

# Accuracy of pressure plate kinetic asymmetry indices and their correlation with visual gait assessment scores in lame and nonlame dogs

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**Objective**—To determine the accuracy of pressure plate kinetic asymmetry indices (ASIs) for diagnosis of unilateral hind limb lameness in dogs and their correlation with visual gait assessment (VGA) scores.

**Animals**—9 healthy dogs and 16 dogs with previously diagnosed unilateral rupture of the cranial cruciate ligament and concurrent unilateral hind limb lameness.

**Procedures**—Dogs were walked over a pressure plate to determine paw contact area (PCA), peak vertical pressure (PVP), peak vertical force (PVF), and vertical impulse (VI) of both hind limbs. An ASI was calculated for each gait variable. Simultaneously, gait was assessed visually and scored by use of a numeric rating scale (0 to 10). The ASI of each variable was tested for its usefulness in discrimination between lame and nonlame dogs and for correlation with VGA scores.

**Results**—Sensitivity and specificity of ASIs to discriminate between lame and nonlame dogs were excellent for PVF, VI, and PCA; these values were substantially lower for ASI of PVP. Cutoff values to discriminate between lame and nonlame dogs were determined by use of ASIs for PVF, VI, and PCA; however, this could not be done for ASI of PVP. Correlations between ASIs of PVF, VI, and PCA and VGA scores were higher than correlation between the ASIs of PVP and VGA scores.

**Conclusions and Clinical Relevance**—Results indicated that ASIs of PVF and VI determined via analysis of pressure plate measurements were reliable indicators of clinical lameness in dogs, but the ASI of PVP was not. The ASI of PCA is an interesting new variable for assessment of limb loading symmetry. (*Am J Vet Res* 2011;72:820–825)

Pressure plates may provide a practical alternative to force plates for gait analysis because simultaneous, consecutive, and collateral foot strikes can be recorded in a single passage over a walkway, requiring fewer trials, compared with traditional single-stride force plate analysis. Other distinct advantages over force plate analysis include the ability to evaluate load distribution among the pads in dogs<sup>1</sup> and the potential for evaluating dogs with neurologic diseases in which spatiotemporal gait variables are altered.<sup>2</sup> Therefore, pressure-measuring equipment will most likely continue to gain popularity in veterinary practices involved in clinical trials, sports medicine, and rehabilitation,<sup>3</sup> offering clinicians a rea-

## ABBREVIATIONS

ASI	Asymmetry index
CCL	Cranial cruciate ligament
PCA	Paw contact area
PVF	Peak vertical force
PVP	Peak vertical pressure
VI	Vertical impulse

sonably priced, quick, portable, and objective means of gait evaluation for routine clinical applications.

Because decreases in PVF and VI have been associated with lameness in dogs, these variables are commonly assessed in gait analysis.<sup>4–8</sup> Furthermore, vertical force ASIs recorded on a treadmill with embedded force plates were reported to have high diagnostic accuracy for detection of lameness in dogs,<sup>9</sup> and this sophisticated equipment allows a user to evaluate ground reaction forces of successive strides in dogs.<sup>10–12</sup> However, research is still needed to ascertain whether treadmill gait is comparable to overground gait.<sup>13</sup>

Previous studies<sup>14,15</sup> on the use and validity of pressure plates as practical tools to objectively evaluate kinetic symmetry in horses have established a basis for similar pressure measurements in dogs. Various com-

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mercially available pressure-measuring devices have already been evaluated for use in dogs<sup>6,16</sup> and cats.<sup>17</sup> However, to the authors' knowledge, the results of detailed analysis on the use of pressure plate data to evaluate dogs with various degrees of unilateral hind limb lameness and to discriminate between lame and nonlame dogs have not been described. Therefore, the objective of the study reported here was to assess the accuracy of PVF, VI, PVP, and PCA ASIs determined by use of a pressure plate under clinical conditions to discriminate between nonlame dogs and dogs with various degrees of unilateral hind limb lameness and to evaluate the correlation between ASIs and visual gait assessment scores.

