Treadmill study of the range of back movement at the walk in horses without back pain

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Objective—To evaluate back movement during walking in horses.

Animals—22 adult horses with no history or signs of back pain.

Procedure—3-dimensional movements of markers on the hooves, head, and back were measured with a motion analysis system while the horses were walking on a treadmill. The positions of markers on the hooves, head, and the skin above the spinous processes of T5, T10, T16, L3, and 2 sacral vertebrae were recorded. From a minimum of 6 walking motion cycles/horse, marker movement and the time of occurrence of minimum and maximum marker positions within the motion cycle were determined. Angles were calculated between the markers on the head, T16, and S4 or S5 and between the markers on T5, T16, and S4 or S5.

Results—Lateral back movement was maximal at L3, where it reached (mean ± SD) 3.5 ± 0.8% of the horses' height at the withers. Maximum dorsoventral back movement was found at the sacrum, where it reached 4.7 ± 1.3% of the height at the withers. In the horizontal plane, the angle between T5, T16, and S4 or S5 was altered by 11 ± 2.5° during the motion cycle. In the sagittal plane, the angle between the head, T16, and S4 or S5 was altered by 7 ± 3°.

Conclusions and Clinical Relevance—Results of this study may be used as basic kinematic reference data for evaluation of back movement in horses. (*Am J Vet Res* 2001;62:1173–1179)

In past decades, back problems have been recognized as an important clinical performance-impairing problem in equine athletes.[1] The protocols for clinical examination of horses with suspected back pain include the induction and evaluation of back movements in the standing horse[2] at walk and trot in hand and under the saddle.[1] Until recently, these evaluations have all been performed subjectively; reliability and repeatability of such subjective grading is problematic. Recently, the kinematics of the back during flexion, extension, and lateroflexion have been documented in the standing horse.[3] In other studies[4,5] in horses, flexion and extension of the back during the trot were investigated. The purpose of the study reported here was to evaluate back movement in horses during walking and establish basic reference data.

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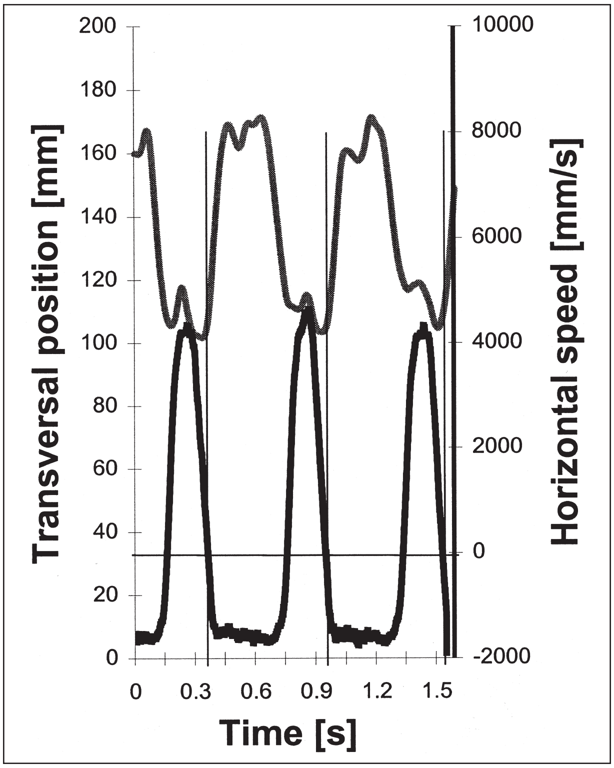

Figure 1—Transverse motion cycle of a marker attached to the skin overlying the dorsal spinous process of T16 of a horse (shaded line); values were recorded during walking. Alternate zero-horizontal-velocity points (thin vertical lines on the figure) of a hoof marker (solid line) were used to divide the tracing into individual walking motion cycles.

Materials and Methods

Horses—Twenty-two adult horses (6 mares, 5 stallions, and 11 geldings) that were 13.6 ± 5.5 years old (mean ± SD; range, 4 to 22 years) and owned by the University of Medicine, Vienna were used for this study. Twenty horses were Warmbloods, and 2 were Standardbreds; mean height at the withers was 161 ± 7.1 cm. Evidence of back pain in each horse was critically assessed by evaluation of the case history and clinical examination of the back.[1] Additionally, the movements of the back in the standing horse at the walk and trot, as well as during backing and turning tightly in both directions, were evaluated. Normal results for all these evaluations were obtained for each horse.

