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ORIGINAL ARTICLE

Force-sensitive resistors to measure the distribution of weight in the pads of sound dogs in static standing position

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ABSTRACT. The purpose of this study was to measure how weight is distributed in the pads of each of the 4 limbs of dogs and evaluate the intra-investigator reproducibility and inter-investigator reliability of the measurement method. Eight dogs were examined 3 times a day by 3 investigators at 1 week intervals for 3 weeks to determine the weight distribution to each of the pads. The force-sensitive resistor was used for measurement and specific software (PetLAB2) was used to calculate the weight applied to each pad. The intra-investigator reproducibility showed moderate to good reliability (ICC range, 0.575-0.873) and the inter-investigator reliability was moderate (ICC range, 0.525-0.746). Based on this study, it can be observed whether the weight distributed to each pad approaches the normal value after treatment in patients with orthopaedic and neurologic diseases. It is expected that this experimental method will be one of the objective indicators to evaluate the degree of recovery in patients with orthopaedic and neurologic diseases.

Keywords: Force-sensitive resistor, pad, weight distribution, reliability, dog.

INTRODUCTION

The evaluation of limb use in dogs with orthopaedic diseases is a major aspect of examinations (Sharkey, 2013). An objective evaluation of limb use involves measuring weight bearing in a static or dynamic state using force plates or pressure-sensitive walkways (Lascelles *et al.*, 2006). Static weight distribution is used to assess the amount of weight each limb bears during standing, whereas dynamic weight distribution is assessed during walking/running, both of which are important assessments in veterinary patients with orthopaedic conditions (Hyytiäinen *et al.*, 2012). In veterinary medicine, these objective measures have been used to evaluate surgical interventions, determine analgesic efficacy, develop surgical models for pain, and monitor patients in rehabilitation programs effectively (Seibert *et al.*, 2012; Tomas *et al.*, 2014; Tomas *et al.*, 2015).

Various tools and methods are used in veterinary clinics to measure static and dynamic weight distribution, and measurement objectivity has been confirmed for the dynamic state evaluation using a pressure-sensitive walkway in healthy Labradors (Light *et al.*, 2010). However, variables such as head position and velocity may affect the kinematic and force plate data in the dynamic state (McLaughlin & Roush, 1994; McLaughlin, 2001).

Static weight distribution is defined as the percentage of body weight distributed to each limb during standing. In sound dogs, 30% of the weight is distributed to each forelimb and 20% of the weight is distributed to each hindlimb (Bosscher *et al.*, 2017). Patients with pain or instability associated with orthopaedic or neurologic disease may alter their weight distribution during standing. Depending on the severity of the disease, it can vary from subtle changes in weight distribution to complete non-weight bearing. In the process of recovery through surgery, the weight bearing of the affected limb is expected to be slightly loaded. Measurement of the static weight distribution has been used previously to assess response to treatment after total hip replacement surgery (Seibert *et al.*, 2012).

In human medicine, the human foot has been divided into regions corresponding to transversal and horizontal cuts to obtain a detailed assessment of weight distribution on the plantar surface (Hennig & Rosenbaum, 1991). The classification of these compartments is important for the measurements because of the complexity of the human foot, allowing for a detailed study of numerous foot disorders (Hessert *et al.*, 2005; Hughes *et al.*, 1987; Yavuz *et al.*, 2009; Zammit *et al.*, 2008). The foot pressure distribution can provide essential information and thus assist in medical diagnoses (Vigneshwaran & Murali 2020). Similarly, in veterinary medicine, many have reported the pressure distribution of the pads and peak vertical force and vertical impulse applied to each pad in a static and dynamic state (Besancon *et al.*, 2004; Souza *et al.*, 2013; Souza *et al.*, 2014) and, further, one study have been conducted by dividing the pads into four quadrants to measure vertical force distribution (Braun *et al.*, 2019).

Additionally, while a few studies have evaluated the vertical force applied to each pad, this is a dynamic state measurement; research on the pressure applied to each pad in a static state is scarce (Besancon *et al.*, 2004; Marghitu *et al.*, 2003; Souza *et al.*, 2013). Recently, body weight distribution in static state in small dogs without orthopaedic or neurosurgical disease has been studied but without measuring the value given to each pad (Linder *et al.*, 2021). In both human and veterinary medicine, many researchers have reported the pressure distribution of the

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pads and peak vertical force and vertical impulse applied to each pad in a static and dynamic state (Besancon *et al.*, 2004, Souza *et al.*, 2013, Souza *et al.*, 2014).