## Materials and Methods

**Dogs**—After informed consent was obtained from owners, 16 client-owned dogs with chronic unilateral hind limb lameness attributable to CCL disease and 9 healthy dogs without signs of lameness were included in the present study. Health and lameness status were determined on the basis of physical examination by a veterinarian. The lame dogs were part of a larger study on various analgesic protocols used to treat perioperative and postoperative pain. The diagnosis of unilateral CCL rupture in these dogs was determined on the basis of history, physical examination, and results of radiographic evaluation and was confirmed via surgical exploration of the affected joint. All lame dogs were free of other orthopedic and neurologic abnormalities, including CCL rupture in the contralateral limb. Both studies were approved by an institutional animal care and use committee.

**Measuring protocol and data evaluation**—A pressure plate<sup>a</sup> was embedded flush and in the middle of a 20 × 2-m runway and covered with a 5-mm rubber mat as described previously.<sup>14</sup> The pressure plate (1.95 × 0.32 m with 2.6 sensors/cm<sup>2</sup> sampling data at 125 Hz over its complete length) was calibrated according to manufacturer's specifications and was connected to a portable computer with dedicated software.<sup>b</sup> The velocity measurement system consisted of 2 pairs of photoelectric sensors<sup>c</sup> that were placed as 2 gates perpendicular to the runway 2 m apart, centered over the measuring area and connected to an electronic timing box.<sup>d</sup> Although acceleration was not measured, the 20-m-long track ensured that the effect of acceleration and deceleration at the start and end of each trial was minimized.

After a 5-minute warm-up period, dogs were walked over the pressure plate by 1 experienced handler. One trial was defined as a dog walking the entire length of the 20-m track in 1 direction. A trial was considered valid if the dog moved in a straight line at a visually constant pace, the 4 paws fully contacted the plate surface, and gait velocity values were within a predetermined range of 0.2 m/s of the first velocity measurement obtained for that dog.

As the dog was walked over the measuring system (before kinetic information was available), the gait was assessed visually by an experienced observer (MO) and scored by use of a numeric rating scale from 0 (no lame-

ness) to 10 (constant non-weight-bearing lameness).<sup>18</sup> Dogs with constant non-weight-bearing lameness (score, 10/10) were excluded from the study. The first 5 valid measurements of both hind limbs were analyzed.

**Statistical analysis**—Left and right hind limb PVP (N/cm<sup>2</sup>), PVF (N), VI (N•s), and PCA (cm<sup>2</sup>) were obtained for each dog by use of commercially available software.<sup>b</sup> For each set of 5 valid measurements, mean values were calculated for the left and right hind limbs separately and were considered representative for that limb in that dog. Asymmetry indices were calculated for all variables by use of the following equation<sup>19</sup>:

$$\text{ASI} = (0.5 \times [X_l - X_r]) / (X_l + X_r) \times 100\%$$

where  $X_l$  = mean of a given gait variable for 5 valid measurements of the left hind limb and  $X_r$  = mean of a given gait variable for 5 valid measurements of the right hind limb. According to this method, an ASI of 0% indicates perfect gait symmetry for the measured variable, whereas positive or negative values indicate right or left hind limb lameness, respectively. Possible values ranged from -50% to 50%. For subsequent statistical analysis, the absolute value of the ASI was used and thus the difference between left and right hind limb lameness was disregarded.

Statistical analysis was performed by use of specific software,<sup>c</sup> with values of  $P < 0.05$  considered significant. Body mass and gait velocity of lame dogs were compared to those of nonlame dogs by use of a Student *t* test, as the assumption of normal distribution of these