Markers—Spherical markers consisting of a hollow hard plastic shell (diameter, 4 cm) coated with reflecting foil were taped to the horse's coat with textile adhesive tape. The markers were placed on the dorsal midline on the skin above the dorsal spinous processes of T5, T10, T16, S2 or S3 (hereafter referred to as OS1), and S4 or S5 (hereafter referred to as OS2). This marker setup was similar to the setup used in our previous study[3] on back movement in standing horses. The lumbosacral junction and the ribs were used as anatomic landmarks to assist in correct placement of the markers. Because of

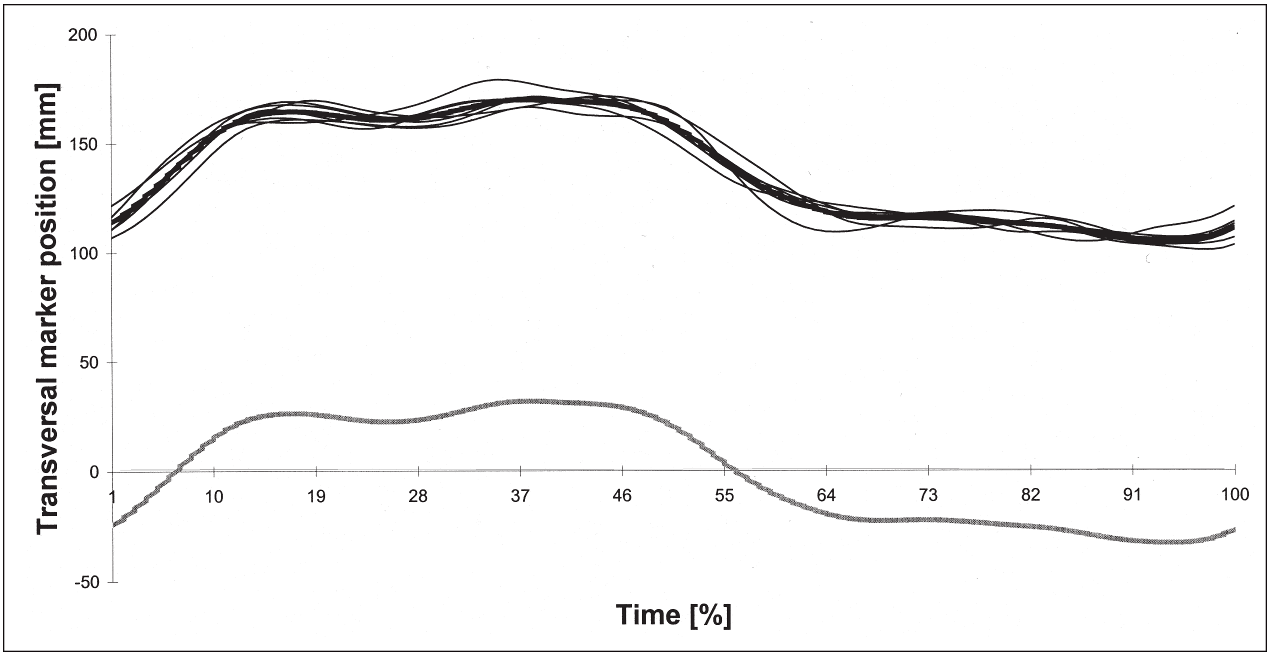

Figure 2—Graph of the position of a marker attached to the skin overlying the dorsal spinous process of T16 of a horse; values were recorded during walking. The x-axis represents time as a percentage of the duration of 1 walking motion cycle. Thin individual lines represent transverse motion of the marker during 7 motion cycles. The thick solid line indicates mean values of the 7 cycles, whereas the shaded line indicates relative transverse position of the marker, determined by setting the mean value of 100 marker positions determined during 1 cycle to zero.

the depth of the overlying soft tissue, palpation of the individual dorsal spinous processes of the sacrum was unreliable; therefore, markers OS1 and OS2 could not be placed precisely. One marker was placed midline between the eyes. To determine the motion cycle and the stance phases, additional semispheric markers were taped to the lateral wall of each hoof.

Motion analysis—Recordings were obtained by use of a motion analysis system.[a] Six cameras (sample rate, 120 Hz) were positioned around a treadmill[b] 1.5 to 3.5 m from the horse and at a height of 1.5 to 2.3 m. The cameras were individually placed for each horse so that a good view of all the markers on the horse was obtained. The system was calibrated to the position of the cameras with a calibration frame of known dimensions.[c] Cameras recorded the position of the markers while each horse was walking on the treadmill.

