Distribution of vertical forces in the pads of Greyhounds and Labrador Retrievers during walking

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Objective—To document peak vertical force (PVF) and vertical impulse (VI) in the pads of Greyhounds and Labrador Retrievers.

Animals—8 Greyhounds and 8 Labrador Retrievers.

Procedure—Velocity and acceleration were restricted to ranges of 0.9 to 1.1 m/s and –0.1 to 0.1 m/s^2, respectively. The PVF and VI measurements were collected from digital pad (DP)-2, -3, -4, and -5 and the metacarpal pad (McP) or metatarsal pad (MtP) of each limb in each dog.

Results—We found no significant differences between the left and right forelimbs or hind limbs for any pad in either breed. Vertical forces in the forelimb were always greater than those in the hind limb. The PVF in the forelimbs of Greyhounds was greatest in DP-3, -4, and -5 and DP-3, DP-4, and the MtP in the hind limbs. The VI in Greyhound forelimbs was greatest in DP-3, -4, and -5 but greatest in DP-4 in the hind limbs. The PVF in the forelimbs of Labrador Retrievers was greatest in the McP, whereas in the hind limbs it was greatest in DP-4. The VI in Labrador Retriever forelimbs was greatest in DP-3, DP-4, and the McP but greatest in DP-3 and -4 in the hind limbs. Significant differences were detected in load distribution between the breeds.

Conclusions and Clinical Relevance—This study confirms that DP-3 and DP-4 are major weight-bearing pads in dogs. However, loads were fairly evenly distributed, and DP-5 and the McP or MtP bear a substantial amount of load in both breeds. (*Am J Vet Res* 2004;65:1497–1501)

Gait analysis by use of a force platform is an accurate and objective way to evaluate limb function in dogs. This type of analysis has been used to evaluate normal **ground-reaction forces (GRFs)** and alterations of those forces attributable to disease or medical or surgical interventions.[1-7] To our knowledge, the most commonly used platforms have been unable to separate forces transferred by the various areas of a foot in contact with the ground. Pressure-platform measurement systems can be an acceptable alternative to traditional force platforms.[8] Furthermore, pressure-platform measurement systems allow researchers to isolate and evaluate specific areas of a foot during the stance phase of the gait. This becomes relevant when clinical decisions are made on the basis of how load through a foot may be transferred to the rest of the limb and the manner in which it affects the foot and the proximal portion of the limb.

Historically, it has been believed that load distribution from the various pads of the feet of dogs is principally transferred through the third and fourth digits.[9] However, the authors are not aware of any supporting literature that documents these conclusions. The purpose of the study reported here was to determine the distribution of load in the pads of Greyhounds and Labrador Retrievers during walking. Our hypotheses were that most of the load would be transferred through the third and fourth digits in all limbs and that Greyhounds and Labrador Retrievers would have similar pressure distribution patterns while walking.

Materials and Methods

Animals—Eight healthy adult Greyhounds ranging from 27.30 to 36.36 kg and 8 healthy adult Labrador Retrievers ranging from 31.40 to 41.82 kg were used in the study. The dogs comprised 6 spayed females, 5 neutered males, 4 sexually intact males, and 1 sexually intact female. Physical, orthopedic, and neurologic examinations were performed; we required that results for all examinations were considered normal for each dog prior to inclusion in the study. All Greyhounds were blood donors at the Iowa State University College of Veterinary Medicine. The Labrador Retrievers were dogs owned by students and faculty of the Iowa State University College of Veterinary Medicine. All client-owned dogs had written consent to be included in this study. All protocols were approved by the Animal Care and Use Committee of Iowa State University.

Data collection—A 2 × 0.75-m pressure walkway[a] was placed in the center of a 10-m runway. The surface of the pressure walkway was level with the surface of the runway. Before data collection, each dog was weighed on an electronic scale and allowed to acclimate to the runway area and pressure walkway. For acclimation, dogs were walked across the pressure walkway in a manner consistent with the data acquisition process until they appeared comfortable; this typically required 5 passages.

Walkway sensors were calibrated in accordance with manufacturer specifications.[10] The pressure walkway was connected to a dedicated computer[b] equipped with specific software[c] designed for data collection and storage.

Walking velocity and acceleration were restricted to ranges of 0.9 to 1.1 m/s and –0.1 to 0.1 m/s^2, respectively. As each dog was walked along the runway, velocity and acceleration were recorded by the use of 3 photoelectric cells placed

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at 1.0-m intervals and coupled with a triggered timer system. The photocells were centered over the walkway, with the starting end of the walkway aligned with the first photocell. Mean velocity and acceleration were measured as each dog progressed along the length of the walkway.

Sampling rate (150 Hz) was selected prior to data collection. The rate was set by the accompanying software on the basis of a 3-second movie recorded at 50 frames/s.

A valid trial consisted of velocity and acceleration within the aforementioned ranges, each of the 4 limbs fully contacting the walkway at least once during a dog's passage, and the dog walking in a straight line. A single observer (MFB) evaluated each trial and determined whether the trial was valid. Ten valid trials were recorded for each dog. Dogs completed all trials in a single day.

