Objective determination of pelvic movement during hind limb lameness by use of a signal decomposition method and pelvic height differences

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Objective—To evaluate pelvic movement over a large number of strides in sound horses and in horses with induced hind limb lameness by applying methods to the pelvis that have been described for evaluating vertical head movement in horses with induced forelimb lameness.

Animals—17 adult horses.

Procedure—Horses were filmed while trotting on a treadmill before and after induction of transient mild and moderate hind limb lamenesses. Vertical pelvic movement was measured by a signal decomposition method. The vertical pelvic signal was decomposed into a periodic component (A1) that occurred at half the stride frequency (representing vertical pelvic movement caused by lameness) and another periodic component (A2) that occurred at stride frequency (representing normal vertical pelvic movement of a trotting horse). Vertical pelvic and foot positions were correlated for each stride to compare the difference between the minimum and maximum heights of the pelvis during and after stance of the right hind limb to the minimum and maximum heights of the pelvis during and after stance of the left hind limb.

Results—Maximum pelvic height difference and lameness amplitude (A1) differed significantly between sound and mild or moderate hind limb lameness conditions. Mean A1 value for vertical pelvic movement in sound horses was less than that previously reported for vertical head movement.

Conclusion and Clinical Relevance—Pelvic height differences and signal decomposition of pelvic movement can be used to objectively evaluate hind limb lameness in horses over a large number of strides in clinical and research settings. (*Am J Vet Res* 2004;65:741–747)

Accurate detection of lameness in horses by veterinary clinicians is essential for reliable diagnosis and assessment of treatment. In lameness of mild severity, unequivocal detection and localization of lameness to the affected limb can be difficult.[1,2] Objective techniques have been developed that allow measurement of limb, head, and trunk movement. These techniques allow quantification of gait compensations that are typically assessed subjectively during clinical examination.

Analysis of vertical pelvic movement involving use of the sacrum as a marker of pelvic position has been suggested as an optimum method for detection of hind limb lameness.[3] Similar to head movement, vertical movement of the sacrum in trotting horses has a sinusoidal pattern in time. Two cycles occur during 1 complete stride. The first minimum height is reached during the middle and the first maximum height is reached immediately after the end of 1 limb's stance phase. The second minimum and maximum heights occur during the middle and immediately after the end of the contralateral limb's stance phase, respectively. In sound horses, the pattern of both head and pelvic movement is nearly symmetrical with pelvic and head heights reaching equivalent respective minimum (during midstance) and maximum (immediately after stance) heights for each limb. In lame horses, asymmetry of head and pelvic movement has been used to detect and measure forelimb and hind limb lameness, respectively.[2-6]

Quantitative methods that have been used to analyze head movement in horses with forelimb lameness include measurement of vertical displacement and acceleration of the head,[3] comparison of the minimum head height during each stance phase of the stride,[5] frequency spectral analysis of vertical head motion,[6,7] and a time domain signal decomposition of vertical head movement that assumes vertical head movement to be a combination of regular periodic and irregular random motion.[8]

Quantitative methods that have been used to evaluate hind limb lameness include measurement of vertical displacement and acceleration of the sacrum,[3] comparison of the minimum sacral height during each stance phase of the stride,[9] frequency spectral analysis of vertical sacral motion,[2,7] and comparison of the ratio of left to right tuber coxae vertical excursion.[9-11]

Although evaluation of hind limb lameness in horses is often difficult, use of objective techniques in evaluation of hind limb lameness in clinical cases and research investigations to evaluate lameness before and after treatment has been limited. Previous studies[2,3,6,9-11] of hind limb pelvic movement have analyzed only a limited number of strides (3 to 15) per condition. In some instances, these strides have not been consecutive.[6,11] Analysis of larger numbers of strides per trial would allow for a better representation of a horse's overall

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movement pattern. Evaluation of a large number of strides is particularly important in horses in which the degree of lameness is mild or the nature of the lameness is intermittent and in situations where horses are being evaluated for partial improvement after administration a diagnostic nerve block or treatment. The SD values of some stride variables increase as a horse's lameness improves[12]; when calculating mean values, evaluation of a large number of strides decreases the likelihood of misrepresenting a horse's overall movement pattern.