Data collection and analysis—The horses were trained to walk on the treadmill by use of described training procedures.[6,7] During the measurements, an assistant standing in front of the treadmill held the horse loosely by a long rope attached to the halter. For each horse, the movement of the back was repeatedly measured during a period of ≥ 10 seconds' duration (mean, 14.5 seconds). A minimum of 6 walking motion cycles (mean, 11.3) were analyzed. The 3-dimensional coordinates of each marker during each cycle were calculated from the video data. These time series were smoothed, using a Butterworth low-pass filter with a cut-off frequency of 5 Hz.[d] Further calculations were carried out by use of computer software.[e] Durations of motion cycles were calculated, using the points at which the horizontal velocity of the marker of the hoof was 0 (**Fig 1**). One cycle was defined as the period between every second point on the graph at which horizontal hoof velocity was 0.[8] Duration of each cycle was standardized to 100 time frames (ie, percentage of motion cycle). Movements were set to the zero position (ie, the mean value of all the x and y coordinates of 1 motion cycle was subtracted from each of the values [**Fig 2**]). For each of the resulting 100 time frames, the mean of each coordinate of each marker was calculated separately for each horse, yielding the individual mean motion cycle of each horse. Values were expressed as **percentage of the height at the withers (PW)** to allow comparison between horses.[3]

Table 1—Mean lateral and dorsoventral movement of markers placed on the skin of the head and sites that overlay the dorsal spinous processes of various vertebrae of 22 horses, measured during walking

Marker position	Lateral		Dorsoventral	
	PW (%)	Distance (mm)	PW (%)	Distance (mm)
Head	3.15 (1.84)	51.2 (29.9)	6.0 (2.1)	91.3 (32.0)
T5	2.24 (0.57)	36.7 (9.3)	2.3 (0.8)	36.9 (12.8)
T10	3.00 (0.84)	48.5 (13.6)	1.7 (0.5)	28.7 (8.4)
T16	3.41 (0.85)	54.8 (13.7)	2.0 (0.6)	32.4 (9.7)
L3	3.49 (0.76)	56.0 (12.2)	3.3 (0.9)	49.6 (13.5)
OS1	2.78 (0.89)	43.8 (14.0)	4.3 (1.2)	64.6 (18.0)
OS2	2.41 (0.91)	37.8 (14.3)	4.7 (1.3)	70.9 (19.6)

Values are expressed as means (SD).
PW = Distance of movement expressed as a percentage of horses' height at the withers. OS1 = Dorsal spinous process of S2 or S3. OS2 = Dorsal spinous process of S4 or S5.

For lateral movement, angles were calculated in the horizontal plane, and for dorsoventral movement, angles were calculated in the sagittal plane.[d] For assessment of the movements of the vertebral column as a whole, the angle between the head, T16, and OS2 was calculated. As a representation of the movement of the entire back, the angle between T5, T16, and OS2 was determined. Each angle was calculated for each of the 100 time frames representing 1 motion cycle. Overall mean values were calculated from the individual mean motion cycles of each horse.

For all marker and angle time curves, the variation between horses was calculated as follows: at each of the 100 time frames, SD of marker position or angle value was calculated. Mean of the resulting 100 SD values was calculated, which will hereafter be referred to as mean SD for each time curve.

Table 2—Maximum and minimum angles between markers placed on the skin of the head and sites that overlay the dorsal spinous processes of various vertebrae of 22 horses, measured in horizontal and sagittal planes during walking

Angles	Maximum (°)	Occurrence (%)	Minimum (°)	Occurrence (%)	Max-Min (°)
Horizontal plane					
T5-T10-T16	183.5 (1.7)	73.9 (11.5)	176.5 (1.7)	28.5 (19.7)	6.9 (3.3)
T10-T16-L3	183.2 (1.1)	83.6 (7.0)	176.8 (1.3)	31.4 (8.6)	6.5 (2.2)
T16-L3-OS1	183.1 (1.1)	75.9 (13.9)	176.7 (1.3)	28.9 (10.6)	6.5 (2.2)
L3-OS1-OS2	182.9 (1.2)	60.4 (38.8)	177.2 (1.3)	40.3 (13.4)	5.7 (2.4)
T5-T16-OS2	185.2 (1.3)	81.3 (3.4)	174.7 (1.2)	30.7 (5.0)	10.6 (2.5)
Head-T16-OS2	183.8 (1.6)	79.1 (17.0)	176.3 (1.6)	34.0 (16.6)	7.4 (3.1)
Sagittal plane					
T5-T10-T16	181. 9 (0.6)	52.0 (27.2)	178.0 (0.6)	57.3 (31.2)	3.9 (1.1)
T10-T16-L3	181.5 (0.5)	64.2 (31.2)	178.5 (0.4)	49.3 (25.2)	3.0 (0.8)
T16-L3-OS1	181. 9 (0.7)	71.8 (24.7)	178.5 (0.5)	52.4 (24.2)	3.4 (1.2)
L3-OS1-OS2	182.1 (0.8)	61.9 (30.3)	178.1 (0.8)	48.3 (30.1)	4.0 (1.4)
T5-T16-OS2	182.5 (0.8)	60.3 (34.5)	177.5 (1.1)	47.6 (25.7)	5.0 (1.8)
Head-T16-OS2	183.7 (1.3)	40.5 (29.1)	176.0 (1.5)	53.0 (24.9)	7.7 (2.7)

Values are expressed as mean (SD). Values > 180° represent angles pointing upwards (ie, arching the back) or to the left (ie, situations in which the back is convex on the left side and concave on the right side). Values < 180° represent angles pointing downwards or to the right.

