Objective assessment of the compensatory effect of clinical hind limb lameness in horses: 37 cases (2011–2014)

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OBJECTIVE
To characterize and describe the compensatory load redistribution that results from unilateral hind limb lameness in horses.

DESIGN
Retrospective case series.

ANIMALS
37 client-owned horses.

PROCEDURES
Medical records were reviewed to identify horses with unilateral hind limb lameness that responded positively (by objective assessment) to diagnostic local anesthesia during lameness evaluation and that were evaluated before and after diagnostic local anesthesia with an inertial sensor-based lameness diagnosis system. Horses were grouped as having hind limb lameness only, hind limb and ipsilateral forelimb lameness, or hind limb and contralateral forelimb lameness. Measures of head and pelvic movement asymmetry before (baseline) and after diagnostic local anesthesia were compared. The effect of group on baseline pelvic movement asymmetry variables was analyzed statistically.

RESULTS
Maximum pelvic height significantly decreased from the baseline value after diagnostic local anesthesia in each of the 3 lameness groups and in all horses combined. Minimum pelvic height significantly decreased after the procedure in all groups except the hind limb and contralateral forelimb lameness group. Head movement asymmetry was significantly decreased after diagnostic local anesthesia for horses with hind limb and ipsilateral forelimb lameness and for all horses combined, but not for those with hind limb lameness only or those with hind limb and contralateral forelimb lameness.

CONCLUSIONS AND CLINICAL RELEVANCE
Results supported that hind limb lameness can cause compensatory load redistribution evidenced as ipsilateral forelimb lameness. In this population of horses, contralateral forelimb lameness was not compensatory and likely reflected true lameness. Further studies are needed to investigate the source of the contralateral forelimb lameness in such horses. (*J Am Vet Med Assoc* 2016;249:940–944)

Although assessment of multilimb lameness is frequently performed in clinical practice, it can be challenging, and it is essential to consider the effect of compensatory lameness to correctly identify the primary lame limb. Recently, our group investigated the effect of forelimb lameness on pelvic movement asymmetry in a clinical population of equine patients.[1] However, hind limb compensatory lameness has not been extensively characterized in a substantial number of clinical patients, although it is commonly referred to and described by the so-called law of sides, which states that, in a horse with apparent forelimb and contralateral hind limb lameness, lameness of the hind limb is frequently compensatory in nature, whereas in a horse with apparent hind limb and ipsilateral forelimb lameness, lameness of the forelimb is frequently compensatory. The compensatory component is not a true lameness.[2–5] In horses with true forelimb lameness, the height of the head is different between stride phases of the right and left forelimbs. The HDmax after the stance phases of the right and left forelimbs changes (increases) with forelimb lameness owing to weaker push-off from the affected forelimb. During the stance phase, there is less downward movement of the head when the horse

ABBREVIATIONS

HDmax	Maximum head height difference
HDmin	Minimum head height difference
PDmax	Maximum pelvic height difference
PDmin	Minimum pelvic height difference

bears weight on the lame limb, as reflected in the minimum head height. This difference in head position during various phases of the stride of the left and right forelimbs is indicative of forelimb lameness.[1]

The objective of the study reported here was to characterize the compensatory load redistribution that results from hind limb lameness and to describe its effect on head movement in horses. We hypothesized that hind limb lameness would result in substantial load redistribution, which would be observed as ipsilateral forelimb lameness.

Materials and Methods

Case selection

Medical records of horses that underwent lameness investigations between September 1, 2011, and October 31, 2014, at the University of Glasgow were reviewed to identify patients that had been instrumented for evaluation with an inertial sensor-based lameness diagnosis system.[a] The system was shown to provide repeatable and reliable data[6–8] and was previously used in conjunction with diagnostic anesthesia for clinical evaluation of horses with lameness[1,9]; it was thus deemed to be a suitable technique for a clinical kinematic study.

