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Vertical force distribution in the paws of sound Labrador retrievers during walking

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ABSTRACT

In contrast to gait analysis in humans, where pedobarography is an integral part of biomechanical studies, veterinary researchers have rarely investigated vertical force distribution (VFD) in the paws of dogs. The aim of this study was to investigate the VFD of peak of vertical force (PFz), vertical impulse (IFz) and time of occurrence of PFz during stance phase (TPFz) in 20 sound, adult Labrador retrievers walking normally on a pressure plate. A technique was used that divided the canine paw prints into quadrants. A general linear model was introduced to investigate the effects of forelimbs/hindlimbs, body side, and medial/lateral and cranial/caudal quadrants on VFD as they related to the total force (sum of all PFz/IFz values).

For PFz and IFz, there were significantly greater effects on VFD in the lateral quadrants compared to the medial quadrants, respectively (6.49 ± 2.56% vs. 6.01 ± 2.60% and 6.62 ± 3.06% vs. 5.88 ± 3.21%; $P < 0.001$), in the forelimbs compared to the hindlimbs (8.02 ± 2.13% vs. 4.48 ± 1.61% and 8.02 ± 2.83% vs. 4.48 ± 2.36%; $P < 0.001$), and in the cranial quadrants compared to the caudal quadrants (7.87 ± 2.09% vs. 4.63 ± 1.93% and 8.57 ± 2.17% vs. 3.88 ± 1.98%; $P < 0.001$). The cranial/caudal ratio was higher in the hindlimbs than in the forelimbs (PFz: 2.10 ± 0.45 vs. 1.65 ± 0.32; $P = 0.001$; and IFz: 3.35 ± 0.80 vs. 2.04 ± 0.46; $P < 0.001$). The TPFz was reached earlier in the hindlimbs than in the forelimbs (46.86 ± 19.16% vs. 54.08 ± 19.62%; $P < 0.001$) and in the caudal quadrant than in the cranial quadrant (32.57 ± 5.77% vs. 68.37 ± 10.01%; $P < 0.001$). These data from sound Labrador retrievers could be used as a basis for future research investigating orthopedically- and/or neurologically-impaired animals.

Introduction

In canine gait research, ground reaction forces are commonly measured with pressure plates (Budsberg et al., 1987; Lascelles et al., 2006; Bockstahler et al., 2007; Lequang et al., 2009; Oosterlinck et al., 2011; Fischer et al., 2013), because they allow for the evaluation of the entire limb as well as the vertical force distribution (VFD) in individual paws. In human gait research, this technique, known as pedobarography, is standard; moreover, in human orthopaedic medicine, it is used routinely to finely assess human gait, particularly in relation to surgery and in rehabilitation programmes (Hughes, 1993; Lee and Pollo, 2001; Klenerman and Wood, 2006).

In contrast to human medicine, most research on canine gait has been based on ground reaction force assessment of the entire limb and, to our knowledge, specific analysis of VFD in the paw pad is scarce (Marghitu et al., 2003; Besancon et al., 2004; Souza et al., 2013, 2014). In a study of six English pointers, Marghitu et al. (2003) determined the pressure on the central area of the weight-bearing pads exerted during walking by affixing a force-sensing resistor to each paw pad; the maximum pressure was in the metapodial pads, followed by digital pads 3 and 5, and digital pads 2 and 4 had the least pressure. In an analysis of eight Greyhounds and eight Labrador retrievers, Besancon et al. (2004) identified digital pads 3 and 4 as the major weight-bearing pads, with loads quite evenly distributed; digital pad 5 and the metapodial pad also bore a substantial proportion of the load. Statistically significant differences in load distribution were detected between the two breeds, and the authors cited the need for more research to develop this method into an accurate diagnostic tool. Souza et al. (2013) evaluated the VFD of 16 German shepherd dogs and reported that values for peak of vertical force (PFz) and vertical impulse (IFz) were greater for the metacarpal than the metatarsal pad; digital pads 3 and 4 had similar loading, but both were often significantly higher than either digits 2 or 5. In addition, Souza et al. (2014) investigated the VFD in Pit bull terriers with cranial cruciate ligament ruptures and demonstrated that this kinetic analysis aided the follow-up assessment of

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surgically-treated dogs. In summary, these studies suggest that differences between breeds exist, although the magnitude and importance of these differences remains to be determined (Besancon et al., 2004; Souza et al., 2013, 2014). Nonetheless, the data indicate a trend towards the sum of the forces of digital pads 4 and 5 being higher than those exerted by the medial pads (digital pads 2 and 3).