Occurrence = Percentage of the motion cycle at which maximum or minimum movement occurred. Max-Min = Difference between maximum and minimum values of each angle (range of movement).

See Table 1 for remainder of key.

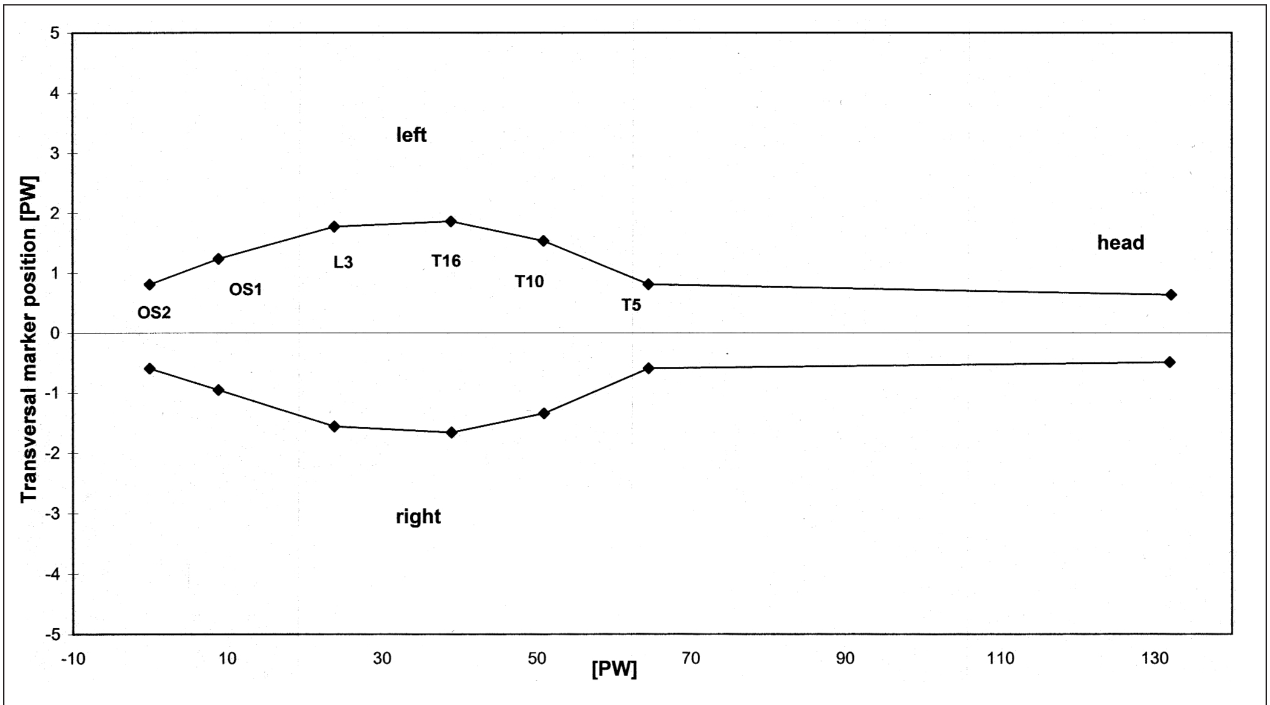

Figure 3—Transverse movement of the back during walking in horses (mean values; n = 22). Markers were attached to the skin overlying the head, T5, T10, T16, L3, S2 or S3 (OS1), and S4 or S5 (OS2). Movement of the markers was measured and calculated as a percentage of the horse's height at the withers (PW) at the times of maximum and minimum angles between T5, T16, and OS2 in the horizontal plane.

Pearson correlation coefficients were calculated to investigate the correlation between the 2 back angles and age. The significance ($P < 0.05$) of the correlation was tested by use of an F-test.

Results

Dorsoventral movement of the markers was found to range between 6.0 PW at the head and 1.7 PW at T10. The lateral movement of the markers ranged between 3.49 PW at L3 and 2.24 PW at T5 (**Table 1**). In the horizontal plane, the angle between T5, T16, and OS2 was altered by 11° during the motion cycle (**Table 2**). At the time when the angle between T5, T16, and OS2 in the horizontal plane reached its minimum and maximum during the motion cycle, T16 was at the most lateral position (**Fig 3**). In the sagittal plane, the angle between the head, T16, and OS2 was altered by 8° during the motion cycle. The position of T5 at the time when the angle between T5, T16, and OS2 in the sagittal plane reached its minimum value was quite similar to the position of T5 when this angle reached its maximum value (**Fig 4**). Each marker