Advances in computer-assisted, video-based motion analysis systems have made it easier to collect large amounts of complex kinematic data quickly. The purpose of this study was to evaluate pelvic movement over a large number of strides (80 to 90) in sound horses and horses with different degrees of induced hind limb lameness by applying a computational algorithm[8] (described for analysis of vertical head movement in horses with induced forelimb lameness) to the pelvis.

Materials and Methods

Animals—Seventeen adult horses of various breeds (12 geldings and 5 mares) were included in the study; the age range of these horses was 3 to 27 years. The horses were individually owned animals or horses that had been donated to the University of Missouri for reasons unrelated to disease of the musculoskeletal system. All horses were clinically sound. The study design was approved by the University of Missouri Animal Care and Use Committee.

Horses were trained to trot on a treadmill[a] at a speed (range, 3.0 to 4.2 m/s) at which they could maintain a stable position on the treadmill. The optimum speed for each horse was then recorded and used during all subsequent evaluations of that horse. Both hind limbs of each horse were shod with custom-made, adjustable heart-bar shoes that were designed to induce a transient lameness by applying reversible pressure to the frog (**Fig 1**).

Study conditions—Horses were filmed while trotting on the treadmill before and after inducing transient lameness in each hind limb. Two levels of lameness were induced in each hind limb. The first level of induced lameness (level 1) was a lameness that was observable at a trot. The second level of induced lameness (level 2) was created by reducing, but not completely eliminating, the frog pressure. Each horse was therefore filmed under 6 conditions: **sound before lameness induction (S1)**; **level-1 right hind limb lameness (RH1)**; **level-2, less severe, right hind limb lameness (RH2)**; **level-1 left hind limb lameness (LH1)**; **level-2, less severe, left hind limb lameness (LH2)**; and **sound after lameness induction (S2)**. The order of limb selection for lameness induction was randomized. It is important to note that in this study, level-2 lameness is less severe than level-1 lameness. Also, these lameness levels bear no relationship to the grades 1 and 2 of the American Association of Equine Practitioners lameness scale.[13]

Figure 1—Photograph of a custom-made adjustable heart-bar shoe used to induce transient lameness in 17 horses. The screw in the straight bar is tightened to raise the heart bar and thereby put pressure on the frog of the horse's foot to create temporary lameness.

Data acquisition—Computer-assisted kinematic gait analysis was performed by use of a motion analysis system.[b] Five strobe-activated, visible-red-light-detecting cameras were used to record each horse's movement at a frequency of 120 Hz. Cameras were placed in the left caudal lateral, right caudal lateral, right lateral, right cranial lateral, and dorsal positions relative to the horse. Cameras were calibrated before each filming session, and the measurement error for a 500-mm distance between 2 markers was < 1 mm (0.02%) for each camera. A single digital video camera (30 Hz) placed at the caudal aspect of the treadmill was used to simultaneously record the horse's movement.

Reflective markers were attached to the dorsal aspect of the sacrum midway between the right and left tubera sacrale and to the lateral aspect of the right hind hoof wall. Two separate consecutive trials (each of 30 seconds' duration) were filmed for each lameness condition, resulting in the collection of 40 to 45 complete strides/trial and 80 to 90 complete strides/condition. Three-dimensional position data of the markers were calculated for each frame throughout the trial and imported into a custom-written computational program.[c]

Signal decomposition of pelvic movement—Analysis of the vertical pelvic and right hind foot movement was performed for each trial. Vertical motion of the pelvis was quantified by use of a previously described algorithm for head movement.[8] Briefly, the vertical motion of the pelvis was assumed to be a function consisting of 3 components: a periodic component occurring once per stride that describes the alteration in vertical movement resulting from unilateral lameness (the first harmonic component of the periodic part of the function), a periodic component occurring twice per stride that describes the normal biphasic vertical pelvic movement (the second harmonic component of the periodic part of the function), and a nonperiodic component that describes random vertical movement of the pelvis. The amplitude of each periodic component was determined for each stride, and the **root-mean square (RMS)** of these amplitudes over all the strides in each trial was calculated to give an overall trial measurement for the vertical movement of the pelvis attributable to lameness (**lameness amplitude**, **A1**) and for the normal biphasic vertical movement of the pelvis in a trotting horse (**natural pelvic movement amplitude**, **A2**). **Stride frequency (f)** for each trial was determined by a fast Fourier transformation of the data. The ratio of A1:A2 was calculated for each trial.

