Evaluation of vertical forces in the pads of German Shepherd dogs

A. N. A. Souza¹; A. C. B. C. F. Pinto¹; V. Marvulle²; J. M. Matera¹

¹Department of Surgery, Faculty of Veterinary Medicine and Animal Science, University of São Paulo, São Paulo, Brazil;
²Center of Mathematical, Computation and Cognition, University of ABC, São Paulo, Brazil

Keywords
Vertical force, kinetic evaluation, dogs, pads, locomotion

Summary
Objective: To evaluate vertical forces in the pads of German Shepherd dogs by relative percentage among total limb vertical forces using a pressure sensitive walkway.

Procedure: A pressure sensitive walkway was used to collect vertical force data for each pad of the limbs of 16 healthy client-owned German Shepherd dogs used for kinetic gait analysis. The vertical force for each pad was evaluated as a percentage of total limb vertical force. Weight distribution among limbs was also recorded. Velocity and acceleration were within a range of 1.3 and 1.6 ± 0.1 m²/s. The ANOVA test was used to compare data and the paired t-test was used to assess symmetry (p <0.05).

Results: The peak vertical force was higher on the metacarpal pad than on the metatarsal pad. Peak vertical force was highest on the metacarpal pad and metatarsal pad followed by the digital pads 3 and 4 of the forelimb, on the hindlimb by digital pads 3 and 4. Vertical impulse was greatest in the metacarpal pad and digital pads 3 and 4 of the forelimb and hindlimb respectively, followed by digital pads 3, 4, and 5 of the forelimb and the metatarsal pad.

Conclusion and clinical relevance: A vertical force distribution pattern was observed on the pads of the German Shepherd dogs. These data are important for improving the understanding of vertical force distribution during gait and to assess orthopaedic conditions.

Introduction
Assessment of foot pressure is a special form of kinetic analysis that provides data on plantar pressure distribution (1). Motion mechanics emerged as a science in 1934 with the first description of a method that relied on the recording of a set of frames of standard points to assess plantar pressure distribution (2). The first studies used pneumatic transducers coupled to a simple device that enabled assessment during walking, running and jumping (3–4). In humans, plantar pressure distribution has been extensively documented (5–13).

As technology advanced, more sophisticated equipment was developed, such as the pressure sensitive platform, which measures the vertical forces applied during the period the limb contacts the ground (5). In human medicine, pressure sensitive in-shoe and floor-mat systems are frequently used to evaluate areas of the plantar surface of feet and these investigations have shown that age and obesity among other factors influence the function of the feet (6, 7). For a detailed assessment of pressure distribution on the plantar surface, the human foot has been divided into regions corresponding to transversal and horizontal cuts: a portion of the medial heel, lateral heel, intermediate region of the foot, first metatarsal head, third metatarsal head, fifth metatarsal head and hallux (8).

Automatic software has been developed to map pressure areas on the plantar surface and to supply data on the vertical forces applied on each region (9). This is of utmost importance due to the complexity of the human foot and enables detailed studies of numerous disorders of the feet (10–13).

In 1987, the introduction of an objective gait analysis using a force plate started a new era in veterinary medicine (14). As technology advanced, new and better tools were developed in the field of kinesiology. Kinesiology is the branch of science that studies movement and is divided into kine- matics and kinetics. The latter studies the relationship between forces generated by movement. In kinetics, the pressure sensitive walkway performs an analysis of the vertical forces and provides objective quantitative data (15). In veterinary medicine, despite the frequent use of kinetics, reports describing the pressure distribution in the pads are scarce. Few studies have concentrated on the vertical forces distribution on each pad, none of which have included German Shepherd dogs (16, 17).

According to Besacon et al. there are differences between breeds in pad vertical force distribution and this evaluation could provide a detailed kinetic analysis of a dog’s locomotion (17). The differences found in pads between Labradors Retrievers and Greyhounds could be relevant in orthopaedic diseases (17). Therefore, it is neces-
ary to explore this method of evaluation in other breeds.