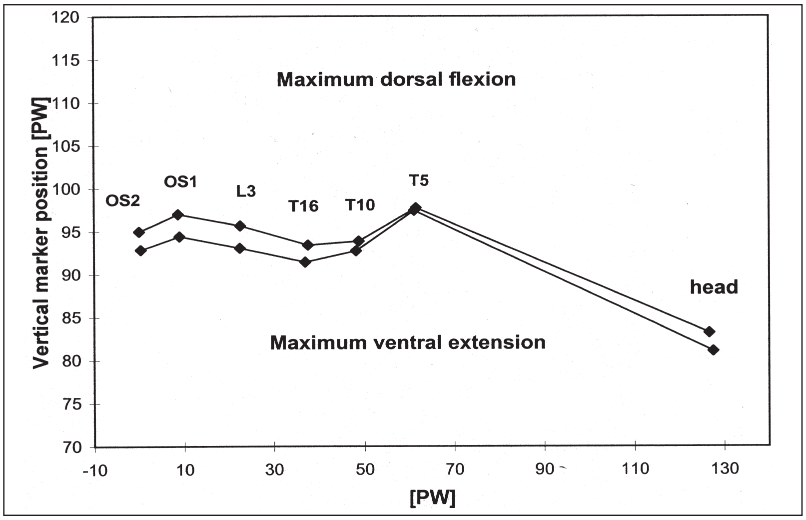

Figure 4—Dorsoventral movement of the back during walking in horses (mean values; n = 22). Markers were positioned and their movements determined as for Figure 3. Upper line indicates dorsoflexion and lower line indicates ventroflexion at the times of maximum and minimum angles between T5, T16, and OS2 in the sagittal plane.