While the study by Souza et al. (2014) showed that the PFz was lower in limbs with stifle injury, with compensatory increase in other limbs, there remains a need for similar detailed studies of VFD in dogs of various breeds (Voss et al., 2011), especially VFD between and within the paws. However, VFD assessment of the toe and metacarpal/tarsal pads is limited, in research and standard clinical settings, by the requirement for high-resolution pressure plates suitable for use in animals, especially those with small paws. As reported by Stadig and Bergh (2014) in their feline study, this challenge can be overcome by dividing the paw into quadrants.

Therefore, the aim of our study was to investigate PFz, IFz and time of occurrence of PFz during stance phase (TPFz) in the paws of sound Labrador retrievers by dividing the paws into quadrants. Based on the findings from previous studies (Besancon et al., 2004; Souza et al., 2013, 2014), we hypothesised that the cranial and lateral quadrants would undergo higher vertical forces than the caudal and medial quadrants.

Materials and methods

Data used in this study were previously sampled data from Strasser et al. (2014) and Bockstahler et al. (2016). Those studies were approved by the Ethics Committee of the University of Veterinary Medicine Vienna according to adherence with Good Scientific Practice guidelines and national legislation (Approval No. 18/03/97/2014, approved 18 March 2014; Approval No. 10/09/97/2011, approved 10 September 2011). Owners of the canine study participants provided written consent for study inclusion.

Animals

Sample size was calculated based on previously published PFz data from the left forelimbs of Labrador retrievers (Besancon et al., 2004). Power calculations were based on an effect size (delta) of 0.6, giving a total sample size of 19 dogs necessary to detect this effect with a power of 80%. Our study population was composed of 20 clinically sound, adult Labrador retrievers (age range, 1.08–9.25 years, mean ± standard deviation [SD], 4.35 ± 2.48 years; bodyweight range, 23.0–31.0 kg, mean ± SD, 27.2 ± 3.4 kg), including twelve females and eight males.

The clinically sound (healthy) designation was made according to complete physical examination. All dogs also underwent standard orthopaedic and neurological examinations to assess all limbs and the vertebral column; there were no signs of lameness or pain during joint manipulation. Findings from visual gait analysis were confirmed as adequate for study inclusion by calculating the symmetry index of contralateral limb pairs. This was done by using the ground reaction force obtained for the entire limb and comparing the results with previously published data (forelimb PFz, 1.6 ± 1.22%; PFz hindlimbs 2.54 ± 1.54%; Strasser et al., 2014 and Bockstahler et al., 2016, forelimb PFz 2.0 ± 1.5%, hindlimb PFz 3.1 ± 2.1%).

Data collection

Kinetic data were collected using the FDM Type 2 203.2 × 55.88 cm pressure plate (Zebris Medical) situated in the middle of a 7 m runway. The surface of the pressure walkway was covered with a 2-mm thick rubber layer embedded with 1.27 cm^2-sized sensors, providing a 100-Hz sampling rate. The rubber layer was placed to hide the measuring area from the dogs' sight and to prevent slipping. Data were recorded using WinFDM software (v1.2.2; Zebris Medical), and video recordings were made using a Panasonic NV-MX500 camera (Fig. 1).

Study design

Dogs were assessed at the University of Veterinary Medicine (Vienna, Austria) and each was given sufficient time to acclimate to the testing environment by first walking freely throughout the measurement room and over the pressure plate. After acclimatisation, owners walked the dogs over the pressure plate several times, allowing the dog to set its own comfortable speed and continuing until accustomed to the procedure. Before beginning the experimental phase and initiating recordings, the dog was required to appear relaxed and to demonstrate a constant and balanced gait. During measurements, the dogs walked with their handler walking on the right side of the plate. Trials were only accepted if the dog walked forward in a straight line without head turning or velocity change. Walking velocity was measured for the left forelimb based on the timing of successive ground contacts. Distances between successive ground contacts were measured to calculate the velocity (range, 0.9–1.1 m/s; mean velocity, 1.1 ± 0.1 m/s). All trial repetitions were recorded on the same day and each dog walked a minimum of seven times over the pressure plate to achieve a sufficient number of valid motion cycles ($n = 5$).

