RESEARCH ARTICLE Indian Journal of Animal Research, Volume 60 Issue 3: 433-438 (March 2026)

Assessment of Gait Symmetry and Peak Vertical Force in Small-sized Dogs with Experimentally Induced Forelimb Lameness

Shin-Ho Lee[1], Sujin Kim[1], Jae-Hyeon Cho[2], Yu-Ri Cha[3]

10.18805/IJAR.BF-2081

ABSTRACT

Background: This study examines load redistribution mechanisms in six small-sized dogs subjected to induced right forelimb lameness during leash walking. The purpose of this investigation, utilizing this experimentally induced lameness, is to determine the compensatory patterns in animal patients presenting with forelimb injuries.

Methods: Peak vertical force (PVF) and symmetry indices (SI) were used as metrics to analyze load distribution across all four limbs under both sound (control) and lame conditions.

Result: The results indicated a significant reduction in PVF in the ipsilateral forelimb (91.33±26.39) during lameness, accompanied by a compensatory increase in the contralateral forelimb (121.72±26.44). The symmetry indices further reflected the degree of asymmetry, with forelimb SI increasing from 8.19±4.88 (sound) to 34.24±20.26 (lame) and hindlimb SI increasing from 8.43±8.16 (sound) to 16.54±11.83 (lame). These findings highlight the significant compensatory mechanisms that occur in response to forelimb lameness in small-sized dogs, with increased loading on the contralateral limbs to compensate for the reduced function of the affected limb. This study provides valuable insights into the biomechanical adjustments in small-sized dogs with lameness, which may inform clinical approaches to diagnosis and rehabilitation.

Key words: Compensation, Dog, Gait analysis, Kinetics, Lameness.

INTRODUCTION

Canine lameness is a common clinical problem, frequently resulting from orthopedic conditions such as joint dysplasia, ligament injuries, or other musculoskeletal disorders. The forelimbs of dogs bear approximately 60% of their body weight during normal locomotion, while the hind limbs bear the remaining 40% (Abdelhadi *et al*., 2012). The most widely used methods for gait analysis include force plates and pressure plates, with the use of force plates recognized as the gold standard (Voss *et al.,* 2011; Schwarz *et al.,* 2017). Force plates, devices designed to measure the forces exerted by dogs' paws on the ground during locomotion, were used to capture vertical, horizontal and lateral forces, enabling a comprehensive analysis of the dogs' gait (Budsberg *et al.,* 1987). Ground Reaction Force (GRF) is a reaction force that occurs when the foot contacts the ground and the vertical component represents the weight support ability of the animal and is generally expressed as a percentage of body weight. The maximum force means the highest value of GRF during the stance phase. Symmetry Indices (SI) are metrics used in gait analysis to evaluate the symmetry between the left and right limbs, primarily calculated based on GRF (Bockstahler *et al.,* 2009).

Gait analysis provides useful information about normal and impaired limb loading and is often used in basic research and treatment outcome assessment (Bockstahler *et al.,* 2007; Foss *et al.,* 2013; Katic *et al.,* 2009). The study aimed to determine the accuracy of pressure plate kinetic asymmetry indices and their correlation with the scores of visual gait assessment in dogs with unilateral hindlimb (Oosterlinck *et al.,* 2011).

[1]Department of Companion Animal Health, Tongmyong University, Busan 48520, Republic of Korea.
[2]Institute of Animal Medicine, College of Veterinary Medicine, Gyeongsang National University, Jinju 52828, Republic of Korea.
[3]Department of Physical Therapy, Sunlin University, Pohang 37560, Republic of Korea.

Corresponding Author: Yu-Ri Cha, Department of Physical Therapy, Sunlin University, Pohang 37560, Republic of Korea. Email: iravu@sunlin.ac.kr
ORCID: https://orcid.org/0000-0003-0450-0048, https://orcid.org/0009-0003-8521-1156, https://orcid.org/0000-0003-1126-9809, https://orcid.org/0000-0002-3057-393X

How to cite this article: Shin-Ho, L., Kim, S., Jae-Hyeon, C. and Yu-Ri, C. (2026). Assessment of Gait Symmetry and Peak Vertical Force in Small-sized Dogs with Experimentally Induced Forelimb Lameness. *Indian Journal of Animal Research.* **60(3):** 433-438. doi: 10.18805/IJAR.BF-2081.

