Effect of velocity on ground reaction forces in dogs with lameness attributable to tearing of the cranial cruciate ligament

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Objective—To ascertain the effectiveness of evaluating ground reaction forces (GRFs) at velocities during walking and trotting in dogs with naturally occurring lameness and determine whether walking would provide sufficient motion to adequately characterize GRFs with respect to trotting.

Animals—29 dogs with a naturally occurring tear of the cranial cruciate ligament.

Procedure—Dogs were walked and trotted over a force platform, and GRFs were recorded during the stance phase. Correlation was used to assess the agreement between walking and trotting for GRF. The coefficient of variation was calculated to assess the relative variation of outcome variables among the gaits. Group means for walking GRF were compared between dogs that trotted and that failed to trot.

Results—GRFs during walking and trotting were highly correlated. The coefficient of variation was smaller for GRFs during walking than during trotting. Dogs that failed to trot had significantly smaller mean values of peak vertical force and vertical impulse during walking, compared with values for dogs that were able to trot.

Conclusions and Clinical Relevance—Either velocity is acceptable for GRF evaluation in dogs. Mean GRF during walking was significantly different between dogs that could and could not trot, principally because dogs with the most severe lameness failed to trot. These dogs would be eliminated from a clinical study, and thus, that study would become biased toward dogs that were less lame. In that situation, differences between interventions may be less pronounced, because they would be evaluated on dogs with less lameness. (*Am J Vet Res* 2003;64:1479–1481)

Gait analysis with a force platform is commonly used as an objective method for evaluation of limb function. Without question, subject velocity is 1 variable that investigators must control when performing gait analysis on a force platform. Investigators have evaluated the effect of velocity on the results of force-platform analysis in dogs.[1,2] However, in those studies, investigators evaluated clinically normal dogs. Clinical studies evaluating a treatment effect have used trotting[3,4] and walking[5,6] gaits. Empirically, some dogs with lameness will use the affected limb while walking, but as the gait velocity increases, they will not use the injured limb while trotting. This observation has led us to question whether a particular velocity is superior when quantifying the effect of treatment in a dog with lameness. One theory suggests that as velocity increases, the rigor of the test increases; thus, gait analysis should be performed at a trot. Of course, this is only important when data collected at a walk do not adequately correlate with data collected at a trot.

Trial variation, which has been described in clinically normal dogs,[7] is also important to consider. To our knowledge, no published results address trial variation in dogs with lameness. For example, a dog may be unable or unwilling to use a limb while trotting or may fatigue quickly at a faster velocity, and only incomplete data can be collected for that limb. Then, use or nonuse of that limb is the only pretreatment outcome that can be measured and used for posttreatment comparisons. Also, evaluating lame dogs at the trot with a force platform may be inefficient because of an increase in trial failures (ie, inability to obtain **ground reaction forces [GRFs]** because of alterations in velocity and intermittent use of the lame limb). Incomplete acquisition of data and increases in trial failures would increase trial variation. Furthermore, it is possible that dogs that cannot trot may be more severely lame than dogs that are able to trot, so failure to obtain objective lameness data may bias studies.

The purpose of the study reported here was to ascertain the effectiveness of evaluating GRFs at velocities obtained during walking and trotting in dogs with naturally occurring lameness. We hypothesized that walking would provide sufficient motion to adequately characterize GRFs with respect to trotting and that trial variation in dogs with lameness would be greater at a trot than at a walk.

Materials and Methods

Animals—Twenty-nine dogs were used in the study. Dogs were eligible for inclusion in the study when they met inclusion criteria, which included body weight of > 20 kg, diagnosis of unilateral disease of a cranial cruciate ligament that was not surgically corrected, and no analgesic medication or sedation during the preceding 24 hours. The study was approved by the Iowa State University Committee on Animal Care.

Procedure—Computer-assisted gait analysis by use of a force platform was performed. Dogs walked and trotted over a biomechanical platform[a] embedded in a 10-m walkway. Three sets of retroflective photocell sensors[b] were attached in series and positioned on the walkway. Sensors were 1 m apart, with the middle sensor positioned at the middle of the force plate. Sensors were used to determine velocity and acceleration over the 2-m measurement region.

To control for a possible effect of the order in which dogs walked or trotted, dogs were randomized to 1 of 2

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groups. Dogs of group 1 were walked over the force plate, rested for a minimum of 1 hour, and then trotted over the force plate until 5 acceptable trials were obtained for the left and right limbs. Dogs of group 2 were trotted over the force plate, rested, and then walked over the force plate. Trials were conducted within the velocity range of 1.0 to 1.3 m/s for the walk and 1.7 to 2.0 m/s for the trot. An acceleration range of ± 0.5 m/s^2 was used for all trials. A single handler conducted all trials.