Similar to pedobarographic studies in humans, we used a pressure sensitive walkway to assess gait kinetics of the anatomic regions that contact the ground. The aim was to determine the relative vertical forces of each pad among the respective limbs for German Shepherd dogs. Kinetic foot strike comparison between dogs and humans is impossible because there is a large anatomical and biomechanical difference among these species. In addition to providing a better understanding of locomotion, our purpose in documenting the pad vertical forces distribution of German Shepherd dogs through kinetic analysis was to test an innovative method that could be useful for the assessment of orthopaedic conditions that cause lameness in a different breed than previously reported (17).

**Material and methods**

This study was approved by the Institutional Bioethical Committee at the University of São Paulo, and owner consent was obtained for the dogs that were enrolled in the study. A total of 16 healthy client-owned German Shepherd dogs participated in the study and each dog underwent physical and radiographic examination, and kinetic gait evaluation.

The dogs included in our study were healthy, ranged between two and six years of age, and weighed between 20 and 35 kg. The exclusion criteria were signs of obesity or cachexia, pregnancy, oestrus, history of orthopaedic surgery, the finding of systemic or orthopaedic disease, and any type of pharmaceutical therapy.

**Radiographic evaluation**

The hip and the entire spine of the dogs were evaluated by veterinarians of the Diagnostic Imaging Service of the School of Veterinary Medicine of the University of São Paulo. Only dogs with hip joint classifications of excellent, good, and fair, according to the Orthopedic Foundation for Animals classification system, and with no evidence of bone alteration in the hip joint or the spinal column, were included in the study. None of the dogs had transitional vertebrae or other spinal abnormalities evident in the radiographic evaluation. The animals were sedated with acepromazine 0.05 mg/kg and meperidine 2 mg/kg.

**Kinetic analysis**

The gait analysis was performed in the Laboratory of Locomotion at the School of Veterinary Medicine using a pressure sensitive walkway. The walkway was 1.5 metres long and 0.5 metres wide. The dogs began their analysis by walking two metres on a platform and this distance was sufficient for the dogs to perform at least two cycles of full strides before the first contact with the walkway. The pressure sensitive walkway contained three aligned plates with a total of over 6,864 sensors. The plates are connected to a dedicated computer equipped with specific software designed for data collection and storage. Prior to each analysis, sensors were calibrated.

**Figure 1** Pads have been delineated by coloured boxes in the left forelimb and hindlimb of dog number 6 using commercially available software (I-scan 5.231, Tekscan Inc. South Boston, MA, USA).

**Figure 2** The graphic lines represent the vertical forces for each pad (dog number 6). The peak vertical force and vertical impulse were measured using commercially available software (I-scan 5.231, Tekscan Inc. South Boston, MA, USA). The force values are showed in Newtons and time in seconds. McP = metacarpal pad. MtP = metatarsal pad. DP = digital pad. FL = forelimbs. HL = hindlimbs.

---

7100 QL Virtual Sensor 3 Mat System, Tekscan Inc. South Boston, MA, USA.

I-scan 5.231, Tekscan Inc., South Boston, MA, USA.
Values of different superscript letters are significantly different in the same column (p < 0.05).

Values are expressed as a percentage of weight distribution. Values for paired limbs with the same superscript letter are not significantly different in the same row (p > 0.05).

Walking velocity and acceleration were limited to a range of 1.3 to 1.6 m/s and a standard deviation of ±0.1 m/s. Velocity was determined with a software tool that calculated the time-distance relationship using the length of the dog’s stride. The acceleration was calculated as the final velocity minus initial velocity, divided by time and also controlled by stance phase to assure the quality of the data. To assure a constant velocity, only a variation of ±0.01 seconds in stance phase was permitted in the foot-strike repetition on the walkway.

A valid trial consisted of velocity and acceleration within the aforementioned ranges, with each of the four limbs fully contacting the walkway at least twice during a dog’s passage. The dogs had to be walking in a straight line without pulling to one side or turning the head. Only the middle full-stride cycles were evaluated. Out of a maximum of 20 consecutive trials, five valid trials were recorded for each dog. The initial four trials were always excluded to avoid collection of data from animals that were not fully acclimated to the platform. A single observer (A.N.A.S) evaluated each trial and determined whether the trial was valid. All trials were performed in the early morning.