This study aimed to determine the distribution of weight in the pads of the four limbs during static standing in sound dogs and evaluate the intra-investigator reproducibility and inter-investigator reliability of force-sensitive resistor. We hypothesised that measurements collected using a force-sensitive resistor would be both reproducible and reliable.

MATERIAL AND METHODS

ANIMALS

After owner consent was obtained, 8 client-owned adult dogs (3 Malteses, 2 Pomeranians, 1 Beagle, and 2 mixed breeds) were included in this study. This study was approved by Jeonbuk National University's Institutional Animal Care and Use Committee (Number: JBNU 2021-0173). The body weights of the dogs used in the study ranged from 2.7 kg. to 11.3 kg. and the average body weight was 5.2 ± 2.8 kg. (mean ± standard deviation (SD)). All dogs underwent physical, orthopaedic, neurologic, and gait evaluations to rule out any lameness that could affect weight distribution.

EXPERIMENTAL DESIGN

Static weight distribution was recorded on a 30 cm × 32 cm piezoresistive-type force-sensitive resistor (Kitronyx, Seoul, South Korea) (figure 1a) equipped with a total of 2,304 nodes. The force-sensitive resistor was connected to a dedicated computer equipped with specific software (PetLAB2; Kitronyx, Seoul, South Korea) designed for data acquisition, storage, and graphic conversion. Two force-sensitive resistors were placed on a digital scale (Jiangyin Ditai Electronics CO, Jiangsu, China) (figure 1b) and calibrated.

After the dog's forelimbs and hindlimbs were placed on each sensor, the exact weight applied to each limb was recorded. Before the analysis, the sensors were calibrated according to the measured weight. During the measurement process, the investigator restricted the dog's movement by carefully wrapping the head. The investigator was placed directly in front of the dog to ensure that the head and neck were facing forward. The measurement time was 1 minute, and the moment when the weight bearing was applied to all pads was determined as the measurement moment. Measurements were taken only when the dog was standing still and looking straight ahead (figure 2a).

As a simplified schematic for measurement, the PetLAB2 software program was used and the hardware was comprised of a digital weighing scale, force-sensitive resistor, and data acquisition electronics (figure 2b). Once the area of each pad was manually set according to the shape of the pad represented by the graphic, the program calculated the pressure in the area and converted it into the weight of each pad (figure 3). The total body weight was set at 100% and the distributed weight of a total of 20 pads (forelimbs and hindlimbs) was calculated as a percentage (%). The sensor used in this study was manufactured using the principle of outputting an electrical signal generated in proportion to the digital signal to indicate how the weight (kg.) was distributed to each pad.

All procedures were conducted by three investigators (small-animal surgery residents) who were instructed on the measurement method through lectures and handouts prior to recording any measurements. On the first day, 8 dogs were measured three times by the three investigators to obtain 72 measurements, and the same measurement was repeated after 7 and 14 days to obtain a total of 216 measurements. For the accuracy of the measurements, animals were given a 5 min. rest between measurements. The experimental order of the investigators and dogs was randomly determined using randomization software (http://www.random.org/) three measurement days.

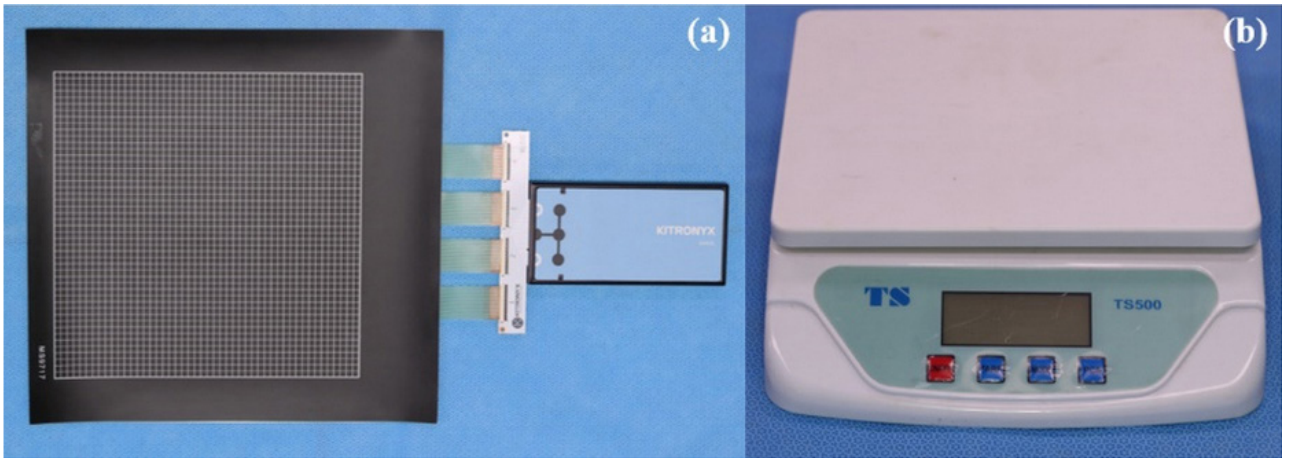

Figure 1. The force-sensitive resistor (MS9717) connected to data acquisition electronics (Baikal force controller) (a) and digital weighing scale (TS500) (b).