Submitted: 16-10-2025 **Accepted:** 23-12-2025 **Online:** 21-01-2026

GRF is a common way to describe gait symmetry and assess limb loading in humans as well as dogs (Strasser *et al.,* 2014). Ground reaction force is the result of the interaction between the dog's body and the ground during landing and it plays a critical role in understanding the biomechanics of jumping, potential injuries and stress on the musculoskeletal system (Pardey *et al.,* 2018; Pfau *et al.,* 2011). GRF measurements, such as peak vertical force (PVF) and vertical impulse have been widely used to quantify the effects of lameness on canine gait. Symmetry indices (SI), which compare the force distribution between limbs, are also valuable for detecting asymmetry in dogs

with orthopedic conditions. These tools enable veterinarians to assess the extent of load redistribution and make informed decisions about treatment options (Abdelhadi *et al.,* 2013; Escobar *et al.,* 2017; Evans *et al.,* 2005). Additionally, more recent studies with a larger number of enrolled subjects have evaluated the variation of PVF in patients with cranial cruciate ligament rupture (Della Valle *et al.,* 2021).

Canine lameness, commonly caused by orthopedic and other musculoskeletal disorders, is routinely evaluated using kinetic gait analysis with force or pressure plates that measure GRF and SI to quantify limb loading, asymmetry and treatment response, mainly in medium- and large-breed dogs (Tuchpramuk *et al.,* 2025).

The presence of clinical lameness in dogs was assessed using asymmetry between the proportion of body weight supported by the two hind limbs (Fanchon and Grandjean, 2007).

Given that most existing literature on canine gait analysis has been focused on medium-to-large-sized breeds, this study aimed to experimentally analyze the weight redistribution and compensatory mechanisms affecting the forelimbs and hindlimbs of six small-sized dogs subjected to induced right forelimb lameness (IRF), using indicators such as PVF and SI during leash walking to comprehensively understand the impact of lameness on their gait. Using indicators such as PVF and SI during leash walking, this study aims to comprehensively understand the impact of lameness on the gait of dogs and present meaningful results for veterinary clinical practice.

MATERIALS AND METHODS

Animals

The study included six adult, clinically sound, client-owned dogs (three Poodles, one Maltese and two Pomeranians) between one and seven years of age (3.0±2.1 years) and weighing 2.7-7.4 kg (4.3±1.5 kg); the dogs were owned by three different clients. All dogs underwent a comprehensive physical, orthopedic and neurologic examination, including assessment of gait at the trot and palpation and manipulation of the thoracic and pelvic limbs and the spinal column. Dogs were included only if they showed no visible lameness, no pain or crepitus on joint manipulation and no history or clinical evidence of musculoskeletal or neurologic disease; dogs receiving analgesic or anti-inflammatory medications or exhibiting any abnormalities on examination were excluded from the study.

Gait analysis

The owners were instructed to walk their dogs at their usual pace across the force plate for 5-10 minutes while providing food treats as positive reinforcement so that the dogs would not show fearful or exaggerated reactions to the gait analysis device; after this acclimation period, peak vertical force (PVF) and the symmetry index (SI) were measured using a gait analysis device (FDM-TPROF CanidGait®, Zebris Medical GmbH, Germany). The pressure plate had a measurement area of 203.2 × 54.2 cm and included 15.360 sensors with a sampling rate of 100 Hz.