Pelvic height differences—**Minimum** and **maximum pelvic height differences** (**MINDIFF** and **MAXDIFF**, respectively) were calculated. The component describing random vertical pelvic movement was first removed from the signal.[8] Minimum pelvic height difference was defined as the difference in minimum pelvic height between right and left stance for each stride. Maximum pelvic height difference was defined as the difference in the maximum pelvic height reached just after left stance and the maximum reached just

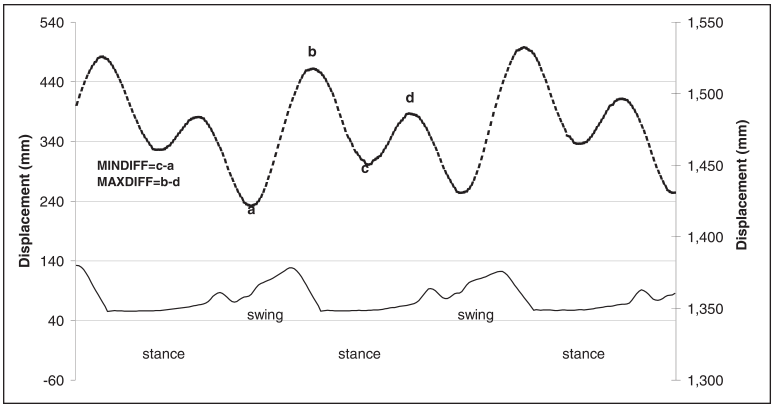

Figure 2—Displacement of the sacrum (dashed line) with movement of the right hind foot (solid line) in a horse with right hind limb lameness. Minimum pelvic height difference (MINDIFF) is defined as the difference in minimum height between right and left stance for each stride (c minus a). Maximum pelvic height difference (MAXDIFF) is defined as the difference in the maximum pelvic height reached after left stance and the maximum reached after right stance (b minus d). Left stance is assumed to occur during right swing.

after right stance for each stride (**Fig 2**). Right and left stance phases were determined by evaluation of the vertical movement of the right hind foot. Left stance was assumed to occur during right swing. For each stride, values of MINDIFF and MAXDIFF were determined. By definition, a MINDIFF value was positive when pelvic position during the right stance phase was greater than that detected during left stance; a MAXDIFF value was positive when pelvic position immediately after the end of left stance was greater than that detected after right stance. These definitions give positive values for MINDIFF and MAXDIFF in right hind limb lameness and negative values for left hind limb lameness. The mean MINDIFF and the mean MAXDIFF values were determined by dividing the sum of the MINDIFF or MAXDIFF values, respectively, by the number of strides per trial.

Statistical analyses—A Shapiro-Wilk W test was used to determine whether the data from trial 1 and trial 2 of each condition were normally distributed. For data that were not normally distributed, a Wilcoxon signed-rank test was used to compare mean values between trial 1 and trial 2. For data that were normally distributed, a paired *t* test was used to compare mean values. Because 6 comparisons were made between trial 1 and trial 2 (A1, A2, A1:A2, f, MAXDIFF, and MINDIFF), a value of $P < 0.008$ (0.05/6, Bonferroni method) was considered significant.

A Shapiro-Wilk W test was used to determine whether the data from each condition (S1, S2, RH1, RH2, LH1, and LH2) were normally distributed. If data were normally distributed, a 2-way ANOVA was used to identify differences between the means of each condition. If data were not normally distributed, a Friedman test was used to identify differences between the means of each condition. Post hoc comparisons were made by use of the Fischer least significant difference method or the nonparametric equivalent.[14] For each test, a value of $P < 0.05$ was considered significant.

Results

Comparison of trial 1 versus trial 2—Data from the first 30 seconds of data collection (trial 1) were compared with that from the second 30 seconds of data collection (trial 2) for each condition. For the S1 and S2 conditions, 2 variables differed significantly between trial 1 and trial 2. Compared with trial 1, the amplitude of natural pelvic vertical displacement (A2) increased by 0.8 mm and the value of f decreased by 0.01 strides/s in trial 2. For the RH1, RH2, LH1, and LH2 conditions, 3 variables differed significantly between trial 1 and trial 2. Compared with trial 1, the A2 value of pelvic movement increased by mean of

Table 1—Mean ± SD values of kinematic variables assessed in 17 trotting horses before and after induction of mild or more severe hind limb lameness