All horses investigated for lameness at the hospital where the study was performed were trotted in a straight line on a hard surface as part of the lameness investigation and had been instrumented with the inertial sensor-based system if time permitted and the client consented. Only horses that had data recorded for ≥ 30 strides before (baseline) and after local anesthesia for lameness evaluation were considered for study inclusion. Horses diagnosed as having unilateral hind limb lameness with a positive response to diagnostic local anesthesia of the affected hind limb (as identified both subjectively and objectively) were included in the analysis. Each horse that met the inclusion criteria was included in the study only once. Lameness classification was determined on the basis of analysis of the kinematic data obtained when the horse was trotted in a straight line on a hard surface. For horses deemed to have primary hind limb lameness, investigation commenced with the hind limb. Horses determined to have primary forelimb lameness by the investigating clinician had the forelimb lameness investigated first, and these horses were excluded from the study.

Medical records review

Information retrieved from the medical records included signalment, results of diagnostic local anesthesia, and final diagnosis for each horse. Inertial sensor-based data that were converted to kinematic data by the system[a] were collected. Analysis of specific variables was undertaken. The mean HDmax after the stance phases of the right and left forelimbs and the mean HDmin during the stance phases of the right and left forelimbs were reviewed. The difference in maximum head height was established by comparing the maximum head height after weight bearing of the right limb with the maximum head height after weight bearing of the left limb. The difference in minimum head height was similarly ascertained by comparing the minimum head height during weight bearing of the right and left forelimbs. The mean PDmax after the stance phases of the right and left hind limbs and mean PDmin during the stance phases of the right and left hind limbs were also reviewed. The latter 2 variables were used as a measure of pelvic movement asymmetry. As a measure of head movement asymmetry, the vector sum of HDmax and HDmin was calculated as previously described[1] and assigned to the left or right forelimb according to the sign of the HDmin within a given trial. A negative HDmin value implies the forelimb lameness is of left forelimb origin (hence a negative sign is assigned to vector sum), whereas a positive HDmin value implies that the forelimb lameness is right in origin (vector sum remains positive).

Procedures

Variables were measured with the inertial sensor-based system as described elsewhere.[1] Briefly, the system consists of 2 accelerometers (1 placed on the midline between the tubera sacrale and 1 on the midline of the highest point of the head between the ears, attached to a felt head bumper produced by the system manufacturer), and a gyroscope placed on the pastern of the right forelimb. The system records the maximum and minimum head and pelvic heights for each limb in the vertical plane and calculates the previously described movement asymmetry measures (HDmax and HDmin between the forelimbs and PDmax and PDmin between the hind limbs). Data from 1 trial/horse were obtained. Evidence of unilateral hind limb lameness was objectively defined as pelvic movement asymmetry > 0.17 mm and a maximum or minimum pelvic height greater than the absolute value of 3 mm.[10] A positive response to diagnostic local anesthesia of the hind limb was defined as a change in pelvic movement asymmetry assigned to the regionally blocked limb to a value below the threshold (≤ 0.17 mm) or a decrease in maximum or minimum pelvic height of > 50% (selected on the basis of the authors' subjective experience). Forelimb lameness was defined as a vector sum of HDmax and HDmin > 8.5 mm during the baseline examination.[7]

For study purposes, all horses were grouped as having primary hind limb lameness only, hind limb and ipsilateral forelimb lameness, or hind limb and contralateral forelimb lameness on the basis of data obtained with the motion analysis system and the described lameness classification criteria. This was undertaken to analyze scenarios typically encountered in clinical practice.

For the mean PDmax and PDmin, corrections were made to account for whether the right or left hind limb was lame at the baseline examination. All hind limb data for horses with left hind limb lameness were multiplied by –1, so that values for horses with right and left hind limb lameness could be compared within the same analysis. This was necessary because the inertial sensor-based system allocates a negative value to lameness of left origin, and there was no need to distinguish the origin (left or right) of the lameness in this analysis. The vector sum of HDmax and HDmin for forelimb lameness classified as left in origin (on the basis of the sign of the HDmin on baseline examination) was similarly multiplied by –1 to allow lameness of left and right origin to be combined for analysis. Subsequently, changes in each of the measured variables following diagnostic local anesthesia were calculated for horses with lameness of the hind limb only, hind limb and ipsilateral forelimb, and hind limb and contralateral forelimb lameness groups by subtracting the baseline measurements from the postanesthetic measurements. These data were also analyzed for all horses combined, regardless of group. A negative change in PDmax or PDmin signified improvement from the baseline degree of hind limb lameness, regardless of whether the lameness was left or right in origin. A positive change in vector sum signified worsening of the forelimb lameness, regardless of the origin of the lameness.