Study design

The experiment was conducted at Tongmyong University from April 10, 2025, to June 30, 2025. Each dog was subjected to temporary, mild lameness by attaching a rubber stopper (9.5 or 14 mm in diameter; Fig 1A) from a syringe to the plantar surface of the right forepaw using tape (Fig 1B). After this procedure, the dogs performed leash walking over the gait analysis platform alongside their owners under the same environmental conditions as during the control trials and the owners adjusted their walking speed and leash handling so that each dog maintained a regular trotting. For each dog and each condition (sound and induced right forelimb lameness), three valid trials showing a consistent trot were collected and the mean of these three trials per condition was used for analysis. Dogs were allowed to rest for at least five minutes between conditions. The owner stood beside the dog (Fig 2A), using the leash to keep the dog oriented forward on the gait analyzer and provided positive reinforcement to help the dog remain calm and avoid stress or fear (Fig 2B). Each of the six dogs contributed three valid trials per condition (sound and induced right forelimb lameness), resulting in a total of six trials per condition for analysis. Trials were excluded if the dog failed to maintain a regular trotting gait, moved outside the predefined velocity range, stopped or turned the head, or did not fully contact the gait analysis platform and only the remaining valid trials were used for statistical evaluation.

Statistical analysis

Statistical analysis was performed using SPSS software (version 22.0; IBM Corp., Armonk, NY, USA). A Wilcoxon signed-rank test to detect differences in PVF and SI was conducted to compare the sound (control) and induced lameness conditions. Statistical significance was defined as $p<0.05$. All statistical analyses were conducted using specialized software.

RESULTS AND DISCUSSION

The summary of PVF values for all four limbs under sound (control) and lame conditions is presented in Table 1. Statistical significance was confirmed. Mean PVF values (expressed as % body weight) did not differ between the two forelimbs or between the two hind limbs (contralateral forelimb: 103.72±22.64%; ipsilateral forelimb: 101.89± 20.96%; contralateral hind limb: 75.11±15.17%; ipsilateral hind limb: 74.00±15.26%; $p>0.05$; Fig 3). When lameness was induced in the right forelimb, PVF of the ipsilateral forelimb decreased to 91.33±26.39% body weight ($p= 0.012$), whereas PVF of the contralateral forelimb increased to 121.72±26.44% body weight ($p = 0.008$); PVF values in the contralateral and ipsilateral hind limbs changed only

slightly (86.50±19.65% and 73.67±13.36% body weight, respectively) and these differences were not statistically significant (p = 0.27 and p = 0.81, respectively; Fig 3).

For SI, no significant asymmetry was detected between the two forelimbs or between the two hind limbs under the sound (control) condition during leash walking (forelimbs SI: 8.19±4.88, p = 0.35; hindlimbs SI: 8.43±8.16, p = 0.42). After induction of lameness in the right forelimb, SI increased to 34.24±20.26 for the forelimbs (p = 0.004) and to 16.54±11.83 for the hindlimbs (p = 0.018), indicating a marked increase in asymmetry despite the absence of significant changes in hindlimb PVF (p = 0.29; Fig 4).

Force platform gait analysis was more sensitive than visual observation in detecting subtle lameness and assessing compensatory load redistribution (Evans *et al.,* 2005). These findings are consistent with previous research on lameness in dogs, which has shown that compensatory mechanisms often involve increased loading on the contralateral limbs (Waxman *et al.,* 2008). Using the variables of PVF and SI, the study was conducted about induced right forelimb's lameness to evaluate compensatory changes in the other limbs and recorded and analyzed the compensatory changes, while also evaluating and analyzing objective information such as kinetics using a gait analysis system on six healthy small dogs.

Fig 3 results show that during the lame condition, the PVF in the ipsilateral forelimb decreased significantly to 91.33±26.39, while the contralateral forelimb exhibited an increase to 121.72±26.44. In the gait of dogs affected by elbow osteoarthritis, mean vertical force was measured to be higher on the unaffected side compared to the affected side. Similarly, in the evaluation of forelimb function after arthrotomy using an approach to the shoulder joint, the mean vertical force was higher on the unaffected side than on the affected side (Bockstahler *et al.,* 2009). As demonstrated in the results of this study, the contralateral forelimb, where lameness was intentionally induced, showed a significant increase compared to the sound condition.

Table 1: Mean (±SD) PVF values (%BW) for each limb under sound (control) and induced forelimb lameness conditions.

