pISSN 1598-298X / eISSN 2384-0749
J Vet Clin 35(5) : 206-210 (2018)
http://dx.doi.org/10.17555/jvc.2018.10.35.5.206

Journal of Veterinary Clinics
www.ksvc.or.kr

Reliability and Validity of a Force-Sensing Resistor for the Measurement of Static Hindlimb Weight Distribution in Beagle Dogs

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(Received: March 08, 2018 / Accepted: July 30, 2018)

Abstract : The purpose of this study was to evaluate the reliability and validity of the Force-Sensing Resistor (FSR) for measurement of static hindlimb weight distribution in beagle dogs and to compare these results to a Digital Weighing Scale (DWS). Nine healthy beagle dogs were recruited for this study. Static weight distribution was evaluated four times at intervals of 5 days with each device and two observers to calculate the intra- and interobserver reliability. The intraclass correlation coefficient (ICC) values of the FSR for intraobserver reliability were moderate to good (0.74). The results for the DWS showed poor to moderate (0.56) ICC values for intraobserver reliability. The ICC values for interobserver reliability were 0.53 and 0.61 for FSR and DWS, respectively, indicating poor to moderate agreement. Our findings suggest that the Force-Sensing Resistor can be used to measure static weight distribution in veterinary medicine. However, caution should be taken when comparing measured values of static weight distribution obtained utilizing both the FSR and DWS due to their low positive correlation ($R = 0.41$, $p < 0.01$).

Key words : force sensing resistor, static weight distribution, intraobserver reliability, beagle dog.

Introduction

Assessing the function of the limbs of patients with orthopedic disorders is very important (20). This assessment is performed through joint goniometry, circumferential measurement of muscle, radiographic assessment and subjective diagnostics for lameness (21). Although lameness may be objectively diagnosed through this process, in some cases, diagnosis may be challenging due to the severity of the disease, the nature of the patient, or the state of excitement in the hospital. In such cases, weight distribution measurements that objectively assess the function of the limb can be a valuable diagnostic method (2). In veterinary medicine, these measurement methods have been used to diagnose disease and determine surgical intervention and to evaluate pain and the effects of analgesia and rehabilitation therapy (19).

The weight bearing measurement can be classified as static, standing, or dynamic, walking or trotting, both of which are reported to be important for evaluating orthopedic patients (19). Force plates and pressure-sensitive walkways are standard and objective measurement methods for evaluating limb function used in research to obtain kinetic ground reaction forces (GRFs) during dynamic weight bearing (1). Although these methods are highly useful for localization of lameness, they are impractical because of their high cost, intensity of labor required and the need for a large area dedicated to the runway (11). In addition, there are limitations associated with the learning curve required from the patient in order to achieve the constant velocity for analysis, footprint overlap, weight in small dogs and the possibility for increased variation in measurements due to repetition of trial (7). Inter-day variation that is statistically significant without any treatment masks subtle symptoms, trial repetition, and significant differences based on patient's posture, which affects the objectivity of the dynamic weight distribution measurement (6).

Alternatively, static weight distribution measures the force on the ground while standing as a percentage of total body weight (2). In dogs without lameness, approximately 30% of their body weight was reported to be distributed on each forelimb and 20% on each hindlimb (4). Weight distribution asymmetry is indicated to reduce the weight of painful limbs by shifting the dog's weight side to side or front to back and back to front (2). In current veterinary medicine, static weight bearing is measured using a bathroom scale, a pressure sensitive walkway, and a weight distribution platform (2,11,14).

Although these two measurement methods are all important for orthopedic surgeons and physiotherapists, static weight distribution systems have several advantages over dynamic weight distribution systems. Clinically, it has been reported that dogs with osteoarthritis often do not exhibit obvious lameness during walking or trotting but show subtle shifting in their weight distribution during standing (15). It is effective for evaluating weight bearing asymmetry through intuitive quantification and is more suitable for clinical use in private practice than dynamic weight distribution measurements because of reduced cost and data collection time, and a

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dedicated space for walkway or skilled operators is not necessary (17). However, there are only a few studies evaluating the reliability and accuracy of static weight distribution for measuring limb function in dogs (2).

In human medicine, digital weighing scales, biofeedback systems, force-sensing resistors, ambulatory devices, and force platforms are used for quantifying limb loading in the standing position (10). In clinical practice, force platforms and force-sensing resistors are considered gold standard tools for static weight bearing, called plantar pressure distribution measurement (22). Although it is less reliable and accurate, digital weighing scales have also demonstrated some degree of reliability and validity compared to standard tools (13).