Statistical analysis

A Shapiro-Wilk test was performed to assess the distribution of the data. Nonnormally distributed baseline data included vector sum (hind limb lameness only and hind limb and contralateral forelimb lameness groups), PDmin (hind limb lameness only group, hind limb and ipsilateral forelimb lameness group, and all horses combined), and PDmax (all horses combined). Data for the change to specific variables following diagnostic anesthesia were nonnormally distributed for PDmin (hind limb and ipsilateral forelimb lameness group and all horses combined) and vector sum (all horses combined).

The effect of group on baseline PDmax and PDmin was tested by ANOVA on ranks with a Dunn post hoc test. The effect of diagnostic anesthesia on vector sum, PDmax, and PDmin for each lameness group (hind limb only, hind limb and ipsilateral forelimb, or hind limb and contralateral forelimb) and for all horses combined was assessed with a paired *t* test or with a Wilcoxon signed rank test as appropriate.

Correlation analysis of the change in hind limb lameness variables (ie, PDmax and PDmin individually) with the change in vector sum following diagnostic local anesthesia was performed separately for each lameness group. Pearson analysis was used for the hind limb only and hind limb with contralateral forelimb lameness groups. Spearman analysis was used to assess correlation of the change in vector sum with the change in PDmin for the hind limb and ipsilateral forelimb lameness group, whereas the association with changes in PDmax was analyzed by Pearson analysis for this group. Correlation of the change in vector sum with the change in PDmin and the change in PDmax was evaluated by Spearman and Pearson analysis, respectively, for all horses combined. Statistical analyses were performed with commercially available statistical software.[b] Values of $P < 0.05$ were considered significant.

Results

Thirty-seven horses of various breeds and ages were included in the 3-year retrospective study. Eighteen horses had a diagnosis of suspensory ligament desmitis made following perineural anesthesia of the deep branch of a lateral plantar nerve, 17 were determined to have osteoarthritis of the distal hock joints after local anesthetic injection of a tarsometatarsal joint, and 1 was determined to have annular ligament constriction after undergoing injection of a digital flexor tendon sheath, with subsequent positive responses. One horse had fragmentation of the plantar aspect of P1 diagnosed following a positive response to a 6-point nerve block. Diagnoses were made on the basis of results of radiography, ultrasonography, or both. In horses undergoing surgical exploration and treatment, the findings were also confirmed during these procedures.

The group of horses with primary hind limb lameness alone comprised 8 mares and 11 geldings from 4 to 22 years of age (5 warmblood-type horses, 4 Thoroughbreds or Thoroughbred crosses, and 1 each of other breeds or crosses [Clydesdale, Friesian, Cob, Welsh pony, and Connemara-Dutch Warmblood cross] as well as 4 sport horses and 1 pony of unspecified breed). Nine of these horses had left hind limb lameness (osteoarthritis of the distal hock joints [n = 5], suspensory ligament desmitis [3], or annular ligament constriction [1]), and 10 had right hind limb lameness (suspensory ligament desmitis [n = 5] or osteoarthritis of the distal hock joints [5]).

The group of horses with hind limb and ipsilateral forelimb lameness included 6 mares and 4 geldings from 5 to 15 years of age (3 Thoroughbreds or Thoroughbred crosses, 3 warmblood-type horses or warmblood-type crosses, 3 ponies of unspecified breeding, and 1 Cob). Six horses in the group had left hind limb lameness (osteoarthritis of the distal hock joints [n = 3], suspensory ligament desmitis [2], or fragmentation of the plantar aspect of P1 [1]), and 4 had right hind limb lameness (osteoarthritis of the distal hock joints [n = 2] or suspensory ligament desmitis [2]).

The group of horses with hind limb and contralateral forelimb lameness comprised 3 mares and 5 geldings from 7 to 22 years of age (5 Thoroughbreds or Thoroughbred crosses, 2 warmblood-type horses, and 1 sport horse of unspecified breeding). Four of these horses had left hind limb lameness (all with suspensory ligament desmitis), and 4 had right hind limb lameness (suspensory ligament desmitis [n = 2] or osteoarthritis of the distal hock joints [2]).