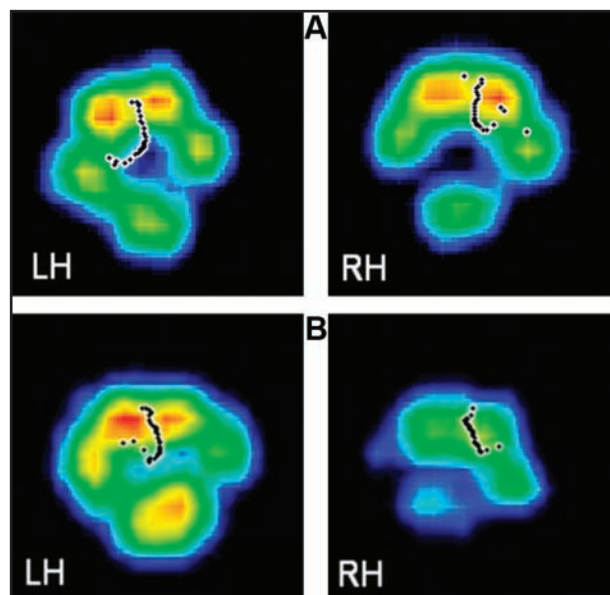


Figure 1—Left (LH) and right (RH) hind limb pressure plate recordings from a representative nonlame dog (A) and from a representative dog with right hind limb lameness (visual gait assessment score, 6/10; B). In panel A, PCAs and pressures were similar for both hind limbs of the nonlame dog. In panel B, a decrease in PCA and lower pressure applied by the right hind limb, compared with the left, is evident. Pressure plate recordings were evaluated in 25 dogs (16 lame and 9 nonlame) of various breeds. Pressure was color coded as follows: dark blue, light blue, green, yellow, orange, and red, where dark blue represents the lowest value and red represents the highest value. Crosses in the center of the contact area represent the path of the center of pressure during the stance phase.

variables could not be rejected by use of rankit plots and Kolmogorov-Smirnov and Shapiro-Wilk tests.

Data are reported as mean  $\pm$  SD unless otherwise indicated. Correlations between visual gait assessment scores and ASIs were evaluated by use of the Spearman rank correlation coefficient.

The sensitivity and specificity of the ASIs of PCA, PVP, PVF, and VI for detection of lameness were determined for various cutoff values. The optimal cutoff value was assessed via receiver operating characteristic curve analysis.<sup>1</sup> The true-positive rate (sensitivity; the probability of classifying a lame dog as lame) was plotted as a function of the false-positive rate (1 – specificity; the probability of classifying a nonlame dog as lame) for various cutoff points.<sup>9</sup> Logistic regression analysis was used to predict the probability of a dog being correctly classified as lame or nonlame on the basis of the ASIs of PCA, PVP, PVF, and VI as indicated by use of the visual gait assessment scores.

## Results

Pressure plate recordings were obtained for the left and right hind limb of each dog (Figure 1). The 16 lame dogs (age,  $6 \pm 2$  years; 7 males and 9 females) were of vari-

ous large breeds (3 each of mixed breed, Golden Retriever, and Labrador Retriever; 2 Boxers; and 1 each of Argentine Dog, Border Collie, Bouvier, German Shepherd Dog, and Weimaraner). The 9 nonlame dogs (age,  $3 \pm 1$  years; 7 males and 2 females) were all Golden Retrievers. The median visual gait assessment score for lame dogs was  $5.5$  (range, 2 to 7). The mean gait velocity of lame dogs ( $1.4 \pm 0.3$  m/s) was significantly ( $P < 0.001$ ) lower than that of nonlame dogs ( $1.8 \pm 0.1$  m/s). Mean body mass of lame dogs ( $35.1 \pm 8.3$  kg) was significantly ( $P < 0.010$ ) higher than that of nonlame dogs ( $28.5 \pm 3.1$  kg). Among nonlame dogs, mean ASIs of PCA, PVP, PVF, and VI were  $-0.26 \pm 0.59\%$  (range, 0.06% to 1.34%),  $0.65 \pm 1.59\%$  (range, 0.11% to 2.42%),  $0.33 \pm 1.66\%$  (range, 0.51% to 2.94%), and  $0.05 \pm 1.45\%$  (range, 0.04% to 2.25%), respectively. Among lame dogs, mean ASIs of PCA, PVP, PVF, and VI were  $10.39 \pm 5.67\%$  (range, 2.17% to 19.78%),  $10.00 \pm 7.89\%$  (range, 0.75% to 25.60%),  $18.36 \pm 9.70\%$  (range, 4.60% to 33.60%), and  $22.23 \pm 11.62\%$  (range, 4.82% to 38.04%), respectively.