Of these tools, force-sensing resistors have been reported to have validity, high accuracy and moderate to good reliability in several studies (3,22). The force-sensing resistor is also useful for pedobarography to measure the displacement of the center of pressure by dividing the area of the foot (8). This procedure has been used to analyze changes in pressure distribution during disease (3). In addition, it is suitable for clinical practice because it has a lower price and portability advantages compared to other measurement methods. However, to the author's knowledge, there is no report of the reliability and validity of force-sensing resistors used in veterinary medicine to measure static weight distribution. These devices have been used in many studies and in clinical practice in human medicine and can be a very useful measurement tool in veterinary medicine if it is shown to be reliable and valid.

Therefore, the purpose of present study was to assess the reliability of the force-sensing resistor and its validity against digital weighing scale in hindlimb loading measurements during static standing in normal beagle dogs.

Materials and Methods

Animals

Nine healthy beagle dogs (6 intact males and 3 intact females; mean age 4.22 ± 1.86 years and mean weight 9.72 ± 1.57 kg) were recruited for this study. All dogs underwent physical and radiographic examination to confirm that there was no orthopedic disease prior to the experiment. The Institutional Animal Care and Use Committee of Chonbuk National University provided ethical approval for the study.

Equipment apparatus

The digital weighing scales (TS500, Jiangyin Ditai Electronics CO., Shanghai, China) have a 215 × 175-mm tray, capacity from 6 kg to 25 kg and an accuracy of 0.5 g for 6 kg and 1 g for more than 6 kg (Fig 1A). The force-sensing resistor (Snowforce Matrix Sensor 1610, Kitronyx, Seoul, South Korea) is 0.43 mm thick (50.8 × 76.2 mm), has a force sensitivity range of 0.1 to 5.7 kg with 3.2 cm^2 surface area and has a sampling rate of 50 Hertz (Hz) (Fig 1B).

Experimental design

All procedures were conducted in a single session by two investigators. The bilateral hindlimbs of each dog were measured using both the digital weighing scales and the force-sensing resistor. Measurements were recorded four times at intervals of 5 days for each dog. Overall, the weight distribution was measured 32 times per dog and 144 measurements per device.

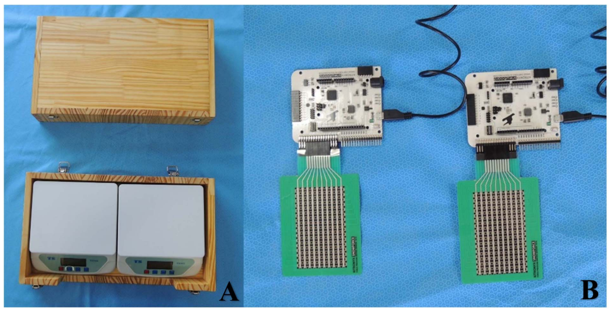

Fig 1. Digital weighing scale (TS500) (A) and Force sensing resistor (Snowforce Matrix Sensor 1610) (B).

Data collection

The dogs were held in the same square-standing position with the head held directly in front for both digital weighing scales and force-sensing resistor measurements. The data collection started after this posture was maintained for 3 to 5 seconds. For the digital weighing scale, two identical commercially available scales were placed under each hindlimb. The forelimbs were placed on a custom-made, non-slippery platform with the same height as the digital weighing scale. Before each measurement, the scales were calibrated to the weight of the dog according to the manufacturer's guidelines. While allowing the assistant to maintain a square-standing posture in front of the dogs, the observer stood behind the dog to confirm whether the hindlimbs were symmetrically placed on the scales and recorded the measurements. At this time, a total of five valid measurements were recorded, and the mean values were calculated for later use in the statistical analysis. After 10 minutes of rest, the dogs were measured in the same way by other observers.

The force-sensing resistor was also measured in the same manner as the digital weighing scale, and calibration was performed according to the manufacturer's guidelines prior to measurement. The sampling rate was 50 frame/s, and the duration of the data acquisition was at least 200 frames per measurement, of which the middle 50 frames were later used for statistical analysis. These procedures were repeatedly measured for 4 days each with an interval of 5 days.

Statistical analysis

All statistical analyses were performed using SPSS software version 24.0 (IBM SPSS Statistics 24.0, IBM Corp., Chicago, US). The normality of the distribution of the static weight distribution was determined by the Shapiro-Wilk test. The data were analyzed as the mean ± standard deviation (SD). The coefficient of variation (COV) was calculated to represent the variability of the measurement method as a percentage and to compare direct variables between the different measurement methods.