The PDmax was significantly ($P < 0.01$ for all comparisons) decreased from the baseline value in each of the 3 lameness groups and in all horses combined ($P < 0.001$) following diagnostic local anesthesia **(Table 1)**. The PDmin was significantly ($P < 0.005$) decreased from baseline after the local anesthetic injection in horses with hind limb lameness only and in those with hind limb and ipsilateral forelimb lame-

Table 1—Summary of data acquired through use of an inertial sensor-based lameness diagnosis system and analyzed in a retrospective study to characterize compensatory load redistribution resulting from hind limb lameness and describe its effect on head movement in 37 client-owned horses.

		Lameness group		
Variable and time point	**All horses**	**Hind limb only (n = 19)**	**Hind limb and ipsilateral forelimb (n = 10)**	**Hind limb and contralateral forelimb (n = 8)**
Vector sum (mm)				
Baseline	8.36 (5.61 to 12.60)	5.68 (4.10 to 6.34)	11.99 (9.58 to 14.51)	15.31 (11.28 to 19.83)
Postinjection	6.20 (1.38 to 11.19)*	3.07 (–0.55 to 5.88)	8.70 (–7.17 to 10.70)*	16.46 (11.90 to 18.85)
PDmax (mm)				
Baseline	5.10 (2.95 to 8.77)	5.10 (2.71 to 8.32)	6.09 (2.99 to 9.05)	4.60 (2.68 to 9.48)
Postinjection	2.20 (–0.81 to 4.29)*	2.20 (–0.18 to 3.61)*	3.08 (–3.32 to 4.73)*	0.08 (–3.26 to 6.45)*
PDmin (mm)				
Baseline	1.27 (0.37 to 3.32)	1.27 (0.58 to 3.13)	1.05 (–0.50 to 2.64)	2.74 (–0.43 to 3.45)
Postinjection	–0.30 (–3.51 to 1.29)*	–0.81 (–3.30 to 1.06)*	–1.33 (–3.93 to 0.19)*	1.15 (–1.75 to 2.56)

All horses underwent diagnostic local anesthesia as part of a clinical evaluation for naturally occurring unilateral hind limb lameness. Results (median [interquartile range]) are reported from assessment of 37 trials (of ≥ 30 strides/horse) before (baseline) and after postinjection diagnostic local anesthesia in the affected region of the lame hind limb. Eighteen horses had perineural anesthesia of the deep branch of a lateral plantar nerve, 17 had local anesthesia of the tarsometatarsal joint, 1 underwent injection of a digital flexor tendon sheath, and 1 had a low 6-point nerve block performed. The PDmax and PDmin were recorded after and during the stance phase of the stride, respectively. The vector sum of HDmax and HDmin, a measure of head movement asymmetry, was calculated as described elsewhere.[1]

*Within a variable for a given group, the postinjection value differs significantly ($P < 0.05$) from that at baseline.

ness as well as in all horses combined ($P < 0.001$), but the difference was nonsignificant ($P = 0.054$) for the group of horses with hind limb and contralateral forelimb lameness. Head movement asymmetry (vector sum) was significantly decreased after injection for horses with hind limb and ipsilateral forelimb lameness ($P < 0.05$) and for all horses combined ($P < 0.01$), but there was no significant change in this variable among horses with hind limb lameness only or those with hind limb and contralateral forelimb lameness. There were no significant differences in PDmax or PDmin at baseline among the 3 lameness groups or between any group and all horses combined. No correlations were identified between the changes in these hind limb variables and change in vector sum following diagnostic anesthesia in any of the groups.