Asymmetry indices of PCA, PVF, and VI classified left or right hind limb lameness correctly in all cases, whereas the ASI of PVP was not in agreement with the

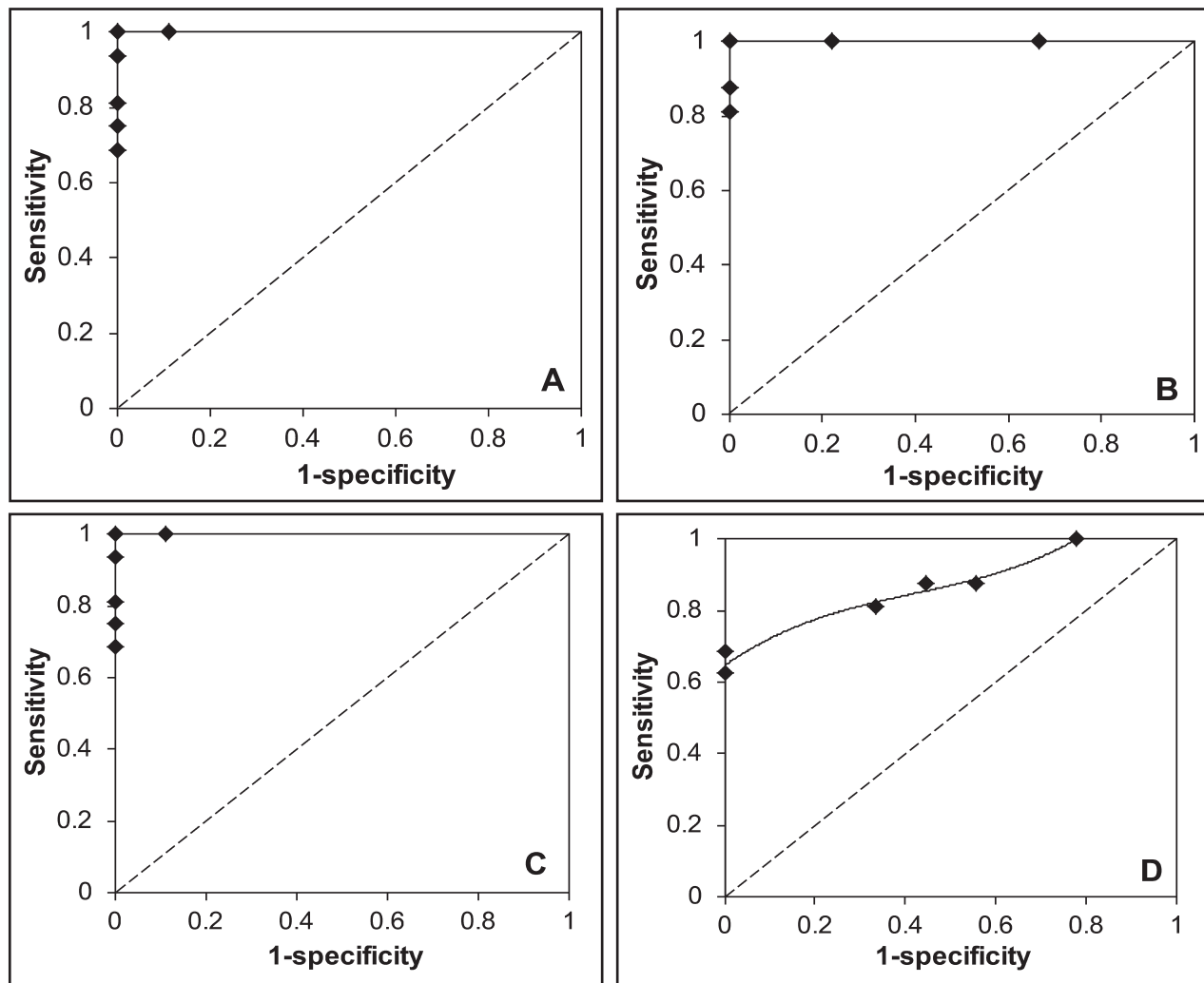


Figure 2—Receiver operating characteristic curve indicating usefulness of the ASIs of PCA (A), PVF (B), VI (C), and PVP (D) to distinguish lame ( $n = 16$ ) from nonlame (9) dogs. The closest point to the upper left corner (100% sensitivity and 100% specificity) represents the maximal accuracy of the diagnostic variable. The dashed diagonal line corresponds to the line of nondiscrimination.