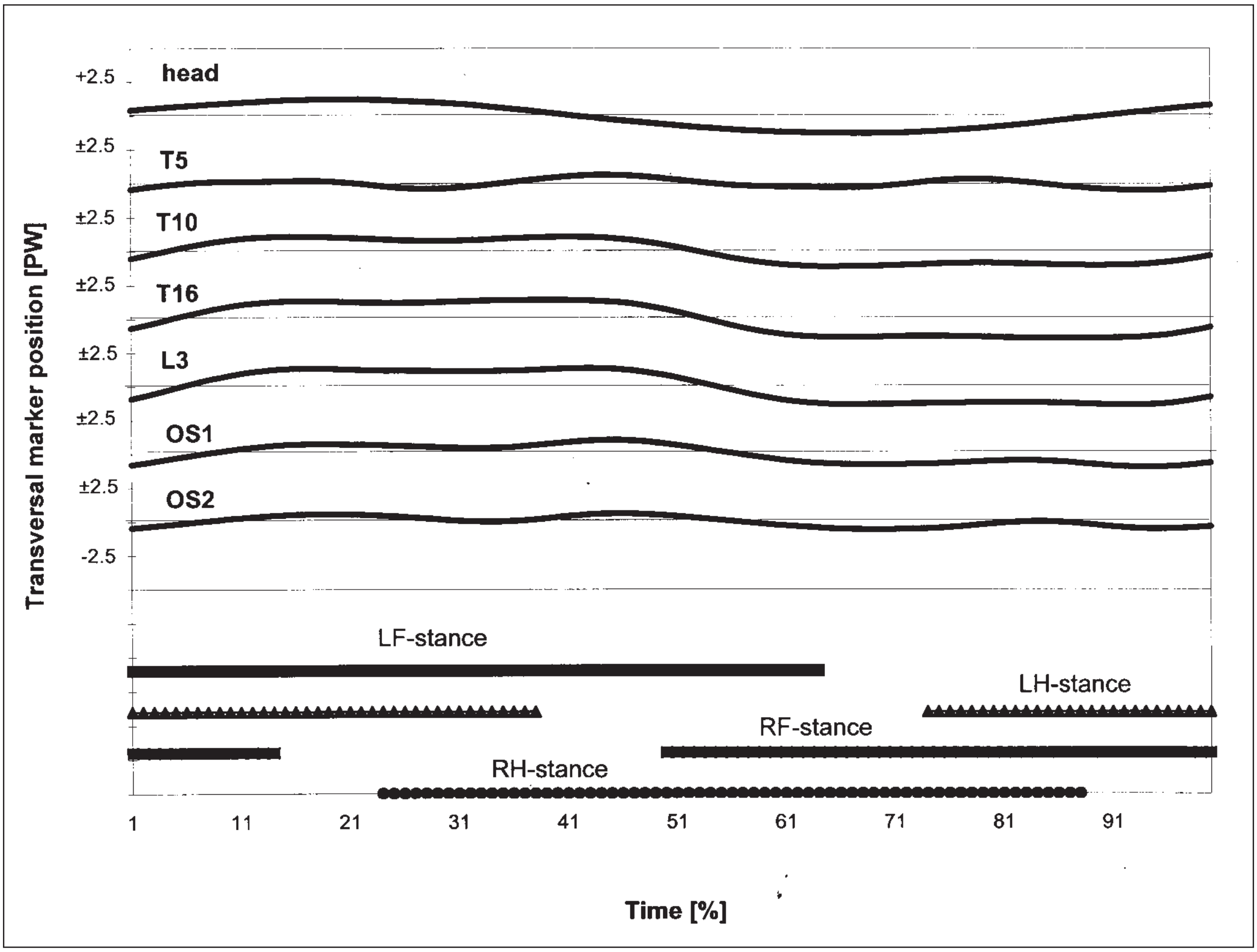

Figure 5—Mean values of the transverse positions of markers attached to the skin overlying various sites in 22 horses; values were recorded during walking. The x-axis represents time as a percentage of the duration of 1 walking motion cycle. Location of the markers on each horse was as described for Figure 3, and transverse position was calculated as PW. The horizontal line within each position curve represents the neutral reference position calculated by assigning a value of zero to the mean position of each marker; values above this line represent a marker position to the left of its starting position, and values below this line represent a marker position to the right of its starting position. The stance phases of the left forelimb (LF), right forelimb (RF), left hind limb (LH), and right hind limb (RH) during the motion cycle are depicted at the bottom of the figure.