Discussion

Forelimb lameness (as assessed by head movement asymmetry [vector sum] data) that responded substantially to diagnostic local anesthesia of the affected region of the lame hind limb was identified in 10 of 37 (27%) horses with unilateral hind limb lameness (ie, the hind limb and ipsilateral forelimb lameness group) in the present study. This result may have been influenced by the referral nature of the caseload at the study hospital, but the finding suggested that compensatory forelimb lameness is fairly common in horses with hind limb lameness and is thus an important phenomenon. The vector sum was significantly reduced for horses with hind limb and ipsilateral forelimb lameness and for all horses combined following local anesthesia of the affected hind limb. Although this change was not detected in the group of horses with hind limb and contralateral forelimb lameness or in horses with hind limb lameness alone, the results provided evidence to suggest that hind limb lameness causes compensatory forelimb lameness in some horses. The reason for the lack of significant change in head movement asymmetry in 2 of the 3 groups could not be explained by differences in the severity of hind limb lameness because there were no significant differences in variables used to measure hind limb lameness at baseline among any of the groups.

The small number of horses in 2 of 3 lameness groups was a limitation of the study. The smallest group comprised horses with hind limb and contralateral forelimb lameness (n = 8). Many horses with primary forelimb lameness will have evidence of (compensatory) contralateral hind limb lameness, and this phenomenon is fairly common.[1] Clinicians frequently investigate the forelimb lameness in horses that have forelimb and contralateral hind limb lameness, as an affected forelimb is frequently the source of the apparent hind limb lameness observed. This may in part explain the relatively low numbers of horses in the hind limb and contralateral forelimb lameness group in the present study because clinical bias often leads to investigation of forelimb lameness in these horses. However, our goal was to incorporate clinical scenarios encountered during lameness examinations in the investigation, and we believed that analysis of horses grouped according to these lameness characteristics was therefore necessary.

Our data indicated that the forelimb lameness observed in horses with hind limb and contralateral forelimb lameness did not reflect compensation for primary hind limb lameness. Although not investigated in this retrospective study, we speculate that such horses likely have primary forelimb lameness in addition to hind limb lameness, and further investigation of this source of forelimb lameness in a larger study is warranted.

No correlations were identified between the changes to the measures of hind limb movement asymmetry (PDmax or PDmin) and changes to the vector sum data following diagnostic anesthesia in any of the groups. Therefore, although the study results indicated that there was a relationship between hind limb and forelimb lameness in some horses, the interdependence of the variables representing hind limb and forelimb lameness was not positively established. Examination of other kinematic variables may provide explanations and is thus warranted.

In addition to the small population of horses meeting the study criteria, limitations to the analysis and findings of the study included the fact that the data were obtained from a referral institution where multilimb lameness is frequently assessed. Variations in horse movement in this study, where the inclusion criteria included a minimum of only 30 strides for each horse, may have resulted in the measured data being more variable than the true stride data. Twenty-five strides are deemed adequate for accurate assessment by the manufacturers of the inertial sensor-based system used in this study, provided the movement is consistent. It was unknown whether outliers were removed by the user at the time of instrumentation when a horse made an unexpected stride because of environmental conditions. The system does automatically remove obvious outliers, but a user has the ability to change this threshold. The correction algorithms within the software thus reduce the influence of head shaking, but erratic head movements may nevertheless pose a problem in some cases. Collecting data from ≥ 2 trials/horse or collecting a larger number of strides per trial may have reduced such effects if they occurred. Considering that certain conditions are bilateral, a positive response to diagnostic local anesthesia in some horses might have revealed some degree of lameness of the contralateral hind limb and could have resulted in a more marked change to the measured variables than in horses with a true unilateral condition. This could have caused changes in some variables to be overrepresented; however, because directionality of the vertical pelvic and head movement asymmetry variables was taken into account through adjustment of the signs allocated to the left limb, this should have affected only the head or pelvic movement data by the magnitude of the change in a given variable being larger in a horse with a bilateral lameness than in one with unilateral lameness.

The results of the present study supported that substantial load redistribution as a result of clinical hind limb lameness results in apparent ipsilateral forelimb lameness in some horses. The results of the study thus supported the so-called law of sides. Contralateral forelimb lameness in this population of horses with unilateral hind limb lameness was not compensatory, and further studies should investigate whether such contralateral forelimb lameness is true forelimb lameness.

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Footnotes

a. Lameness Locator, Equinosis LLC, St Louis, Mo.
b. SigmaPlot 11.2, Systat Software LLC, San Jose, Calif.

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