Ground reaction forces for all limbs during the stance phase were recorded[c] for each time a dog walked or trotted over the force plate. Walking and trotting were repeated until 5 valid measurements were obtained for each limb. A trial was considered valid when the feet of the forelimb and ipsilateral hind limb were isolated on the force platform, and gait abnormalities were not detected. The first 5 valid trials for each limb were used for analysis.

A dog was determined to be unacceptable for force-plate analysis (ie, gait data could not be reasonably obtained) when the 141st trial was completed without 5 acceptable trials (for both hind limbs), the affected limb was consistently not used to bear weight during passage over the force plate, fatigue prevented crossing the force plate at the required gait velocity, or there were 20 consecutive unsuccessful trials (for either hind limb).

Statistical analysis—The primary outcome variables were **peak vertical force (PVF)** and **vertical impulse (VI)** measured as the percentage of body weight on the lame limb. Data were analyzed to determine the mean number of trials needed to obtain 5 successful trials for each hind limb, relative variation associated with each gait, proportion of dogs that could provide GRFs at a walk, proportion of dogs that could provide GRFs at a trot, and the correlation between walking and trotting.

Walking GRFs were compared with trotting GRFs on dogs that successfully completed at least 5 trials on the lame limb. The mean value was determined for the 5 trials[8]; thus, each dog had 2 values/limb (ie, mean value for the walking trials, and mean value for the trotting trials) for PVF and VI.

All analyses were performed by use of commercially available software.[d] When appropriate, data were reported as the mean ± SEM. There were 2 parts to the analysis. The first part consisted of analyses of data from dogs that provided GRFs at a walk and trot (5 successful trials at both gaits). A linear correlation analysis (Pearson's **correlation coefficient** [r^2]) was used to determine the relative agreement between the magnitudes of GRFs during walking and trotting. For example, we hypothesized that dogs with relatively large GRFs at a walk would also have relatively large GRFs at a trot.

The coefficient of variation was used to assess relative variation among gaits. The coefficient of variation is a percentage that is used to compare variation among variables with differing scales.

To determine whether dogs that did not trot were more lame than dogs that did trot, the dogs were allocated into 2 groups. Group 1 consisted of dogs that could successfully trot, and group 2 consisted of dogs that failed to trot. Group means for the walking GRFs were compared between these groups by the use of *t* tests.

Finally, we compared the proportion of dogs that could be measured at the walking velocity and the proportion of dogs that could be measured at the trotting velocity. We also compared the mean number of trials required to obtain GRFs for both hind limbs.

Results

All 29 dogs enrolled in the study successfully completed 5 trials for each hind limb at a walk, but only 18 (62%) were able to successfully complete 5 trials for each hind limb at a trot. Thus, the proportion of dogs successfully completing trials at a walk was significantly ($P = 0.04$) higher than the proportion of dogs successfully completing trials at a trot. There were 2 dogs that were able to successfully provide data at the trot at least 5 times (out of a maximum of 141 potential trials) on the lame limb but not on the healthy limb. We were primarily focused on the assessment of the lame limb, so data for these 2 dogs were included in the analyses.

For dogs that could walk and trot, the mean ± SEM number of trials to obtain data for 5 trials at a walk (both limbs) was 45.3 ± 4.7, and the mean number of trials to obtain data for 5 trials at a trot was 57.8 ± 6.0. These mean values did not differ significantly.

Order of the gait (walking followed by trotting or trotting followed by walking) did not have a significant effect on results. Order of the gait did not significantly affect results for PVF (trotting data, $P = 0.99$; walking data, $P = 0.64$) or VI (trotting data, $P = 0.71$; walking data, $P = 0.97$)

Data from 20 dogs were available for correlation analysis for walking and trotting **(Fig 1)**. The points for PVF closely fit a superimposed regression line (r^2, 0.85; $P < 0.001$). Findings were similar for VI (r^2, 0.82; $P < 0.001$).

For PVF, the coefficient of variation for data obtained at a walk was 20%, whereas it was 30% for data obtained at a trot. For VI, the coefficient of variation for data obtained at a walk was 23%, and it was 32% for data obtained at a trot. Therefore, the relative variation for PVF and VI during walking was at least 9% smaller than during trotting.

Mean walking PVF (in Newtons expressed as a percentage of body weight) for dogs that could successfully trot was 30.5 ± 1.2, which was significantly ($P < 0.001$) different from the mean walking PVF for dogs that failed to trot (18.2 ± 1.9). Mean walking VI for dogs that could successfully trot (9.7 ± 0.5) was significantly ($P < 0.001$) different from the mean walking VI for dogs that failed to trot (5.6 ± 0.7).