Vertical forces were assessed based on the graphs and figures generated by the software. The peak vertical force (PVF) was reported in Newtons and the vertical impulse (VI) in N*s. The duration of the stance phase was in seconds. The PVF, VI and stance phase were generated by the software program automatically. For each foot-strike that was evaluated, measurements of PVF and VI were obtained from five areas (Figure 1, Figure 2): metacarpal pad, metatarsal pad, and digital pads.

Results

The group consisted of eight entire males and eight entire females, with an average weight of 28.5 ± 4.6 kg and an average age of 4.2 ± 1.2 years. These data were normally distributed.

Table 1 contains a summary of the total pressure distribution of a limb according to the method previously described (17). There was no significant difference in symmetry between limbs (p > 0.05). To assure symmetry between the limbs, the data were also evaluated in percent of body weight and there were no significant differences (Table 2). Tables 3 and 4 present ground reaction forces for the right and left limbs expressed as a percentage of total limb vertical force, respectively. The values obtained for PVF and VI show that weight-bearing was higher for the metacarpal pad.
than for the metatarsal pad (p <0.001) (Figure 2).

The values for PVF and VI for digits three and four were not significantly different, but were often significantly greater than for digits two or five in both forelimbs and hindlimbs (Tables 2–4). In Table 3 and Table 4, only the differences that had a sample power higher than 80% were reported as significant. The comparisons between the pads of contralateral limbs had a sample power less than 20%.

### Discussion

Similar to pedobarography in humans, we used manual mapping of the ground contact surface of each pad of the limb, in order to perform a detailed kinetic analysis of vertical forces distribution in the pads of German Shepherd dogs. This is a valid approach because with dogs, the anatomical structures that contact the ground are easier to identify than those of human feet.

This method allowed for the analysis of gait dynamics and identified the differences in vertical force distribution among pads of the forelimbs and hindlimbs. In order to use this technique as a tool for the evaluation and understanding of the gait of dogs, breed specific vertical force distribution patterns must be identified and reported. The need for specific patterns is a limitation of this method, which would be ineffective for gait analysis of mixed-breed dogs (17).

The criteria to accept a valid trial are very important to provide data with high quality (18). The velocity controlled by stance phase was very useful to reach a constant velocity (18). Another advantage of the pressure sensitive walkway is the capability to measure the velocity of footprints because the entire cycle of locomotion can be evaluated (19). The start of dog’s walking at two metres of distance on a walkway provides the same results as walking eight metres, and for this reason our choice of initial distance was adequate to avoid bias (20).

The finding that the PVF was higher in the forelimbs than the hindlimbs is in agreement with previous reports (16, 17). According to our results, the right and left sides were symmetrical with minor variations, which is considered normal (18). The symmetry between the right and left limb remains under discussion and according to other studies it is possible that a normal symmetry variation between the breeds exists (21). We estimated that the sample size must be two hundred dogs to assure an 80% sample power in comparisons of symmetry. It is important to note that despite the good sample power (>80%) between some statistical comparison, the sample size had limitations in the comparison between more similar regions with p >0.05. The enrolment of larger homogeneous groups that meet the selection criteria is a major challenge for this type of study. Nevertheless, the results reported herein provide an opportunity for better understanding of locomotion because only the differences that had a sample power higher than 80% were considered significant.

The smaller vertical force percentage for the metatarsal pad than for the metacarpal pad could be associated with the interaction between the contact areas, centre of mass, and morphometric measurements resulting from kinematic differences between thoracic and pelvic limbs. There is a possibility that the discrepancies between our results and previous studies may have been caused by different kinematic patterns between breeds (17, 22). Kinematic studies are improving this kind of evaluation through new methods and technologies that provide important findings about the locomotion of dogs (22–26).

Despite our speculations, we must emphasize that the differences between our results and the literature could also be attributed to several extensively documented factors that affect kinetic evaluation, such as velocity, speed and acceleration control, equipment calibration, equipment type, body weight and size (14, 17, 19, 23, 24).