Condition	Contralateral forelimb	Ipsilateral forelimb	Contralateral hindlimb	Ipsilateral hindlimb
Sound(control)	103.72±22.64	101.89±20.96	75.11±15.17	74.00±15.26
Lame	121.72±26.44	91.33±26.39	86.50±19.65	73.67±13.36



Fig 1: A. 10 cc syringe's rubber stopper was positioned at the center of the metacarpal pad on the right forelimb's paw of the dog to induce lameness in the limb. B. Using 3M paper tape, the rubber stopper was wrapped around the entire paw to prevent it from falling off, there by inducing reversible lameness.

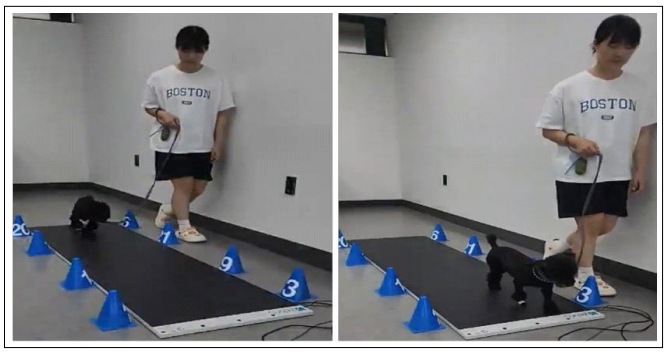
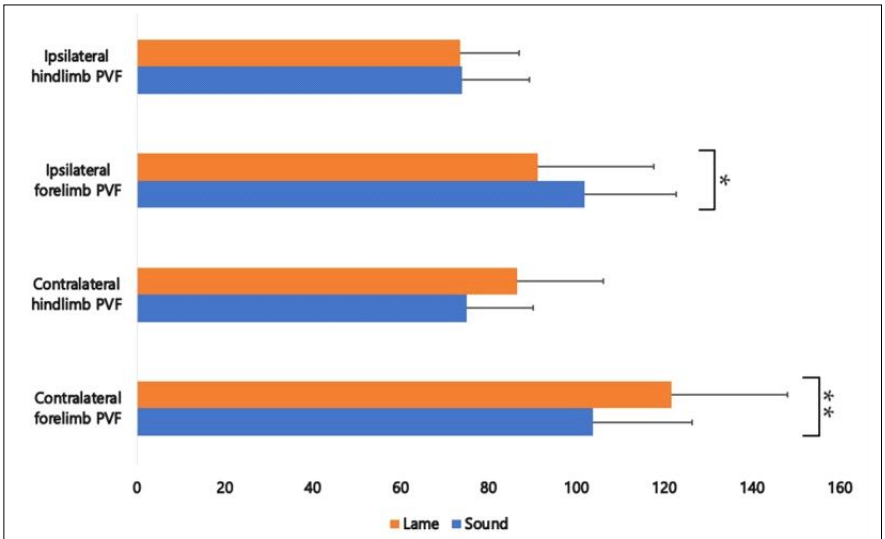


Fig 2: A. At the beginning, the owner positioned themselves between the dog's head and shoulders, ensuring that the dog walked without excessive tension or pulling on the leash. B. Throughout the process, the owner maintained a natural gait without exerting force on the leash.

In the evaluation of the ipsilateral forelimb, a significant increase was also observed in the sound condition, indicating that unilateral lameness leads to compensatory changes in the contralateral limb.