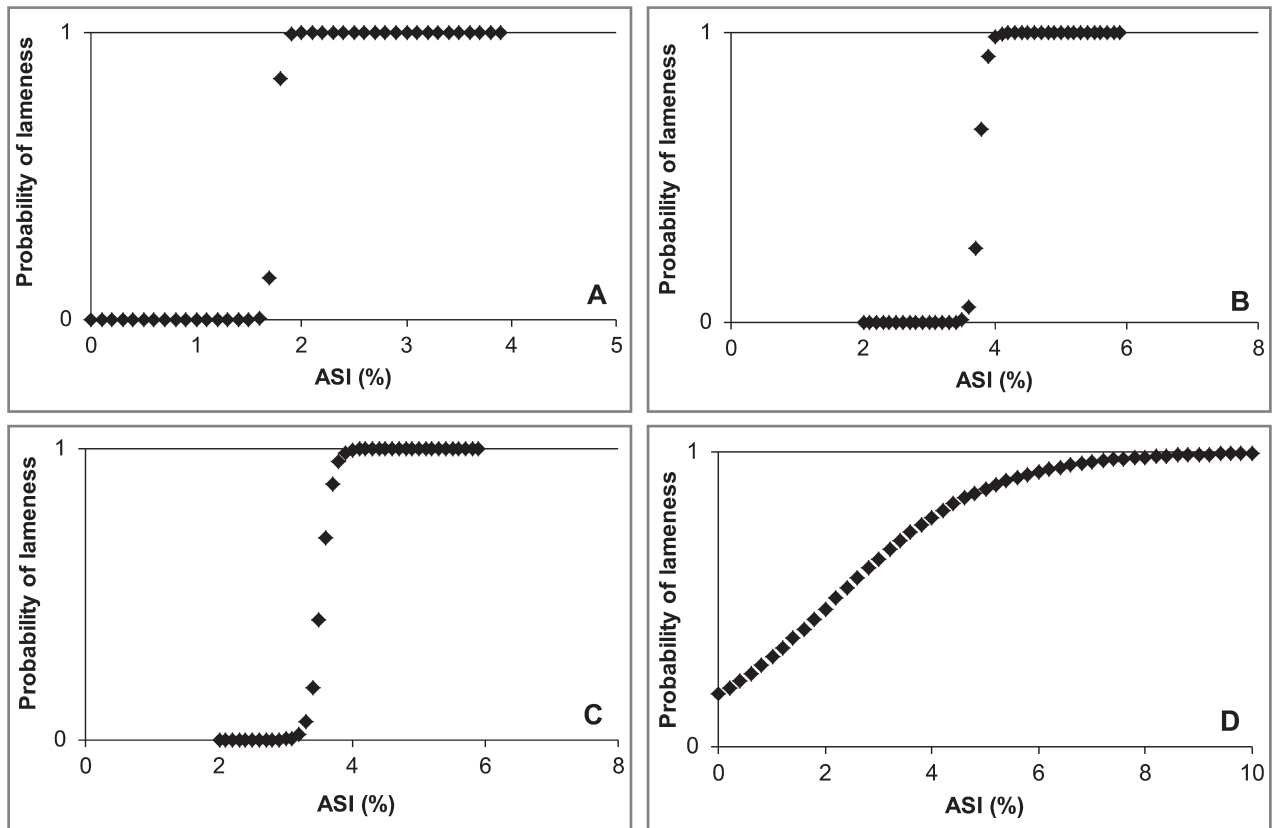


Figure 3—Logistic regression analysis of the ASIs of PCA (A), PVF (B), VI (C), and PVP (D) in the same 25 dogs in Figure 2. A clear cutoff value can be distinguished for PCA (approx 1.7%), PVF (approx 3.7%), and VI (approx 3.5%), whereas for PVP, a gradual transition pattern (ie, lack of a clear cutoff value to discriminate between lame and nonlame dogs) is evident.

visual gait assessment score in 1 dog. Correlations between visual gait assessment scores and the ASIs of PVF, VI, and PCA were high ( $r = 0.937, 0.919, \text{ and } 0.894$ , respectively;  $P < 0.001$ ), but the correlation between visual gait assessment scores and the ASI of PVP was lower ( $r = 0.761$ ;  $P < 0.001$ ).