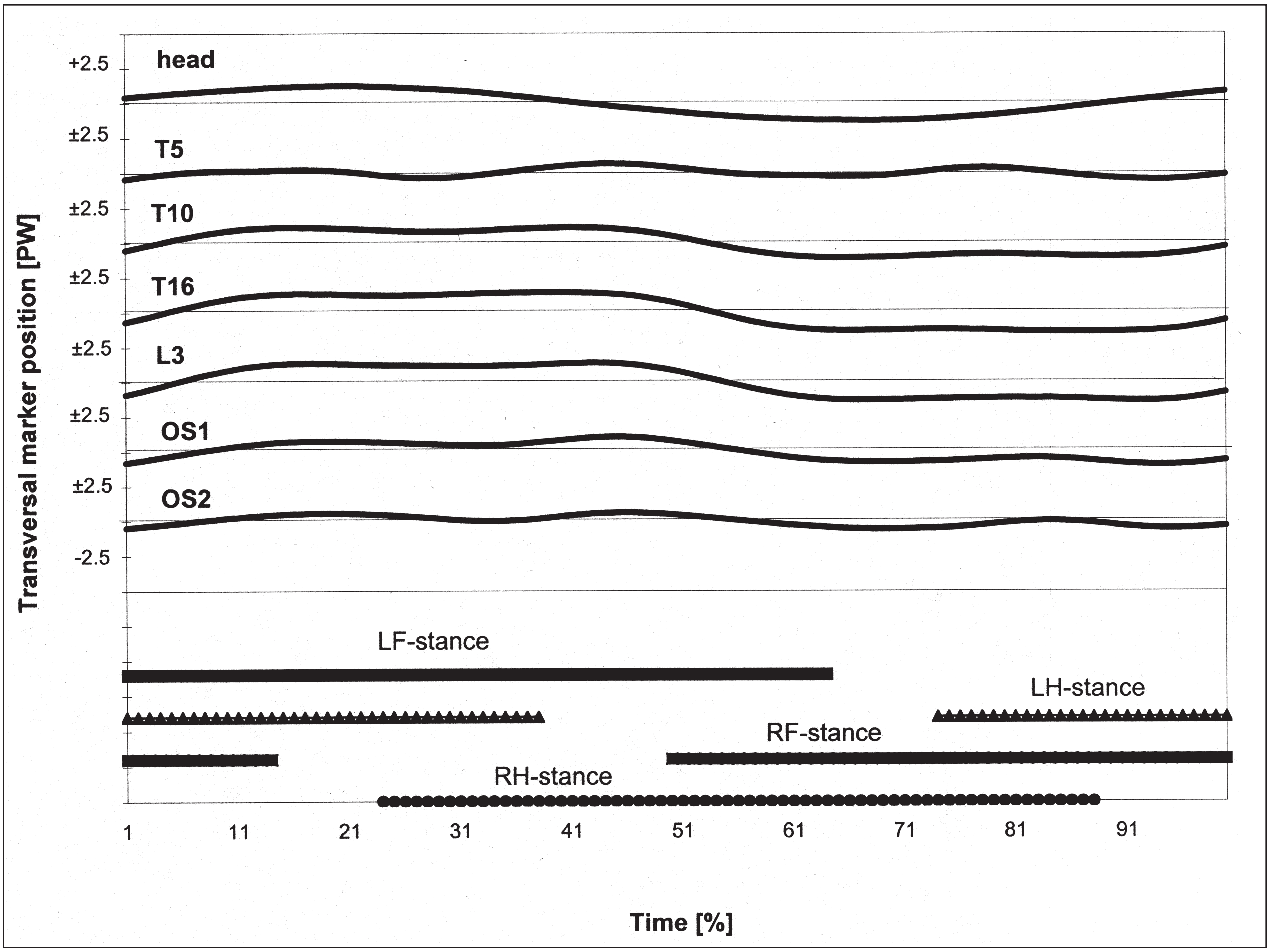

Figure 6—Mean values of the vertical positions of markers attached to the skin overlying various sites in 22 horses; values were recorded during walking. The x-axis represents time as a percentage of the duration of 1 walking motion cycle. Location of the markers was as described for Figure 3, and vertical position was calculated as PW. Values above the horizontal line within each position curve represent a marker position above its starting position, and values below this represent a marker position below its starting position.

reached its maximum and minimum position at a different time during the motion cycle (**Fig 5 and 6**).

In the horizontal plane, the back moved toward the side of the forelimb that was at stance. During the second half of the stance phase of the hind limb, the back moved away from the side of the hind limb that was at stance, indicating medial propulsion (Fig 5). At the time of the forelimb stance phase, the back moved dorsally. During the hind limb stance phase, a short ventral movement of the back occurred before and after the marked dorsal movement (Fig 6). In the sagittal plane, the stance phases of the forelimbs primarily influenced the cranial markers (head, T5, T10), whereas the stance phases of the hind limbs primarily influenced the caudal markers (L3, OS1, OS2); T16 was influenced by the stance phases of hind limbs and forelimbs.

In the sagittal and the horizontal planes, maximal and minimal angles between the head, T16, and OS2 corresponded with the times of tripedal support (**Fig 7**). The phase of tripedal support occurred in the middle of the forelimb stance, at the same time the head motion ventrally and laterally was maximal (Fig 5 and 6). The T5-T16-OS2 segment had the greatest dorsal flexion during diagonal limb support and greatest ventral extension during tripedal support with 2 hind limbs and 1 forelimb (Fig 7). During the motion cycle, the angle between the head, T16, and OS2 and the angle between T5, T16, and OS2 changed simultaneously in the horizontal plane. In the sagittal plane, the angle between the head, T16, and OS2 had more variation throughout the motion cycle than the angle between T5, T16, and OS2 did. The existence of 2 local maxima and minima within the time curves of both angles in the sagittal plane led to a large variation in the determination of the percentage of motion cycle when the overall maximum and minimum values occurred (Table 2).

In the horizontal plane, the time curve of the T16 marker had the lowest mean SD (0.47 PW). The largest variation was detected in the time curve of the head marker (mean SD, 0.88 PW). In the sagittal plane, the time curves (mean SD) of all thoracic markers varied little between horses (T5, 0.42 PW; T10, 0.42 PW; T16, 0.44 PW).

Mean SD of the time curve of the T5, T16 and OS2 angle was 1.2° in the horizontal and sagittal planes. Mean SD of the time curve of the head, T16, and OS2 angle was 1.4° in the sagittal plane and 1.7° in the horizontal plane. Back movement and age were not significantly correlated.