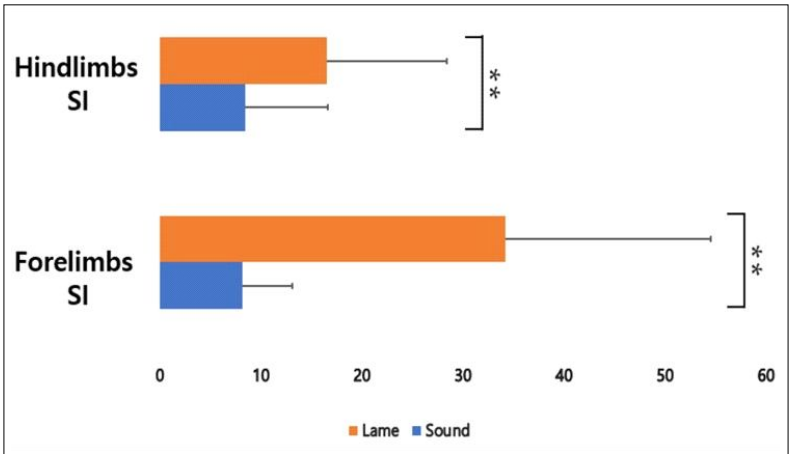
Furthermore, no compensatory alterations in PVF were identified in the contralateral hindlimb, where PVF was 86.50±19.65, or in the ipsilateral hindlimb, which showed a PVF of 73.67±13.36. However, a notable reduction in PVF was observed in the ipsilateral forelimb, alongside a significant increase in the contralateral hind limb. In contrast, no PVF changes were detected in the contralateral forelimb and ipsilateral hind limb in a study involving 24 dogs clinically diagnosed with elbow joint osteoarthritis.

These results may be linked to the severity of the traumatic injury, as superficial and acute injuries tend to trigger less pronounced compensatory responses compared to deep and chronic injuries. Additionally, variations in the affected joints, such as the elbow versus the carpus, may influence the degree of weight redistribution and compensatory mechanisms during movement.



PVF = Peak vertical force. The data are presented as the mean ± SD of the percentage of body weight. *Within each limb, values are significantly different (*p<0.05, **p<0.01) compared to those observed under the sound condition.

Fig 3: PVF across all four limbs in six dogs under normal (control) conditions and following the induction of lameness in the right forelimb (ipsilateral forelimb).



SI = Symmetry indice. The values are expressed as mean ± SD. An SI of 0 indicates perfect symmetry. Negative SI values signify that the measured variable was higher in the left limb compared to the right, whereas positive values indicate the opposite. *Within a limb pair, values differ significantly (**p<0.01) from those recorded under the sound condition.

Fig 4: SI values measured in six dogs during the sound (control) condition and following the induction of lameness in the right forelimb.

In our study, although induced lameness, differences found significant increases and decreases in both sound and lameness in the contralateral forelimb and ipsilateral forelimb in the forelimb, but no significant changes in the hindlimb. The difference is that the previous study was conducted on medium-sized dogs weighing 27.2±5.5 kg, while the present study was conducted on small dogs weighing 4.3±1.5 kg. It can be speculated that small dogs may be able to compensate for contralateral forelimb gait during induced lameness without clearly detectable effects on hindlimb PVF. In this small-sized dog group, distinct compensatory changes were observed between the forelimbs, whereas corresponding changes in hindlimb PVF were not apparent within the sensitivity of the present analysis. This may highlight the role of the hindlimbs in maintaining stability and balance during gait. This study did not directly evaluate the effects of morphometric measures (*e.g.*, body weight, withers height and speed) on GRF. However, according to previous literature, these variables are likely to influence GRF not as isolated factors but through their interactions. Future studies should include such morphometric variables to provide a more comprehensive assessment of the variability in GRF.

SI measures the differences in force application between the ipsilateral (same side as the induced lameness) and contralateral (opposite side) limbs. For the sound condition (before lameness induction), there was no significant asymmetry between the left and right forelimbs, indicating a balanced load distribution. However, after lameness was induced, a significant asymmetry was observed in all variables. The increased hindlimb SI suggests that the pelvic limbs contribute to maintaining dynamic postural control during induced forelimb lameness (Abdelhadi *et al.,* 2012; Abdelhadi *et al.,* 2013). In this study, SI results, as shown in Fig 4, provide further evidence of asymmetry during lameness. For the forelimbs, the SI in sound dogs was 8.19±4.88, but this value increased to 34.24±20.26 in lame dogs, indicating a significant imbalance between the left and right forelimbs during lameness. Similarly, the hindlimb SI was 8.43±8.16 in the sound condition and rose to 16.54±11.83 in the lame condition, reflecting the compensatory load redistribution to the contralateral hindlimb. In the hindlimbs, SI increased significantly despite the absence of significant changes in PVF. This pattern suggests that fore-hind compensation may involve subtle left-right redistribution or timing adjustments in the pelvic limbs that are captured by SI but not by limb specific PVF alone, highlighting the comple-mentary value of SI for detecting compensatory gait changes.