Receiver operating characteristic curve analysis revealed that ASIs of PCA, PVF, and VI all provided 100% sensitivity and specificity at cutoff points of approximately 2% for PCA and between 3% and 4% for PVF and VI, whereas the maximum sensitivity and specificity were considerably lower for ASI of PVP (Figure 2). For ASI of PVP, the maximum sum of sensitivity and specificity was 1.6875.

Logistic regression was used to refine optimal cutoff values and revealed a distinct cutoff value for discrimination between lame and nonlame dogs for the ASIs of PCA (approx 1.7%), PVF (approx 3.7%), and VI (approx 3.5%), whereas a cutoff value could not be established for ASI of PVP, for which a more gradual curve pattern was observed (Figure 3).

## Discussion

In the study reported here, dogs with various degrees of unilateral hind limb lameness due to CCL rupture and a control group of healthy nonlame dogs were assessed by use of a traditional visual gait assessment scoring system and by use of ASIs determined via pressure plate analysis.

In an earlier kinetic study<sup>19</sup> in nonlame dogs, mean vertical ASIs deviated  $< 8\%$  from perfect symmetry for all kinetic variables. This is similar to reported degrees of symmetry in joint angular moments<sup>20</sup> and vertical forces under the paw pads in walking dogs.<sup>1</sup> However, sophisticated inverse dynamic analysis to calculate joint moments and powers has shown that some degree of asymmetry is evident even in nonlame dogs.<sup>21</sup> Asymmetry indices in the present study were similar to those reported in the earlier kinetic study<sup>19</sup> and showed clear differences between lame and nonlame dogs, with only minimal overlap between values for lame and nonlame dogs. Although a limited number of dogs was used, ASIs of PCA, PVF, and VI were excellent predictors for objective gait assessment and diagnosis of lameness. The optimal cutoff value of ASI of PVF of approximately 3.7% in the present study was similar to that reported in a study<sup>22</sup> in which an instrumented treadmill was used to obtain measurements. Results of the present study indicated that the ASI of PVP had important limitations in the ability to discriminate between lame and nonlame dogs. However, our results suggesting that ASIs of PVF, VI, and PCA are reliable indicators of clinical lameness in dogs with unilateral CCL rupture provide a basis for further research in a larger group of dogs with different degrees and different types of fore- and hind limb lameness. Moreover, the possibility of analyzing overlapping fore- and hind limb paw strikes and even consecutive strides, dramatically reducing the number of trial repetitions required ( $\leq 5$  trials/dog in the present study)



and the amount of time needed to obtain sufficient data and report results (20 to 30 min/dog, including initial calibration) highlights the advantages of this pressure plate system as a practical tool for rapid acquisition of objective data on limb loading symmetry. This also suggests practicality for widespread use in clinical settings. In addition to considerations such as these, another important drawback of traditional force plate analysis is eliminated in that there is no need for a heavy concrete foundation or laborious installation procedures.

Most lame dogs in the present study were determined to have moderate to severe lameness (median visual gait assessment score, 5.5 [range, 2 to 7]). Dogs were only assessed at walk. In accordance with results of earlier force plate studies,<sup>7,23-25</sup> this enabled swift data collection, even in dogs with moderate to severe lameness. The measurement of consecutive left and right paw strikes and the relative evaluation by use of ASIs as opposed to actual kinetic values for each limb decreases the importance of intertrial variability attributable to slight changes in variables such as gait velocity and acceleration. Moreover, this evaluation method eliminates bias caused by significant differences in body mass and gait velocity between the groups of lame and nonlame dogs, as these differences equally affect left and right limbs evaluated in each trial.