The evaluation of intra- and inter-observer reliability for the digital weighing scale and force-sensing resistor was performed with an intraclass correlation coefficient (ICC) and 95% confident intervals (CIs). The interpretation of ICC was made according to the criteria of Portney and Watkins, and is considered poor when lower than 0.5, moderate between 0.5 and 0.75, good between 0.75 and 0.9, and excellent when higher than 0.9 (18). The ICCs with 95% CIs were evaluated based on a single measurement, absolute-agreement, 2-way mixed-effects model for intra-observer model and a single-rating, absolute-agreement, two-way random effects model for interobserver reliability (12).

Pearson's correlation coefficients were used to observe the dependence of the force-sensing resistor compared to the digital weighing scale.

Bland-Altman plots were used to represent bias between the left and right side for both the digital weighing scale and force-sensing resistor. $p < 0.05$ was considered statistically significant.

Results

Two hundred eighty-eight measurements were collected and analyzed. The measurements from the digital weighing scale and force-sensing resistor were summarized as the mean, SD, and 95% CI (Table 1). Digital weighing scale measurements varied slightly less than force-sensing resistor measurements at each hindlimb. The standard deviations for each side ranged from 2.94 to 3.03 for the digital weighing scale and 4.71 to 5.87 for the force-sensing resistor. The coefficient of variation (COV) of the force-sensing resistor was relatively higher than that of the digital weighing scale.

The ICC values of the digital weighing scale for both intra- and inter-observer reliability were poor to moderate, and the ICCs for the force-sensing resistor were moderate to good for intra-observer measurements and poor to moderate for inter-observer measurements (Table 2). The standard error of measurement (SEM) was higher for the force-sensing resistor than for the digital weighing scale for both intra- and inter-observer reliability.

The Pearson's correlation coefficient showed a statistically significant low positive correlation between the digital weighing scale and the force-sensing resistor (Pearson's correlation coefficient R = 0.41, $p < 0.01$).

The Bland-Altman plots showed a slight bias in body weight loading between both hindlimbs (Fig 2, 3). The digi-

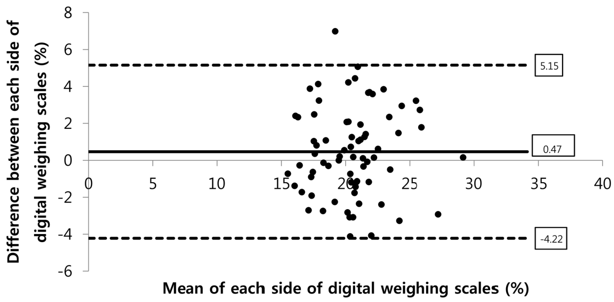

Fig 2. Bland Altman plot of weight distribution on each side from a digital weighing scale. The dashed lines represent the 95% confidence interval, and the middle black line (0.47%) indicates the mean value. The increased mean value indicated that the weight distribution shows a slight positive bias toward the left hindlimb.

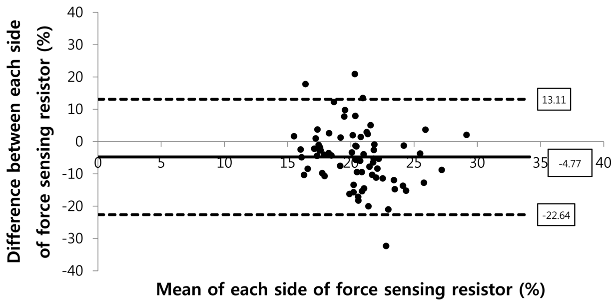

Fig 3. Bland Altman plot of weight distribution on each side from the force-sensing resistor. The dashed lines represent the 95% confidence interval, and the middle black line (–4.77%) indicates the mean value. The decreased mean value indicated that the weight distribution shows a slight positive bias toward the right hindlimb.

Table 1. Summary of measurements from a digital weighing scale and a force-sensing resistor

Variable	Left				Right			
	Mean	SD	COV	95% CI	Mean	SD	COV	95% CI
Digital weighing scale	20.70	3.03	14.64	19.99-21.42	20.24	2.94	14.53	19.55-20.93
Force-sensing resistor	18.10	4.71	26.02	17.00-19.21	22.87	5.87	25.67	21.49-24.25

SD: standard deviation; COV: coefficient of variation; CI: confidence interval.

Table 2. Intra- and inter-observer reliability statistics of a digital weighing scale and a force-sensing resistor

Measure	ICC	95% CI		SEM
		Lower	Upper	
Intra-observer Reliability of Digital Weighing Scale	0.56	0.26	0.75	1.98
Intra-observer Reliability of Force-Sensing Resistor	0.74	0.55	0.86	2.89
Inter-observer Reliability of Digital Weighing Scale	0.61	0.38	0.76	1.87
Inter-observer Reliability of Force-Sensing Resistor	0.53	0.25	0.71	3.89

ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement.

tal weighing scale overestimated the weight placed on the left hindlimb by 0.47%, and the force-sensing resistor overestimated weight on the right hindlimb by 4.77%.