Data on pressure distribution were then collected from each of the 10 recorded trials for each dog. The first foot strikes of the right and left forelimb and right and left hind limb for each breed were evaluated from each trial. For each foot strike that was evaluated, measurements of **peak vertical force (PVF)** and **vertical impulse (VI)** were obtained from 5 areas: **metacarpal pad (McP)** of the forelimb or **metatarsal pad (MtP)** of the hind limb, respectively, and **digital pad (DP)**-2, -3, -4, and -5. The PVF and VI for the entire foot strike were also recorded. All forces were adjusted on the basis of the dog's body weight and expressed as a percentage of body weight.

Statistical analysis—Histograms and summary statistics were used initially to verify distributional assumptions and confirm quality of the data. Two types of analyses were then performed to assess differences among pads within each breed and to test differences between breeds for each pad. To assess differences among pads within a breed, paired *t* tests were performed on each pair of pads (eg, DP-2 from the left forelimb was compared with DP-2 of the right forelimb). Next, for the 5 pads in each foot strike, *t* tests were used to make comparisons of GRFs between breeds. Separate analyses were conducted for PVF and VI. Significance was defined at $P < 0.05$. Type I error corrections were not required because the pairs of tests did not originate from an ANOVA experimental design with independent groups.

Results

Mean ± SD values for velocity and acceleration for Greyhounds were 0.95 ± 0.02 m/s and 0.03 ± 0.03 m/s^2, respectively. Mean velocity and acceleration for Labrador Retrievers were 0.99 ± 0.04 m/s and 0.02 ± 0.03 m/s^2, respectively.

We did not detect significant differences between the left and right forelimbs or left and right hind limbs for any pad in either group. Vertical forces of each pad of the forelimb were always greater than those of the corresponding pad of the hind limb (**Table 1**).

The PVF in the forelimbs of Greyhounds was greatest in DP-3, -4, and -5 and the McP, followed by DP-2 (**Figure 1**). The PVF in the hind limbs of Greyhounds was greatest in DP-3 and -4 and the MtP, followed by DP-5 and -2, respectively. The VI in Greyhound forelimbs was greatest in DP-3, -4, and -5, followed by the McP and DP-2, respectively. The VI in Greyhound hind limbs was greatest in DP-4, followed by DP-3 and -5, the MtP, and DP-2, respectively.

The PVF in the forelimbs of Labrador Retrievers was greatest in the McP, followed by DP-3 and -4, DP-5, and DP-2, respectively. The PVF in the hind limbs of Labrador Retrievers was greatest in DP-4, followed by DP-3 and the MtP, then DP-5 and -2, respectively. The VI in Labrador Retriever forelimbs was greatest in DP-3 and -4 and the McP, followed by DP-5 and -2, respectively. The VI in Labrador Retriever hind limbs was greatest in DP-3 and -4, followed by DP-5, then the MtP and DP-2, respectively.

Comparison among the pads within each breed revealed that DP-3 and -4 were similar for PVF and VI in almost all limbs (**Table 2**). The exception was for PVF in the hind limbs of Labrador Retrievers and VI in the hind limbs of Greyhounds.

Comparison of the pads between breeds revealed significant differences for PVF in DP-4 and -5 in the forelimbs and DP-3, -4, and -5 in the hind limbs. Evaluation of VI revealed significant differences in DP-4 and -5 in the forelimbs and DP-2, -3, -4, and -5 in the hind limbs.

Table 1—Mean ± SD values for peak vertical force (PFV) and vertical impulse (VI) for Greyhounds and Labrador Retrievers.