	Lameness condition*					
Variable	**S1**	**S2**	**RH1**	**RH2**	**LH1**	**LH2**
MAXDIFF (mm)	0.8 ± 6.0[b,c,d,e]	0.5 ± 7.3[b,c,d,e]	23.2 ± 12.5[a,c,d,e]	9.0 ± 9.0[a,b,d,e]	–18.6 ± 11.9[a,b,c,e]	–8.5 ± 7.7 [a,b,c,d]
MINDIFF (mm)	–0.4 ± 6.3[b,c,d]	1.5 ± 9.4[b,c,d]	30.5 ± 16.3[a,c,d,e]	13.7 ± 13.7[a,b,d,e]	–25.2 ± 11.3[a,b,c]	–15.7 ± 8.6[a,b,c]
A1 (mm)	4.6 ± 1.6[b,c,d,e]	5.5 ± 2.6[b,c,d,e]	21.2 ± 8.1[a,c,e]	12.3 ± 5.1[a,b,d]	17.6 ± 5.9 [a,c,e]	10.8 ± 3.9[a,b,d]
A2 (mm)	35.3 ± 4.3[b,d]	35.0 ± 4.3[b,d]	30.5 ± 5.1[a,c,e]	33.0 ± 4.3[b,d]	31.8 ± 5.1[a,c,e]	33.5 ± 5.2[b,d]
A1:A2 ratio	0.17 ± 0.05[b,c,d,e]	0.2 ± 0.07[b,c,d,e]	0.7 ± 0.35[a,c,e]	0.38 ± 0.15[a,b,d]	0.57 ± 0.23[a,c,e]	0.33 ± 0.15[a,b,d]
Stride frequency (Hz)	1.36 ± 0.04 [b,d]	1.4 ± 0.04[b,d]	1.4 ± 0.05[a,c,e]	1.37 ± 0.04[b,d]	1.38 ± 0.05[a,c,e]	1.36 ± 0.04[b,d]

*Lameness conditions were designated as follows: S1 = Sound condition before induction of hind limb lameness; S2 = Sound condition after removal of all induced hind limb lameness; RH1 = More severe level of right hind limb lameness; RH2 = Less severe level of right hind limb lameness; LH1 = More severe level of left hind limb lameness; LH2 = Less severe level of left hind limb lameness; MAXDIFF = Maximum pelvic height difference (the difference in the maximum pelvic height reached after left stance and the maximum reached after right stance); MINDIFF = Minimum pelvic height difference (the difference in minimum height between right and left stance for each stride); A1 = Amplitude of a periodic component occurring once per stride that describes the alteration in vertical movement resulting from unilateral lameness ; and A2 = Amplitude of a periodic component occurring twice per stride that describes the normal biphasic vertical pelvic movement in a trotting horse.

[a] Value significantly ($P < 0.05$) different from both sound conditions. [b] Value significantly ($P < 0.05$) different from RH1. [c] Value significantly ($P < 0.05$) different from RH2. [d] Value significantly ($P < 0.05$) different from LH1. [e] Value significantly ($P < 0.05$) different from LH2.

Table 2—Comparison of lameness variables for each of the lameness conditions assessed in 17 horses

Variable	Relative magnitude of each lameness condition
MAXDIFF	RH1 > RH2 > S1 = S2 > LH2 > LH1
MINDIFF	RH1 > RH2 > S1 = S2 >LH2 = LH1
A1	RH1 = LH1 > RH2 = LH2 > S1 = S2
A2	RH1 = LH1 < RH2 = LH2 = S1 = S2
A1:A2 ratio	RH1 = LH1 > RH2 = LH2 > S1 = S2
Stride frequency	RH1 = LH1 > RH2 = LH2 = S1 = S2

Significant differences between conditions are designated by greater than (>) or less than (<) symbols. Lack of significant differences is designated by an equal (=) symbol. Note the lack of significant differences between right- and left-sided lameness for A1, A2, A1:A2 ratio, and stride frequency values. *See* Table 1 for key.

0.9 mm, f decreased by a mean value of 0.01 strides/s, and the A1:A2 ratio decreased by a median value of 0.04 (median reported because of non-normal distribution) in trial 2.