The limitations of this study include, first, the very small number of participating dogs (n = 6), which restricts the statistical power and the generalizability of the findings. In addition, the experimental lameness model induced by attaching a stopper to the paw has not been fully validated in terms of reproducing the gait patterns and pain behaviors observed in naturally occurring orthopedic diseases and the degree of lameness may have varied between individuals, potentially introducing additional variability into the results.

Nevertheless, this study demonstrates that induced forelimb lameness in dogs' results in significant load redistribution to the contralateral forelimb and hindlimb, as evidenced by changes in PVF and SI. These findings contribute to our understanding of the biomechanical adaptations that occur in response to lameness and highlight the importance of comprehensive gait analysis in the diagnosis and treatment of lameness in dogs. From a broader welfare perspective, integrating objective kinetic variables with information on housing and husbandry practices or structured need indices, as proposed for pet dogs in Kerala, may provide a more comprehensive assessment of canine welfare in future studies (Vijayakumar *et al*., 2003; Vijayakumar *et al*., 2006).

CONCLUSION

This study investigated the biomechanical adaptations in small-sized dogs with induced forelimb lameness, focusing on compensatory load redistribution during leash walking. Significant changes in PVF and SI were observed in the forelimbs, particularly increased loading on the contralateral forelimb, while no significant alterations were detected in the hindlimbs for PVF. However, SI values showed asymmetry between the hindlimbs, suggesting a potential role in maintaining balance rather than direct compensation for forelimb lameness. The study has limitations, including the lack of consideration for variations in trauma severity (*e.g.*, superficial and acute versus deep and chronic injuries) and the influence of specific joint involvement (*e.g.*, elbow versus carpus), which may significantly affect compensatory mechanisms. Future research should address these factors while exploring how body size, joint involvement and trauma severity influence compensatory strategies across different breeds and sizes of dogs to provide deeper insights into biomechanical adaptations and improve clinical approaches to managing canine lameness.

ACKNOWLEDGEMENT

This research was supported by Culture, Sports and Tourism R and D Program through the Korea Creative Content Agency grant funded by the Ministry of Culture, Sports and Tourism in 2023 (Project Title: Development and Application of Second Life Using Pet Digital-Twin Based on Real Pet. Number: RS-2023-00227775, Contribution Rate: 100%).

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

The animal study protocol was approved by the Ethics Committee of Gyeongsang National University (protocol code: GNU-250409-D0084).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Abdelhadi, J., Wefstaedt, P., Nolte, I. and Schilling, N. (2012). Fore-aft ground force adaptations to induced forelimb lameness in walking and trotting dogs. *PLoS One*. **7:** e52202.

Abdelhadi, J., Wefstaedt, P., Galindo-Zamora, V. anders, A. and Schilling, N. (2013). Load redistribution in walking and trotting Beagles with induced forelimb lameness. *American Journal of Veterinary Research*. **74:** 34-39.

Escobar, A.S.A., de Souza, A.N.A., de Campos Fonseca Pinto, A.C.B. and Matera, J.M. (2017). Kinetic gait analysis in English bulldogs. *Acta. Vet. Scand.* **59:** 77.

Bockstahler, B.A., Skalicky, M., Peham, C., Müller, M. and Lorinson, D. (2007). Reliability of ground reaction forces measured on a treadmill system in healthy dogs. *Vet J*. **173:** 373-378.

Bockstahler, B.A., Vobornik, A. and Müller, M. *et al.* (2009). Compensatory load redistribution in naturally occurring osteoarthritis of the elbow joint and induced weight-bearing lameness of the forelimbs compared with clinically sound dogs. *Vet. J.* **180:** 202-212.