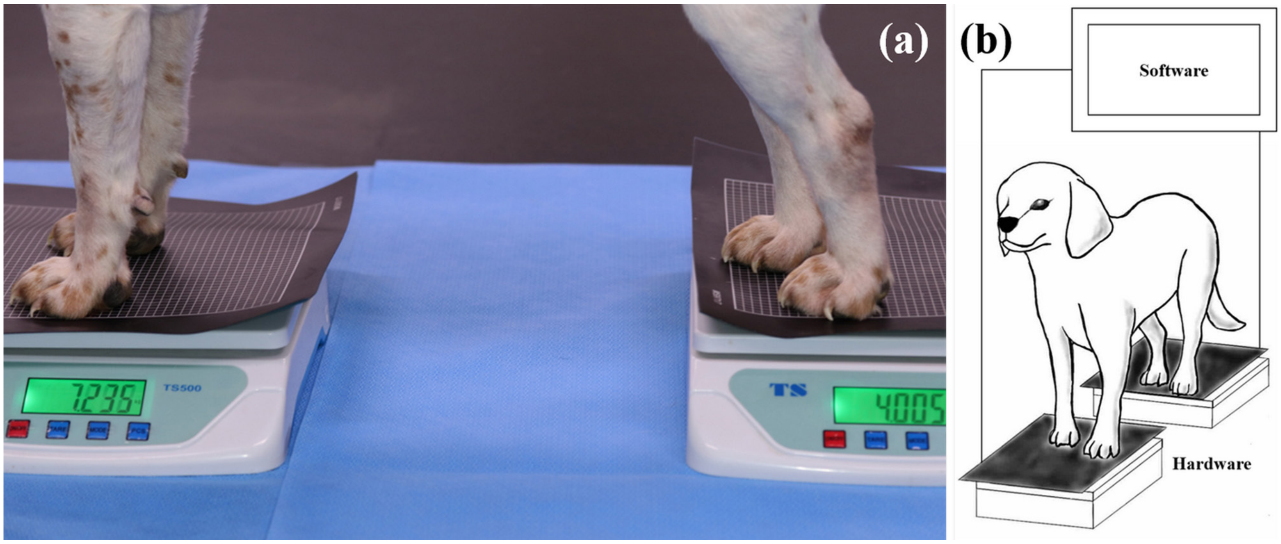

Figure 2. Placement of the dog and devices during measurement (a). As a simplified schematic for measurement, the software was created using the PetLAB2 program, and the hardware is composed of a digital weighing scale, force-sensitive resistor, and data acquisition electronics (b).

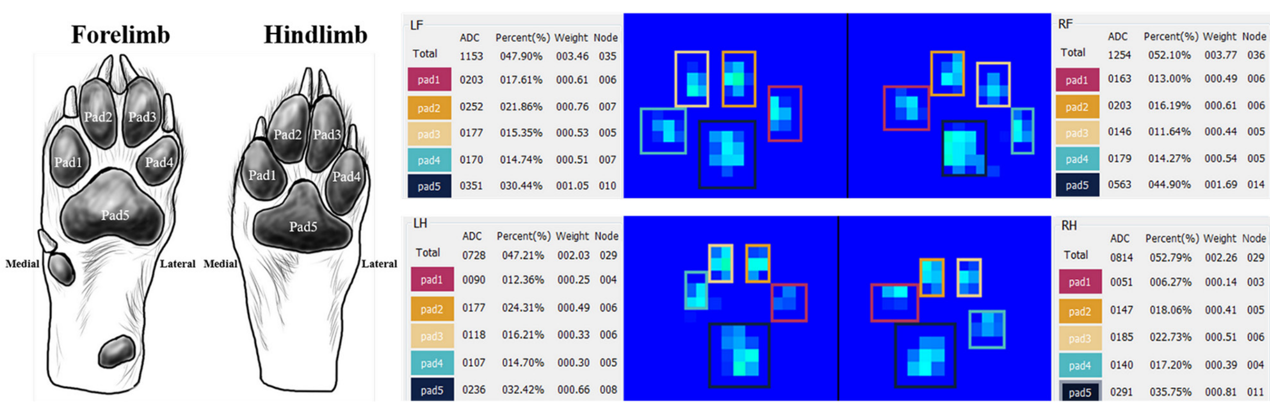

Figure 3. Pads of both forelimbs and hindlimbs were designated as Pad 1, 2, 3, and 4 in the lateral direction from the medial direction, and the metacarpal/metatarsal pad was designated as Pad 5. The picture on the right shows the manual setting of the area of each pad to measure the weight using the PetLAB2 program.