Although the differences between trial 1 and trial 2 were significant for the aforementioned variables, these differences were considered clinically unimportant because of the small absolute differences, and data from trial 1 and trial 2 of each condition were combined for further analyses.

Comparison of sound conditions—After combining trial-1 and trial-2 data, the S1 and S2 conditions were compared. No significant differences were identified between the data associated with the S1 condition and that associated with the S2 condition (measured after all lameness conditions had been induced and removed; **Table 1 and 2**).

Comparison of sound and lame conditions—After combining trial-1 and trial-2 data for each condition, the S1 and S2 and RH1, RH2, LH1, and LH2 conditions were compared by analysis of values of f, MAXDIFF, MINDIFF, A1, A2, and A1:A2 ratio.

Analysis of MAXDIFF values—After induction of level-1 (more severe) hind limb lameness, the absolute value of the MAXDIFF increased by 19.4 mm and 22.4 mm for LH1 and RH1, respectively. After induction of level-2 (mild) hind limb lameness, the absolute value of MAXDIFF increased by 9.3 mm and 8.2 mm for LH2 and RH2, respectively. For both left and right induced hind limb lameness, both levels of lameness had significantly ($P < 0.017$) different MAXDIFF values, compared with those of both the S1 and S2 conditions. Changes in pelvic maximum heights during sound, level-1, and level-2 lameness conditions were evident in plots of pelvic displacement versus time (**Fig 3**).

Analysis of MINDIFF values—After induction of level-1 (more severe) hind limb lameness, the absolute value of MINDIFF increased by 24.8 mm and 30.9 mm for LH1 and RH1, respectively. After induction of level-2 (mild) hind limb lameness, the absolute value of pelvic MINDIFF increased by 15.3 mm and 14.1 mm for LH2 and RH2, respectively. The MINDIFF values for the RH1 and LH1 conditions were significantly ($P < 0.001$) greater than values obtained for the S1 and S2 conditions. The MINDIFF values for the RH2 and LH2 conditions were significantly ($P < 0.014$) greater than values obtained for the S1 and S2 conditions. The MINDIFF value for the RH2 condition was significantly ($P < 0.001$) different from that for the RH1 condition. The MINDIFF value for the LH2 condition was not significantly ($P = 0.102$) different from that for the LH1 condition.

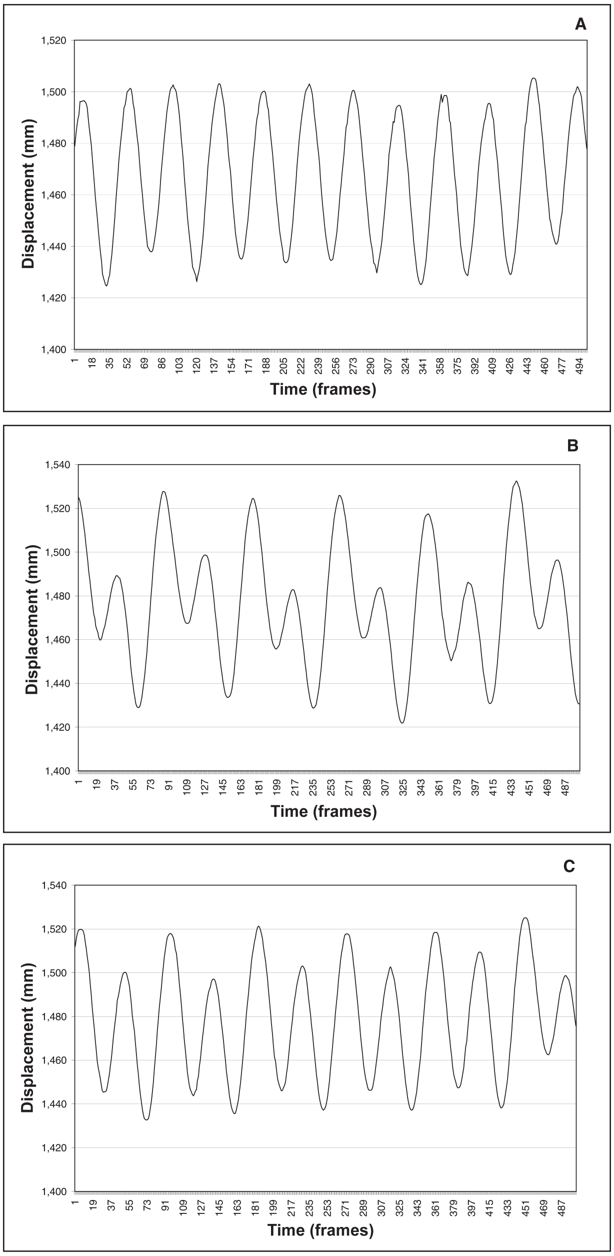

Figure 3—Vertical position of the sacrum before (sound condition, A) and after induction of more severe (level 1, B) and mild (level 2, C) lameness in a horse recorded at 120 frames per second by the use of a computerized motion analysis system. Five strides are shown.