It has been reported that acceleration can influence kinetics, especially in the craniocaudal axis.<sup>26</sup> Therefore, the use of 3 or even 5 photocells has been recommended.<sup>27</sup> However, at a visually constant pace, the effect of acceleration on variables in the vertical axis should not be substantial.<sup>26</sup> Therefore, in the present study, each dog was allowed to walk at its own preferred velocity, and walking in a straight line at a visually constant pace within 0.2 m/s of the first velocity measurement obtained was a necessary condition for each subsequent measurement to be considered valid. Because the degree of lameness varied among dogs, setting a fixed, narrow gait velocity range for all dogs would have made it more difficult to complete a sufficient number of valid trials of all dogs. Gait velocity of nonlame dogs in the present study was at the upper limit of walking gait as a threshold of approximately 2 m/s has been reported at the transition of walking to running gaits,<sup>28</sup> but verification of the footfall sequence on the pressure plate and calculation of duty factors (ie, proportion of the stride for which the limb is in contact with the ground) as > 50% confirmed that all dogs were evaluated at a walk.

Results of the present study indicated good correlation between ASIs for several variables and visual gait assessment scores. This is in contrast with reports of gross discrepancies between human perception and objective force plate analysis as means to evaluate the weight-bearing function of 1 limb expressed as a percentage of body weight<sup>1,4,7,10,16,17,23-26,29</sup> or as a percentage of normal function.<sup>30</sup> These ASIs could provide a more suitable determination of comprehensive locomotion function<sup>9,31</sup> than does the weight-bearing capacity of each individual limb for comparison with clinical visual assessment of symmetric gaits such as a walk or trot. Despite the issue of compensatory overloading of the nonlame limb<sup>4,11</sup> precluding its use as an absolute control, ASIs can be a useful clinical tool to quantify symmetric or asymmetric locomotion.<sup>31</sup>

Although multivariate kinetic analysis, in which several ground reaction force variables are combined, has been shown to be capable of increasing gait analysis accuracy,<sup>24,29</sup> results of the present study are in agreement with other reports<sup>6,9</sup> that indicated PVF and VI are useful variables in kinetic evaluation of limb symmetry, with a high correlation between PVF and VI symmetry ratios and visual gait assessment scores. The lower correlation between the ASI of PVP and visual gait assessment scores and its lower sensitivity and specificity suggest that this variable most likely should not be used for clinical evaluation of lameness in dogs.

In the present study, PCA, PVF, and VI in the lame hind limb were consistently lower than values for the contralateral, nonlame limb in the same dog, resulting in increasing ASIs of these variables as the degree of lameness increased. In contrast, the ASI of PVP often was surprisingly low, even in dogs with severe lameness. Therefore, results of the present study strongly suggest that the decreased loading of a lame limb can be compensated by a concurrent decrease in PCA of the affected limb, and increased loading of the contralateral nonlame limb can be similarly affected by an increased PCA, resulting in misleadingly high PVP symmetry and hence a falsely low ASI for this variable.

In the present study, we determined that ASIs of PVF and VI measured via a pressure plate system are reliable measurements for use in further research and evaluation of this system as a tool for clinical lameness assessment in dogs. Because a pressure plate with high sensor density provides a means for measurement of PCA, the ASI of this variable may provide a highly accurate indicator of canine weight bearing; however, further research is needed before this variable can be taken into consideration for gait assessment. In contrast, the ASI of PVP most likely should not be used for clinical evaluation of lameness in dogs, as confounding compensatory effects may exist in lame dogs.

- a. Footscan 3D 2-m system, RsScan International, Olen, Belgium.
- b. Footscan Scientific Gait 7, RsScan International, Olen, Belgium.
- c. WE260-S270, Sick AG, Waldkirch, Germany.
- d. Timer Interval Meter K3HB-P, Omron Corp, Kyoto, Japan.
- e. S-Plus 8.0 for Windows, Tibco Software Inc, Palo Alto, Calif.
- f. Excel 2007 for Windows, Microsoft Corp, Redmond, Wash.

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