STATISTICAL ANALYSIS

SPSS version 23 (SPSS Inc, Chicago, IL, USA) was used to verify normality assumptions and to confirm the quality of the data obtained in the study. The normal distribution of percentage value for each pad was investigated using the Kolmogorov-Smirnov test. The data were presented as the mean ± SD.

The evaluation of intra-investigator reproducibility and inter-investigator reliability for the force-sensitive resistor was performed using the intraclass correlation coefficient (ICC). The interpretation of the ICC was evaluated using the criteria introduced by Portney and Watkins based on the 95% confidence interval of the ICC estimate. Specifically, values < 0.5 indicated poor reliability, those between 0.5 and 0.75 indicated moderate reliability, those between 0.75 and 0.9 indicated good reliability, and those > 0.90 indicated excellent reliability.

RESULTS

A total of 216 measurements were obtained and analysed. As previously described, the area for each pad was used to calculate each pad's weight out of the total weight distributed. These data were found to be normally distributed. The figure 4 shows the mean value of the weight applied to each pad as a percentage of the total weight. The data showed that weight-bearing was higher for the metacarpal pad than for the metatarsal pad. The tables 1 and 2 present the results of the reproducibility and

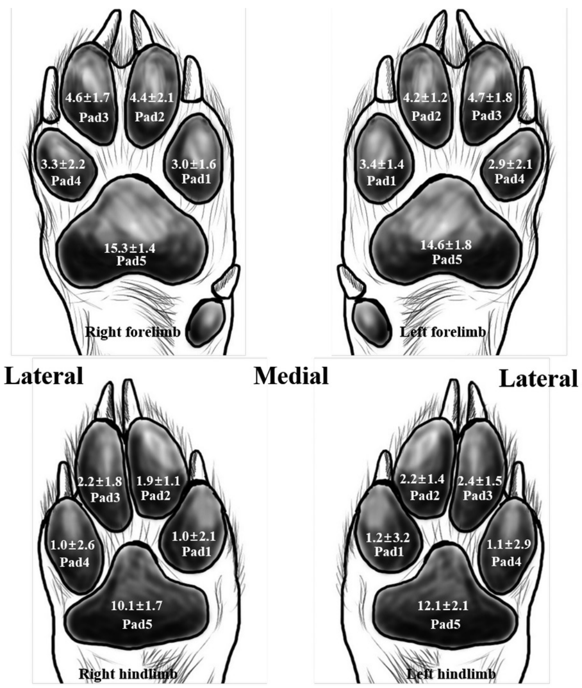

Figure 4. Value of the weight given to each pad expressed as percentages (mean ± SD) for the four limbs of each of the 8 dogs.

reliability evaluation respectively. The intra-investigator reproducibility showed moderate to good reliability (ICC range, 0.575-0.873), and the inter-investigator reliability was moderate (ICC range, 0.525-0.746).

DISCUSSION

To the best of our knowledge, no study has been conducted on the distribution of total body weight to each pad in standing sound dogs. Therefore, we investigated the normal weight value applied to each pad through a force-sensitive resistor in a static state.

When diagnosing lameness in dogs, dynamic state evaluation is more sensitive than subjective lameness scoring scales (Quinn *et al.*, 2007; Waxman *et al.*, 2008). However, it is difficult to perform dynamic measurements using a pressure-sensitive walkway in veterinary patients with severe neurological and orthopaedic diseases. These patients cannot ambulate normally due to severe pain, and the measurement value cannot be regarded as reliable. Even if the pain is not severe, in the case of severely nervous patients, it is difficult to perform dynamic measurements because the animal is not ambulating normally, and therefore, the test is not accurate. In addition, compared to kinetic

Table 1. Intra-investigator reproducibility (95% confidence intervals).