Amplitude of pelvic movement attributable to lameness—The amplitude of the first harmonic component of vertical pelvic movement (A1) differed significantly between level-1 and level-2 lameness conditions and between both lameness levels and the S1 and S2 conditions. After the more severe hind limb lameness induction, A1 increased by 13.0 mm and 16.6 mm

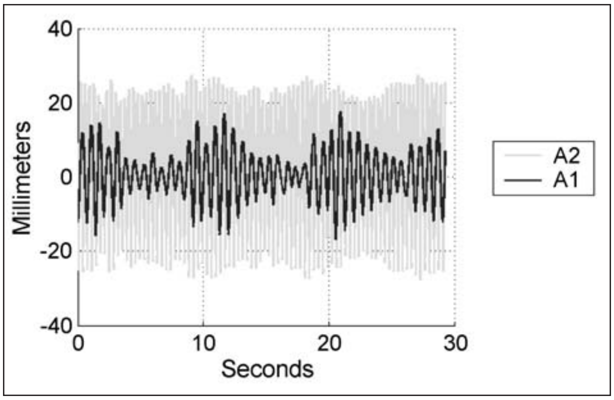

Figure 4—Amplitudes of a periodic component occurring once per stride (A1) that describes the alteration in vertical movement resulting from unilateral lameness and a periodic component occurring twice per stride (A2) that describes the normal biphasic vertical pelvic movement in a horse with level-2 lameness. Notice the variation in the lameness amplitude A1 during a 30-second filming period.

for LH1 and RH1, respectively. After the less severe hind limb lameness induction, A1 increased by 6.2 mm and 7.7 mm for LH2 and RH2, respectively. No differences were identified between right and left lameness conditions. In certain horses, A1 periodically increased and decreased during the 30 seconds of data collection, whereas A2 remained relatively constant from stride to stride (**Fig 4**).

Amplitude of natural pelvic movement—The amplitude of the second harmonic component of vertical pelvic movement (A2) in the more severe lameness condition (LH1 and RH1) differed significantly from that of the S1 and S2 conditions. After induction of RH1, A2 decreased by 4.8 mm; after induction of LH1, A2 decreased by 3.5 mm. No difference in A2 was identified between both S1 and S2 and the RH2 and LH2 conditions. No difference in A2 was identified between right and left lameness conditions.

A1:A2 ratio—The A1:A2 ratio differed significantly between level-1 and level-2 lameness conditions and between both lameness conditions and corresponding sound conditions. After induction of level-1 lameness, the A1:A2 ratio increased by 0.53 and 0.40 for right and left hind limb lameness, respectively. After induction of level-2 lameness, the A1:A2 ratio increased by 0.21 and 0.16 for right and left hind limb lameness, respectively. No difference in the A1:A2 ratio was identified between right and left lameness conditions.

Stride frequency—Stride frequency differed between level-1 lameness and S1 conditions only. After induction of level-1 lameness, values of f increased by 0.04 strides/s and 0.02 strides/s for RH1 and LH1 conditions, respectively. No difference was identified between S2 and the RH2 and LH2 conditions. Additionally, no difference was identified between right and left lameness conditions.

Discussion

In horses, pelvic height during trotting reaches a minimum value near midstance and a maximum value shortly after hind limb push off. In an ideal sound horse, the minimum and maximum heights reached near midstance and after push off of 1 hind limb are equal to the subsequent minimum and maximum heights, respectively, reached during midstance and after push off of the contralateral hind limb. In our study, induction of a transient, shoe-induced lameness in horses consistently resulted in less downward movement of the pelvis during stance phase of the affected limb and less upward movement of the pelvis after push off of the affected limb. The hip or pelvic hike (discussed in many descriptions of visually-assessed lameness) may actually be the result of push off of the sound limb that elevates the pelvis to a higher degree than push off of the lame limb and occurs immediately before weight bearing of the lame limb. The absolute value of maximum pelvic height difference increased consistently and significantly with increasing lameness, suggesting that it is a good measure for quantifying changes in the level of hind limb lameness.