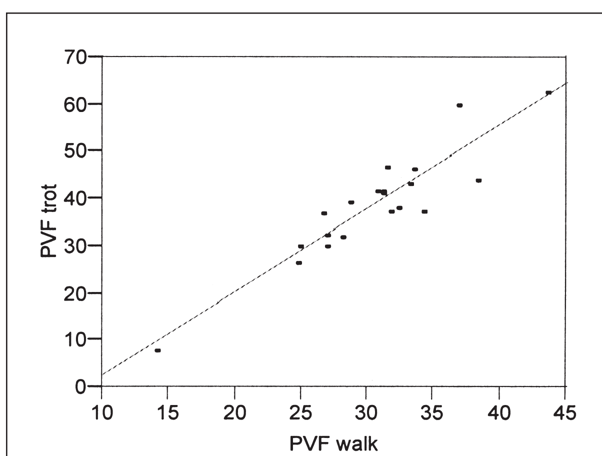

Figure 1—Scatter plot of peak vertical force (PVF, in Newtons expressed as a percentage of body weight) obtained for 20 dogs at a trot and at a walk on a force plate. Each symbol represents the mean of 5 trials at each gait. Notice that values obtained for each gait are highly correlated (r^2, 0.85; $P < 0.001$).

Discussion

The relatively large proportion of dogs (38%) that failed to provide acceptable trotting trials in the study reported here could indicate a potential impact of subject accrual for clinical studies. First, the mean GRF at a walk was significantly different among dogs that could and could not successfully trot; this is essentially because the dogs that were the most severely lame failed to trot. These dogs would be eliminated from a clinical study, and the study would be biased toward dogs that are less lame. In that situation, differences between interventions (eg, treatment and control groups) may be less pronounced, because they would be evaluated on dogs that are less lame. Also, dogs with the poorest outcomes would be eliminated, possibly making a procedure or medication appear better than had the evaluations been performed for dogs at a walk. Second, use of trotting velocity would require many more candidate dogs to accrue the necessary sample size for the study. For example, for a study in which 50 dogs are required, approximately 81 candidate dogs would be needed to perform the study to determine trot velocity (assuming the 38% failure rate reported here). In contrast, a similar study to evaluate 50 dogs at a walk would likely require only 50 candidate dogs.

Ground reaction forces observed at a trot are accepted objective quantities for assessing lameness in dogs. For dogs that are able to complete 5 trotting trials, analysis of correlation results suggests that walking and trotting data for PVF and VI are linearly related and highly correlated (ie, for PVF, 85% of the trotting variation can be accounted for by use of data obtained at a walk, whereas for VI, 82% of the trotting variation can be accounted for by use of data obtained at a walk). An alternative to the method we used would be to decrease the number of acceptable trials from 5 to 2. This would permit dogs that are more severely lame at the trot to provide data for the correlation analysis, which would yield a better idea of the relationship for lower values of GRF between walking and trotting. However, reducing the number of trials would increase the SE for the GRFs.

Among dogs that could walk and trot, fewer trials were required to obtain acceptable walking data than trotting data. Although this was not significantly different, it is important to remember that only 62% of the dogs generated testable data at a trot, and these dogs were less lame. It is possible that these dogs with less lameness were more able to ambulate over the platform. Had we included all the dogs (ie, used the default maximum number of 141 trials for the 11 dogs that could not provide data at the trot), the difference between the groups would have been much larger. Inability to use the lame limb was the most common reason for failure to obtain data. Only 1 dog was excluded after completing 141 trials without providing 5 successful trials for each limb.

The smaller coefficient of variation for walking data suggests that walking has less inherent variation than trotting. Low variation in clinical studies is important, because variation affects the results of statistical testing of interventions. Smaller differences among interventions can be detected when there is a smaller amount of variation, and smaller sample sizes are required to detect such differences.

The study reported here compared outcomes of walking and trotting in dogs with cranial cruciate rupture. Lameness attributable to other causes may result in different relationships between GRFs at a walk and GRFs at a trot. We found that gait analysis with a force platform performed at a walking velocity in dogs with cranial cruciate rupture is an acceptable way to measure GRFs for clinical studies. We also found that more dogs could be tested when gait analysis was performed at a walk than at a trot. Therefore, fewer trials had to be conducted, and the coefficient of variation was less, compared with the values for gait analysis performed for dogs at a trot.

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[a]OR6-6-1000, Advanced Mechanical Technology Inc, Watertown, Mich.
[b]Me 92-TPAD retroflective photocell, Srcon Controls, Mississauga, ON, Canada.
[c]Acquire, Sharon Software Inc, Dewitt, Mass.
[d]JMP software, SAS Institute Inc, Cary, NC.

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