	Left forelimb (CI value)					Right forelimb (CI value)				
	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5
INV 1	0.658	0.751	0.732	0.575	0.791	0.601	0.645	0.705	0.744	0.821
INV 2	0.651	0.742	0.717	0.719	0.836	0.741	0.733	0.732	0.736	0.823
INV 3	0.708	0.693	0.873	0.789	0.793	0.742	0.716	0.707	0.670	0.866
	Left hindlimb (CI value)					Right hindlimb (CI value)				
	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5
INV 1	0.707	0.635	0.636	0.740	0.836	0.727	0.654	0.773	0.815	0.851
INV 2	0.624	0.854	0.779	0.717	0.707	0.743	0.757	0.753	0.733	0.727
INV 3	0.791	0.781	0.699	0.711	0.827	0.720	0.733	0.806	0.767	0.838

INV: investigator, Pad 5: metacarpal or metatarsal pad.

Table 2. Inter-investigator reliability (95% confidence intervals).

	Left forelimb (CI value)					Right forelimb (CI value)				
	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5
1st	0.681	0.685	0.671	0.677	0.711	0.690	0.717	0.746	0.706	0.717
2nd	0.617	0.631	0.618	0.639	0.714	0.654	0.659	0.621	0.595	0.691
3rd	0.644	0.531	0.606	0.615	0.697	0.673	0.650	0.676	0.639	0.687
	Left hindlimb (CI value)					Right hindlimb (CI value)				
	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5	Pad 1	Pad 2	Pad 3	Pad 4	Pad 5
1st	0.665	0.706	0.678	0.665	0.725	0.617	0.673	0.661	0.544	0.702
2nd	0.525	0.647	0.679	0.615	0.686	0.589	0.541	0.651	0.669	0.678
3rd	0.630	0.557	0.614	0.632	0.681	0.627	0.567	0.592	0.594	0.697

1st: the first day of measurement, 2nd: 7 days later, 3rd: 14 day later, Pad 5: metacarpal or metatarsal pad.

measurement in static state, the method of measuring the dynamic state requires more space and data acquisition skills and is more expensive (Bosscher *et al.*, 2017; Clough *et al.*, 2018; Cole & Millis 2017).

The comparison between the values measured in this study, set to a normal value, and the values obtained from dogs with orthopaedic and neurologic diseases, shows how the weight distribution on each pad has been altered. In these patients, if the weight applied to the pad is continuously measured in the process of recovery after surgical or/and rehabilitation treatment, it is expected that as it approaches the normal value, this may be a more objective indicator of the patient's recovery.

For the evaluation of the reliability of the equipment and programs used in this study, the intra-investigator reproducibility showed moderate to good reliability, while the inter-investigator reliability was moderate. This may be related to various factors, such as the dog's temper or the investigator's ability to soothe the dogs; however, to increase the objectivity of the values measured by the equipment, a method that can increase the reliability between investigators is necessary.

One limitation of this study was the necessity of adjusting both the forelimbs and hindlimbs of the dog to fit on the sensor. Therefore, when the limb moved away from the sensor, the investigator needed to handle the limb which may have altered the patient's neutral position. Even if the dog's body does not deviate significantly from the sensor, it is impossible to measure when the dog is holding the leg up or sitting down due to severe pain, and in this case, there is a limitation in that the accurate weight load cannot be measured.

In addition, the force-sensitive resistor used in this study could not be used to accurately measure the weight, so it was necessary to measure the exact weight by placing the resistor on a digital scale and placing the dog's forelimbs and hindlimbs on the resistor. In small dogs, the distance between the two pieces of equipment was narrow, so it was possible to measure it as if it was almost attached. However, for medium to large–sized dogs, there was more distance between the two pieces of equipment, which could have affected the dog's balance. Therefore, the authors and the research team are considering a method to accurately measure the weight with the force-sensitive resistor.

We hope the results of this study will help veterinarians evaluate the limbs and assess abnormal weight distribution of pads by comparing them with normal values measured in this study. In addition, it may be another indicator that can objectively be used to evaluate the patient's recovery through assessment of the gradual changes in the weight distributed to the pads compared to normal values. Further research is needed, but various advantages are expected compared to dynamic state measurements and we anticipate it will be a more useful test method if measurement elements are added through clinical application and discussion.

COMPETING INTERESTS STATEMENT

The authors declare that they have no competing interests.

ETHICS STATEMENT

This experiment was carried out at the Jeonbuk Animal Medical Center (JAMC), College of Veterinary Medicine, Iksan, Korea, and it was approved by the Committee of Animal Experiments of the Jeonbuk National University, Jeonju, Korea, for the use of animals in the experiment.

AUTHOR CONTRIBUTIONS

CC and JK conceived this study. SJ and SH designed the study. CC and JK conducted the experiment and collected important background information. CC and JK analysed the data. All authors were involved in data interpretation, write up and final approval of the manuscript.

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