Because calculation of maximum and minimum height differences is correlated with vertical position of the foot, the side of the horse on which the lameness has occurred can be determined. From our definitions of maximum and minimum height, right hind limb lameness will have positive values for the height difference and left hind limb lameness will have negative values. Theoretically, sound horses will have minimum and maximum height differences of 0. In our study, the mean maximum and minimum height differences before lameness induction were 0.6 ± 6.5 mm and 0.5 ± 7.2 mm, respectively.

Calculation of minimum and maximum height differences for head movement in the determination of forelimb lameness can be difficult in certain horses because of random movement of the head as the horses become curious or excited. An algorithm that removes this random movement by extracting a moving mean from the raw signal has been determined.[8] The resulting low-frequency-smoothed, periodic signal represented a more accurate summation of vertical head movement attributable to lameness (A1) and natural, vertical head movement (A2). The resulting values of A1 and the A1:A2 ratio were more useful in the determination of forelimb lameness than the uncorrected MINDIFF and MAXDIFF values for the head.[8] Although the random movement of the pelvis in the horses of the study of this report was smaller than that of the head, we believe that application of this same algorithm to pelvic movement is useful. The magnitude of pelvic height changes as a result of hind limb lameness is considerably smaller than height changes of the head observed in forelimb lameness; thus, even small amounts of random pelvic movement may obscure or diminish the changes caused by mild hind limb lameness.

In the method used in our study, vertical movement of the pelvis is assumed to be a signal consisting of 3 components. These components are obtained mathematically by a time-domain, signal decomposition method. Initially, a random component is removed from the signal before the A1 and A2 components are determined. The A1 component of the signal occurs once during each stride and is the measure of vertical pelvic movement because of lameness. The A2 component occurs twice during the stride and is a measure of the expected or natural vertical motion of the pelvis. Theoretically, the A1 value is 0 for the perfectly sound horse. In our study, the mean A1 value before lameness induction was 5.9 ± 1.6 mm. In another study[8] that involved the use of this algorithm for head movement evaluation, the mean A1 value for vertical head movement in sound horses was 24.8 ± 10 mm. The baseline A1 values for lameness evaluation of head movement during forelimb lameness are 3 times as great as the baseline A1 values for evaluation of pelvic movement during hind limb lameness. From this, it can be said that the vertical pelvic motion in sound horses is naturally more symmetrical than the vertical head motion.

The amplitude of the A1 signal and the A1:A2 ratio were useful indicators of the presence and intensity of hind limb lameness. As the level of lameness increased from baseline, both A1 and A1:A2 values increased. However, determination of the A1 value and A1:A2 ratio does not differentiate the side of lameness in a horse. Vertical position of the foot can be correlated in time with the occurrence of A1 and used to determine the side of lameness. Alternatively, the sign (ie, positive [+] or negative [–]) of the maximum or minimum pelvic height values can be used to determine the side of lameness.

This signal decomposition method may potentially be useful in a bilateral lameness condition wherein the horse intermittently alternates between right and left hind limb lameness. As the side of the lameness changes, the measured mean MINDIFF and MAXDIFF values are reduced, but the mean A1 value or A1:A2 ratio are not affected.

In the study of this report, we measured a slight increase in f value, but only after induction of the more severe level of lameness. Because the speed of the treadmill remained constant, this suggested a decrease in stride length after induction of the more severe lameness. Decreased protraction has been associated with hind limb lameness.[9,15] Decreased protraction may have resulted in a decrease in stride length in the horses of our study, but protraction and stride length were not measured. Additionally, in horses with the more severe level of lameness, the amplitude of A2 decreased slightly. This means that the overall vertical displacement of the pelvis decreased with more severe lameness. In combination with the increased f value observed in level-1 lameness, these findings suggest that horses with more severe lameness push the trunk up less during suspension after both the lame and sound hind limb stance phases. Because these findings were observed only at the more severe level of lameness, neither can be considered sensitive indicators of lameness.