Discussion

The present study demonstrates that the force-sensing resistor showed better reliability when measuring static weight distribution compared to the previously reported digital weighing scale (11). Therefore, the force-sensing resistor should be considered a relatively more reliable tool than the digital weighing scale when follow up is required, such as evaluation of postoperative prognosis or rehabilitation therapy. In addition, according to a previous study, the group with osteoarthritis or lameness had obvious weight bearing asymmetry, and thus, the reliability of the digital weighing scale or stride length measurement was significantly higher than in the control group (11,16). Therefore, additional studies should be followed, but the force-sensing resistor is considered to show better reliability in the presence of diseases. In addition, it is necessary to be careful not to interchange the results of the two measurement methods because of the low positive correlation.

To the author's best knowledge, a comparison of interobserver reliability for digital weighing scales and force-sensing resistors have not been reported previously in veterinary medicine. According to our results, both measurement methods showed poor to moderate reliability in measuring static weight distribution. Therefore, care should be taken interpreting the results when the observer changes.

Both methods showed high variability, among which the force-sensing resistor showed higher SD, COV and SEM with 95% confidence intervals. These results indicate the possibility that the accuracy of the values measured by the force-sensing resistor may be impaired. The possible cause of this variability includes postural instability in the process of placing the foot on a small sensor, or that the sensor might not recognize all the foot prints. In human medicine, variability in force-sensing resistors has been reported to be high and low depending on the foot area, but it is considered a developmental limitation (22).

The Bland-Altman plot analysis of the force-sensing resistor revealed a slight bias of 4.77% to the right hindlimb. As this bias was not observed on the digital weighing scale in the same experimental conditions, our testing station was not considered to be responsible for that bias. Rather, it was considered to be a result of postural instability as mentioned above, a slight error between the two sensors used in this experiment, or a bias in the weight distribution to the dominant right hindlimb of healthy dogs as reported in previous studies (5,11,17). Previous studies have shown that when using a 10% asymmetry threshold, 10 out of 19 normal Labrador Retrievers dogs with no history of lameness were right-dominant, 1 was left dominant, and 8 were symmetric in their hindlimbs. Although these were results of trotting dogs, additional research is needed, but it is considered to be responsible for the bias in this study.

In addition, the cut-off value was 6% in the static weight bearing distributions presented in other studies. Therefore, the bias in this study was not considered to have a clinical significance, but further studies are necessary to identify the mechanical characteristics of the hindlimbs of normal dogs and to apply force-sensing resistors.

The limitations of this study including only measuring both hindlimbs. Thus, the possibility of compensation in the weight bearing distribution towards the forelimb was ignored. In addition, since clinical or disease-induced models of force-sensing resistors were not studied in the present study, it is possible that different results will be obtained in actual clinical practice. However, the results were considered to have clinical significance in that they can provide a reference point for measuring the reliability and weight distribution of a force-sensing resistor in normal dogs. The intra-observer reliability of the force-sensing resistor analyzed in the present study was moderate to good, but there was poor to moderate inter-observer reliability. These results were less reliable than those reported in human medicine, and additional development and research is needed on force-sensing resistors (9). Additionally, the results of this study alone have limitations in making clear conclusions about the bias of the weight bearing distribution from force-sensing resistors.

Therefore, further studies on the reliability and accuracy of force-sensing resistors using inanimate objects with definite mass are needed. Additionally, it is necessary to develop a mat-type pressure distribution measurement system using this force-sensing resistor to evaluate correlations with other systems, such as pressure sensitive walkways and force platforms and to study static weight distribution in a clinical disease model. Ultimately, as in human medicine, it is necessary to map the footprints through pedobarography and analyze the mechanical characteristics of the diseases.

Conclusion

The results of this study revealed that force-sensing resistors can be used as a reliable and objective measurement methods for static weight bearing distribution and evaluating the symmetry of both hindlimbs in veterinary medicine. To the best knowledge of the authors, the present study is considered to have a clinical significance as a first report in veterinary medicine to assess the reliability of force-sensing resistors and compare them with digital weighing scales for measuring static weight distribution in normal dogs. Further studies on clinical data and pedobarography using force-sensing resistors will be needed for application to clinical practice and research.

Acknowledgements

This study was supported by research fund of Chungnam National University.

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