Data analysis and outcome parameters

As shown in Figs. 1 and 2, the pressure plate measured the vertical force distribution within the paws. The paw prints from the entire foot were visually and manually identified with the help of video recording, and the trial data were analysed using specially developed software (Pressure Analyzer, v3.0.0.10, Michael Schwanda; Fig. 1). To analyse the VFD, the paw prints were divided into equally-sized quadrants (cranio-lateral, cranio-medial, caudo-lateral and caudo-medial; Fig. 2), and the following measurements were made: PFz (Newtons), IFz (Newton seconds) (Table 1) and TPFz (% of stance phase) (Table 2). The TPFz represented the time of PFz during the stance phase when the total duration of stance time was defined as 100%. Mean PFz, IFz and TPFz were calculated for each dog from all valid evaluated steps. The cranial/caudal ratio was calculated by dividing the PFz and IFz of the cranial quadrant by the corresponding value of the caudal quadrant.

The PFz and IFz of each quadrant were expressed as a percentage of total force (TF) by setting the sum PFz or IFz of all 16 quadrants as 100% -

$$TF_{nk}(\%) = \frac{100 * X_{nk}}{\sum_{k=1}^{4}\sum_{n=1}^{4} X_{nk}}$$

In this equation, X represents PFz or IFz, n symbolises a limb (left forelimb, right forelimb, left hindlimb or right hindlimb) and k denotes one quadrant (cranio-lateral, cranial-medial, caudo-lateral or caudo-medial).

The evaluated parameters were analysed from various viewpoints, with each quadrant compared to the corresponding quadrants of other limbs. For example, the left forelimb cranio-lateral quadrant was compared to the corresponding (cranio-lateral) quadrant of one of the other three limbs (Fig. 3). Additionally, the quadrants of one limb were compared with each other on the same pad; for example, the cranio-lateral quadrant was compared to the caudo-lateral quadrant for the left forelimb (Fig. 4).

Statistical analysis

Data (repeated measures for each parameter) were analysed using a general linear model, with the following factors added to the model: fore/hind limbs, body side (left/right), cranial/caudal quadrants and lateral/medial quadrants. When a factor showed significant influence, post-hoc testing was applied using Bonferroni's alpha correction. The level of significance was set at $P < 0.05$.

Results

Body side (left vs. right) did not significantly influence any of the evaluated parameters. The forelimbs showed higher PFz and IFz than the hindlimbs (8.02 ± 2.13% vs. 4.48 ± 1.61% and 8.02 ± 2.83% vs. 4.48 ± 2.36%, respectively; $P < 0.001$). The TPFz was reached earlier in the hindlimbs than in the forelimbs (46.86 ± 19.16% vs. 54.08 ± 19.62%; $P < 0.001$), in general, with the exception of the right caudo-lateral quadrants ($P = 0.066$; Table 2).

There was higher PFz and IFz in the cranial than the caudal quadrants (7.87 ± 2.09% vs. 4.63 ± 1.93% and 8.57 ± 2.17% vs. 3.88 ± 1.98%, respectively; $P < 0.001$). In contrast, the TPFz was reached earlier in the caudal than in the cranial quadrants (32.57 ± 5.77% vs. 68.37 ± 10.01%; $P < 0.001$). In the hindlimbs, the caudo-lateral quadrants reached their maximum (TPFz) later than the caudo-medial quadrants (Table 2).

Lateral quadrants had higher PFz and IFz than medial quadrants (6.49 ± 2.56% vs. 6.01 ± 2.60% and 6.62 ± 3.06% vs. 5.88 ± 3.21%; $P < 0.001$). The TPFz did not differ between these quadrants.

The PFz and IFz of the cranio-medial quadrants were higher in left hindlimb than in the right hindlimb, and the PFz of the caudo-medial quadrant generated higher values for the right hindlimb than for the left hindlimb. Only one difference was found between the cranial quadrants: the IFz of the right forelimb had higher values for the lateral side than for the medial side. In general, the caudo-lateral quadrants had higher values (PFZ and IFz) than the caudo-medial quadrants, with the exception of PFz of RH. Details of the