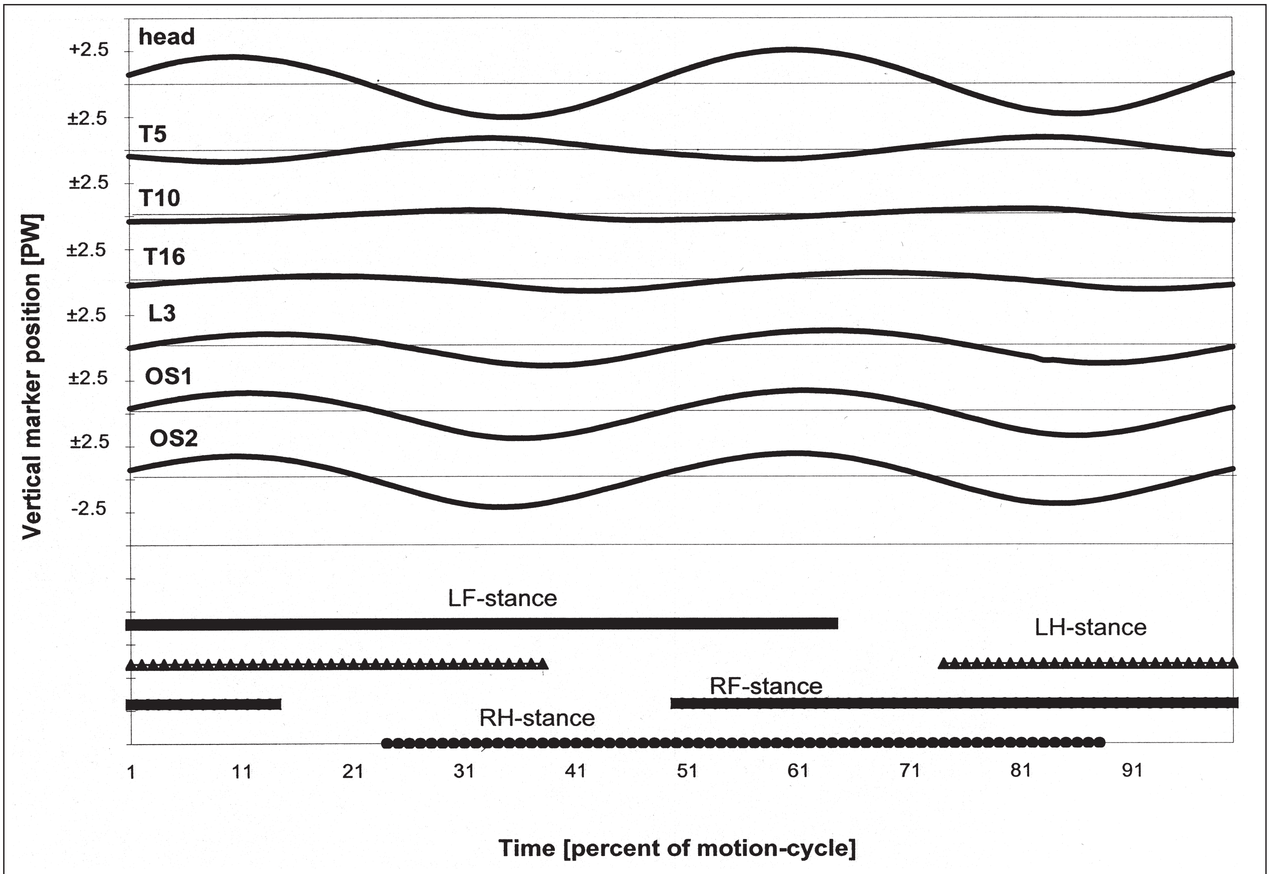

Figure 7—Angular movement of the back in horizontal and sagittal planes in 22 horses; values were recorded during walking. The x-axis represents time as a percentage of the duration of 1 walking motion cycle. The angle between markers placed on the head, T16, and OS 2 and the angle between markers placed on T5, T16, and OS2 were measured. The horizontal line within each angle curve represents the neutral reference position calculated by assigning a value of zero to the mean angle for the walking motion cycle; values above this line represent angles pointing upwards or to the left and values below this line represent angles pointing downwards or to the right.

Discussion

Assessing back movement is an important part of examination of the equine locomotor system. For comprehensive evaluation, the back should be evaluated while the horse is standing and at exercise. Previously, abnormal back movement was evaluated subjectively and often described as stiffness of the back.[2] For obvious reasons, objective determination of values associated with back movement is needed.

Until recently, measurements of spinal movements in horses have been restricted to those obtained by manipulation of cadavers.[9-12]

Variability of results within and between horses in our study was comparable to that of other kinematic studies[3-5] of the back in horses. To differentiate horses with mild back pain from horses without back pain, comparisons of measurements before and after treatment with anti-inflammatory drugs should be undertaken. This is also suggested for clinical examination of horses with suspected back pain.[1]

In relation to the stance phases of the limbs, lateral back movement indicates that the forelimb predominantly supports the trunk while the hind limb also exerts some medial propulsion. This finding is in accordance with measurements of transversal ground reaction forces of horses during walking.[13,14] The dorsoventral movement of the back in relation to the stance phases of hind- and forelimbs is in accordance with the inverted pendulum theory of walking.[15] Results of our study indicate that back movement at the walk is driven by the motion of the limbs. In human males, lumbar spine movements and age are negatively correlated.[16] In our study of horses, no significant correlation between age and the difference between minimum and maximum values of the 2 angles of the back was found. However, investigation of a larger number of horses with a wide age range may reveal a similar correlation.

The kinematic measurement of back motion in horses in our study was simple and noninvasive, and it allowed evaluation of movement of the entire back as a functional unit. Values obtained by this study may be used as reference values for evaluation of back movement during walking in horses with suspected back problems.

[a]ExpertVision System, Motion Analysis Corp, Santa Rosa, Calif.
[b]Mustang 2200, Kagra Corp, Fahrwangen, Switzerland.
[c]Calibration frame, Motion Analysis Corp, Santa Rosa, Calif.
[d]EVA software, version 4.0, Motion Analysis Corp, Santa Rosa, Calif.
[e]Microsoft Excel, version 5.0, Microsoft Corp, Redmond, Wash.

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