The variations by dog size in the dispersion of results can be reduced by the normalization of ground reaction forces and impulses by body weight; however they cannot be completely avoided (14). Considering this fact, we also chose to report

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Values for peak vertical force (PVF) and vertical impulse (VI) expressed as mean ± SD for the right limbs in the German Shepherd dogs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground reaction force</td>
<td>Metacarpal or metatarsal</td>
</tr>
<tr>
<td>Forelimb</td>
<td>PVF</td>
</tr>
<tr>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>PVF</td>
</tr>
<tr>
<td></td>
<td>VI</td>
</tr>
</tbody>
</table>

Values are expressed as a percentage of total limb vertical force. Values with different superscript letters are significantly different in the same row (p <0.05)

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Values for peak vertical force (PVF) and vertical impulse (VI) expressed as mean ± SD for the left limbs in the German Shepherd dogs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground reaction force</td>
<td>Metacarpal or metatarsal</td>
</tr>
<tr>
<td>Forelimb</td>
<td>PVF</td>
</tr>
<tr>
<td></td>
<td>VI</td>
</tr>
<tr>
<td>Hindlimb</td>
<td>PVF</td>
</tr>
<tr>
<td></td>
<td>VI</td>
</tr>
</tbody>
</table>

Values are expressed as a percentage of total limb vertical force. Values with different superscript letters are significantly different in the same row (p <0.05)
the importance of each pad, among the respective limbs, and an evaluation of the relative percentage of total limb vertical force was also performed. The magnification of the values in percentage of body weight did not change our statistics in relation to the relative percentages, but this factor must be checked to avoid the possibility of statistical error. This could provide more concise information to the surgeon during the follow-up time period in other orthopaedic conditions such as cranial cruciate ligament rupture when the vertical forces of the metatarsal pad seems to be the most affected measurement which correlates with the consequences of this orthopaedic disease (28).

The dogs performed the trials in the morning to avoid interference by exercise activity during the day even though it is known that exercise does not change the vertical forces in healthy dogs after 1.2 km of trot (29). Values for ground reaction forces derived from the pressure sensitive walkway were found to be significantly lower than values derived from the force plate (19). However, data derived by the use of the pressure sensitive walkway were consistent and could be used to evaluate kinetic variables (19). According to Gibert et al, sensitivity and specificity measurements to determine lameness in dogs with a pressure walkway system were 84.6 and 91.1% respectively, and these results were similar to those obtained using a force plate (30, 31). Despite many variables, kinetic evaluation remains one of the most accurate methods for detecting lameness (30–32).

Our results for hindlimb PVF as a percent of body weight were lower than those reported in previous studies and this difference could have been caused by the factors previously mentioned such as speed and morphometry (16, 17). The velocity selected in our research (1.3 to 1.6 m/s) was higher than in previous studies (0.9 to 1.1 m/s) and that could cause an increase in PVF and a decrease in VI, but that does not explain the discrepancies in our results (17, 33).

In the hindlimbs, the VI was greater in the third and fourth digits than in the metatarsal pad, thus propulsion is centralized in the internal digits. On the other hand, this centralization of digits has not been observed in the forelimbs, and the VI relative percentage was highest in the metacarpal pad. The pattern described herein is different from those reported in other studies (16, 17). The main findings of this study, in comparison to previous findings, are that German Shepherd dogs appear to have relatively more load on the metatarsal pads than on the digital pads, whereas, especially with Greyhounds, there are similar loads between the metacarpal and digital pads (17). Labradors seem to be in an intermediary value area. This suggests that German Shepherd dogs walk more on the back of their paws than the other two breeds, which could have some correlation with limb morphometry. It is necessary to emphasize that this comparison is speculative and must be interpreted with caution (34).

The use of this method proved successful in large breed dogs because individual structures of paw prints are easily identified by the software. Our study population was homogeneous in that age and weight variations were limited within a specific range. As in conventional kinetic analysis, this represents a bias which must be taken into consideration. Conventional kinetic analysis is frequently used in the assessment of orthopaedic conditions such as dysplasia and cranial cruciate ligament rupture (35–37). Reporting vertical force distribution patterns in healthy German Shepherd dogs could improve the understanding of gait dynamics in these dogs. In addition to providing a useful tool for detailed evaluation of conditions that involve lameness, this method could be useful in follow-up and in the initial evaluation of orthopaedic diseases (28, 37).

Acknowledgments
This research was supported by FAPESP (Fundação de Amparo a Pesquisa do Estado de São Paulo).

Conflict of interest
None declared.

References
18. Renberg WC, Johnston SA, Ye K. Comparison of stance time and velocity as control variables in