curvature of the back suggests that the other thoracolumbar joint complexes also contribute to this movement.

Lateral bending can be stimulated and observed in the live horse by stroking the longissimus region with a sharp object (Jeffcott 1975). Rotation is somewhat more difficult to observe but the pace is an excellent gait for demonstrating the importance of axial rotation during locomotion. When the pacing Standardbred horse is observed end-on it can be appreciated that the pelvic limbs swing, as a pair, from side to side in a pendulum-like motion. The same movement occurs in the thoracic limbs but to a lesser extent. Without ignoring the ability of the animal to abduct and adduct the limbs through the joints distal to the spinal column, it seems likely that much, if not all, of this lateral swinging motion occurs as a consequence of axial rotation in the spinal column.

The distance between the sole of the hoof and the vertebral column in normal horses is substantial and only a small amount of axial rotation has to occur in the spinal column to produce a wide arc at the level of the hoof. It is probable that the lateral swinging of the limbs is much more easily and simply coordinated through axial rotation of the spine than by the individual abduction and adduction of four separate limbs. Wentink (1978) found that when the horse is trotting, the pelvis rotates around the longitudinal axis. Because little, if any, movement normally occurs in the sacroiliac joint (Adams 1969; Jeffcott and Dalin 1980), the axial rotation observed at the level of the pelvis must occur in the thoracolumbar spine. Finally, when jumping horses are viewed from behind it can be seen that many swing the limbs to one side in order to clear the jump with their hooves and it seems probable that this is also accomplished with the aid of spinal, axial rotation.

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Résumé

Trois types de mouvement au moins se produisent dans les complexes articulaires de la colonne vertébrale thoraco lombaire du cheval; flexion et extension dorso ventrales, rotation axiale et courbure latérale. En utilisant le système coordonné cartésien dextre ces mouvements penvent être définis comme des rotations autour des axes x, y et z. A l'exception des cas de fusion inter vertébrale ces trois types de mouvement se produisent dans chaque complexe articulaire du dos du cheval. Les mouvements dorso ventraux les plus fréquents se produisent dans l'articulation lombo sacrée et dans la première articulation intervertébrale thoracique. Les mouvements de rotation axiale et de courbure latérale les plus nombreux se constatent dans la partie centrale de l'axe thoraco lombaire, 11 ème et 12 ème articulations intervertébrales thoraciques. La partie caudale du segment thoracique et le segment lombaire forment la région la moins mobile du dos du cheval. Dans la partie méso-thoracique, la courbure latérale est toujours couplée avec une rotation axiale. L'armature costale protège les vertèbres thoraciques craniales d'une rotation axiale.

Zusammenfassung

Mindestens drei Bewegungstypen laufen in den Gelenken der thorakolumbalen Wirbelsäule des Pferdes ab: eine dorsoventrale Flexion und Extension, eine axiale Rotation und eine laterale Biegung. Innerhalb des rechtsgerichteten, karthesischen Koordinatensystems können diese Bewegungen als Rotationen um die x, y und z Achse definiert werden. Ausser in Fällen einer intervertebralen Fusion laufen die drei Bewegungstypen in jedem Gelenkskomplex des Pferderückens ab. Das grösste Ausmass nimmt die dorsoventrale Bewegung in den lumbosacralen und in den ersten thorakalen Intervertebralgelenken an. Das grösste Ausmass der axialen Rotation und der lateralen Biegung wurde in der Mitte der thorakolumbalen Wirbelsäule auf der Höhe des 11. und 12. Zwischenwirbelgelenks gemessen. Die hintere thorakale und die lumbäre Wirbelsäule ist am wenigsten beweglich. In der mittleren Brustwirbelsäule war die laterale Biegung immer begleitet von einer "gekuppelten" axialen Rotation. Der Rippenkorb stabilisiert die vordere Brustwirbelsäule gegen die axiale Rotation.

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ABSTRACT

Anatomy and physiology

Correct anatomic nomenclature for the joints of the equine tarsus

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THE author describes the detailed anatomy of the equine "hock" joints and justifies his opinion for changing some currently used terms. These are talocalcaneocentral joint instead of talocentral or medial part of the proximal intertarsal joint; tarsocentral joint instead of tibiotarsal or talocrural joint; and calcaneoquartal joint instead of lateral part of the proximal intertarsal joint.

The author states that, typically, there are three distinct synovial cavities in the hock joint: one common to all of the proximal joints (tarsocrural, talocalcaneal, talocalcaneocentral and calcaneoquartal), one for the central distal joint and one for the three tarsometatarsal joints. Injection studies have, however, shown that there may occasionally be communications between the tarsometatarsal joint and the centrodistal joint and rarely with the tarsocrural joint.

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