The number of strides analyzed per condition in our study was large (80 to 90), which allowed for an accurate representation of the horses' overall movement patterns. In certain horses with lameness, we have observed that the intensity of lameness varies from stride to stride. The ability to analyze a large number of strides is essential for accurate evaluation of the level of lameness in these horses.

In a kinematic study,[3] vertical displacement of the sacrum over 12 strides after shoe-induced lameness was measured and displacement amplitude symmetry was calculated by comparing the vertical displacement of a marker on the sacrum during the stance of the sound limb with the displacement measured during stance of the lame limb. Our data suggest that a decrease in the maximum height of the pelvis achieved after push off of the lame limb as well as an increase in the minimum height of the pelvis during stance of the lame limb are responsible for these changes in the displacement amplitude symmetry. The relative importance of changes in maximum pelvic height versus changes in minimum pelvic height for determination of the severity of hind limb lameness has not been previously determined. Results of our study indicated significant differences in both MAXDIFF and MINDIFF values, but the lack of significant differences in MINDIFF between LH1 and LH2 conditions suggests that measurement of MAXDIFF may be more important when evaluating mild differences.

Evaluation of pelvic movement in hind limb lameness by comparison of right and left tubera coxae displacement has been reported.[3,9,11] Tuber coxae displacement is affected by rotation of the pelvis relative to the vertebral column as well as by translational displacement of the trunk. The rotational movement of the pelvis around the vertebral column results in the pelvis rotating away from the weight-bearing limb. As a result, the vertical displacement of each tuber coxae during 1 stride in sound horses is normally asymmetrical. The minimum height reached by the left tuber coxae during right hind limb stance is lower than the minimum height the left tuber coxae reaches during left hind limb stance and vice versa. In contrast, vertical movement of the pelvis at the level of the sacral tubers is primarily influenced by translational displacement of the pelvis and is nearly symmetrical. Application of 3-dimensional methods to evaluate the movement of the left tuber coxae relative to the right would require filming of the horse from both sides. Filming of a horse from 1 side only is required for 3-dimensional analysis of vertical sacral movement. Additionally, there is variation in the natural degree of asymmetry between tuber coxae among sound horses,[11,16] which increases the difficulty of differentiating between mild lameness and soundness by use of this measure.

Frequency spectral analysis has been used clinically to quantify hind limb lameness in horses.[2,6] The primary advantage of our time-domain, signal-processing method over frequency domain methods is that the lameness amplitude is measured for each stride during any time period that is recorded. With frequency spectral analysis, the lameness amplitude is a composite value obtained from several strides. Local spikes of increased lameness and increasing and decreasing amplitudes of lameness with time are not detected. With the signal processing method used in our study, the lameness severity (as measured by the determination of the A1 amplitude) at each stride as well as the mean lameness severity (the RMS of A1 amplitude) were evaluated. This allows for identification and more complete evaluation of lameness in horses in which the lameness amplitude varies from stride to stride (eg, a horse with intermittent, erratic lameness or a horse with mild lameness that diminishes with movement).

Other methods of quantifying hind limb lameness involving joint angle calculations and symmetry correlations between right and left limbs have been described.[9,15-18] These methods require additional marking of the horse and filming from both sides of the horse, which results in extended set up and data processing times. As a result, only limited numbers of strides have been analyzed, and to our knowledge, the techniques are not easily available for clinical use. As other investigators have noted, the quantification of hind limb lameness by use of markers placed only on the sacrum and 1 hind foot is appealing because of short set up and data processing times.[3,6] Although the method described in the study of this report was developed and used for horses trotting on a treadmill, the same algorithms can be adapted and used for overground techniques that employ wireless transmission of body position data from accelerometers attached to the head and pelvis[19] and may simplify the clinical application of these techniques.

Development and determination of objective methods that accurately and efficiently evaluate hind limb lameness in horses over a large number of strides is important for improved evaluation of clinical cases and collection of objective research data. Expedient and objective hind limb lameness evaluation can be performed by measurement of pelvic height differences and signal processing of the components that describe vertical pelvic movement.

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[a] Sato equine treadmill, Equine Dynamics, Raymore, Mo.

[b] Vicon motion analysis system, Vicon 250 Workstation, Vicon Motion Systems, Lake Forest, Calif.

[c] MATLAB, version 4.2, MathWorks Inc, Natick, Mass.

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