Budsberg, S.C., Verstraete, M.C. and Soutas-Little, R.W. (1987). Force plate analysis of the walking gait in healthy dogs. *American Journal of Veterinary Research.* **48:** 915-918.

Della Valle, G., Caterino, C., Aragosa, F., Micieli, F., Costanza, D., Di Palma, C., Piscitelli, A. and Fatone, G. (2021). Outcome after modified maquet procedure in dogs with unilateral cranial cruciate ligament rupture: Evaluation of recovery limb function by use of force plate gait analysis. *PLoS ONE.* **16:** e0256011.

Evans, R., Horstman, C. and Conzemius, M. (2005). Accuracy and optimization of force platform gait analysis in labradors with cranial cruciate disease evaluated at a walking gait. *Vet. Surg.* **34:** 445-449.

Fanchon, L. and Grandjean, D. (2007). Accuracy of asymmetry indices of ground reaction forces for diagnosis of hindlimb lameness in dogs. *Am. J. Vet. Res*. **68:** 1089-1094.

Foss, K., da Costa, R.C., Rajala-Shultz, P.J. and Allen, M.J. (2013). Force plate gait analysis in Doberman Pinschers with and without cervical spondylomyelopathy. *J. Vet. Intern. Med.* **27:** 106-111.

Katic, N., Bockstahler, B.A., Mueller, M. and Peham, C. (2009). Fourier analysis of vertical ground reaction forces in dogs with unilateral hind limb lameness caused by degenerative disease of the hip joint and in dogs without lameness. *Am. J. Vet. Res*. **70:** 118-126.

Oosterlinck, M., Bosmans, T., Gasthuys, F., Polis, I., Van Ryssen, B., Dewulf, J. and Pille, F. (2011). Accuracy of pressure plate kinetic asymmetry indices and their correlation with visual gait assessment scores in lame and nonlame dogs. *Am J. Vet Res*. **72:** 820-825.

Pardey, D., Tabor, G., Oxley, J.A. and Wills, A.P. (2018). Peak forelimb ground reaction forces experienced by dogs jumping from a simulated car boot. *Vet Rec*. **182(25):** 716.

Pfau, T., de Rivaz, A.G., Brighton, S. and Weller, R. (2011). Kinetics of jump landing in agility dogs. *The veterinary Journal.* **190(2):** 278-283.

Schwarz, N., Tichy, A., Peham, C. and Bockstahler, B. (2017). Vertical force distribution in the paws of sound Labrador retrievers during walking. *Vet. J.* **221:** 16-22.

Strasser, T., Peham, C. and Bockstahler, B.A. (2014). A comparison of ground reaction forces during level and cross-slope walking in Labrador Retrievers. *BMC Vet. Res*. **10:** 241.

Tuchpramuk, P., Kaenkangploo, D., Srithunyarat, T., Seesupa, S., Hoisang, S., Lascelles, B.D.X. and Kampa, N. (2025). Force plate gait analysis in dogs after femoral head and neck excision. *Vet Sci.* **12(5):** 469.

Vijayakumar, P., Francis Xavier, L. and Leena Anil, K. (2003). A need index for pet dogs. *Indian Journal of Animal Research*. **37(2):** 155-156.

Vijayakumar, P., Francis Xavier, L. and Leena Anil, K. (2006). Housing management practices of pet dogs in Central Kerala. *Indian Journal of Animal Research*. **40(1):** 73-75.

Voss, K., Wiestner, T., Galeandro, L., Hässig, M. and Montavon, P.M. (2011). Effect of dog breed and body conformation on vertical ground reaction forces, impulses and stance times. *Vet. Comp. Orthop. Traumatol.* **24:** 106-112. doi: 10.3415/VCOT-10-06-0098.

Waxman, A.S., Robinson, D.A., Evans, R.B., Hulse, D.A., Innes, J.F. and Conzemius, M.G. (2008). Relationship between objective and subjective assessment of limb function in normal dogs with an experimentally induced lameness. *Vet. Surg.* **37:** 241-246.