		PVF				VI			
Breed	Pad	Left forelimb	Right forelimb	Left hind limb	Right hind limb	Left forelimb	Right forelimb	Left hind limb	Right hind limb
Greyhound	McP or MtP	13.41 ± 3.92	14.09 ± 4.54	10.87 ± 2.16	10.33 ± 2.41	3.70 ± 1.44	3.70 ± 1.60	2.12 ± 0.93	1.96 ± 0.85
	DP-2	9.38 ± 2.23	8.99 ± 1.69	6.51 ± 1.38	6.18 ± 0.65	3.76 ± 0.93	3.69 ± 0.82	2.26 ± 0.57	2.18 ± 0.33
	DP-3	14.21 ± 2.49	14.29 ± 1.60	11.61 ± 1.62	11.48 ± 1.48	5.49 ± 0.92	5.58 ± 0.65	4.27 ± 0.65	4.45 ± 0.57
	DP-4	14.29 ± 2.24	13.45 ± 1.64	11.82 ± 1.01	10.96 ± 0.73	5.60 ± 1.02	5.33 ± 0.78	4.92 ± 0.50	4.39 ± 0.36
	DP-5	13.21 ± 1.87	12.48 ± 2.03	8.48 ± 1.32	8.13 ± 1.61	5.41 ± 0.81	5.18 ± 0.80	3.34 ± 0.37	3.11 ± 0.64
	Total for entire foot	56.74 ± 4.80	54.59 ± 3.84	41.64 ± 3.57	40.14 ± 4.08	25.56 ± 1.97	24.76 ± 2.49	17.91 ± 0.83	17.02 ± 1.58
Labrador Retriever	McP or MtP	16.92 ± 5.18	17.54 ± 5.58	10.81 ± 5.68	10.86 ± 6.38	4.60 ± 2.27	4.90 ± 2.53	2.32 ± 1.76	2.34 ± 1.91
	DP-2	8.16 ± 1.60	7.62 ± 2.05	4.33 ± 1.16	4.56 ± 1.29	2.91 ± 0.66	2.70 ± 0.71	1.33 ± 0.36	1.44 ± 0.41
	DP-3	13.08 ± 2.10	13.04 ± 1.93	8.99 ± 1.46	9.71 ± 1.35	4.67 ± 0.74	4.52 ± 0.69	3.43 ± 0.68	3.48 ± 0.67
	DP-4	12.07 ± 1.37	13.07 ± 2.05	10.22 ± 1.22	9.69 ± 1.48	4.57 ± 0.61	4.81 ± 0.60	3.96 ± 0.36	3.70 ± 0.65
	DP-5	10.47 ± 1.77	11.55 ± 1.97	7.82 ± 1.99	7.42 ± 1.59	3.89 ± 0.58	3.44 ± 0.68	2.59 ± 0.57	2.38 ± 0.47
	Total for entire foot	54.29 ± 7.76	55.69 ± 7.37	39.10 ± 7.14	38.12 ± 6.15	22.39 ± 3.70	22.74 ± 3.74	14.24 ± 2.36	14.29 ± 2.12

Values are expressed as a percentage of body weight.
McP = Metacarpal pad. MtP = Metatarsal pad. DP = Digital pad.

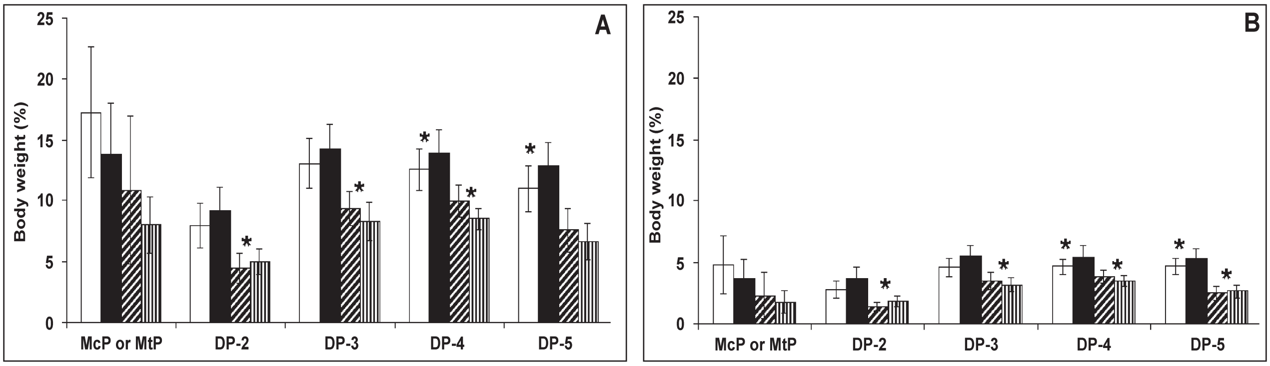

Figure 1—Mean ± SD values for peak vertical force (A) and vertical impulse (B) in the pads of 8 Greyhounds (forelimbs, black bars; hind limbs, vertical-striped bars) and 8 Labrador Retrievers (forelimbs, white bars; hind limbs, diagonal-striped bars). *Within a pad, values differ significantly ($P < 0.05$) between the 2 breeds. McP= Metacarpal pad. MtP=Metatarsal pad. DP=Digital pad.

Table 2—Comparison of PVF and VI between pads within the same limb in Greyhounds and Labrador Retrievers.

		PVF		VI	
Breed	Pad	Forelimb	Hind limb	Forelimb	Hind limb
Greyhound	McP or MtP	A	A	B	D
	DP-2	B	C	B	D
	DP-3	A	A	A	B
	DP-4	A	A	A	A
	DP-5	A	B	A	C
Labrador Retriever	McP or MtP	A	A,B	A	C
	DP-2	C	C	B	C
	DP-3	B	A,B	A	A
	DP-4	B	A	A	A
	DP-5	B,C	B	A,B	B

Within a limb of each breed, letters that differ are significantly ($P < 0.05$) different.
See Table 1 for remainder of key.

Discussion

The canine foot is a complex structure that gives support and balance during standing and provides the required restraint and propulsion during gait. During the stance phase, it has to adapt to a changing pattern of loading and must be relatively compliant yet still maintain its functional integrity. To our knowledge, all gait analysis in dogs until this time has centered on GRFs that are generated by the entire foot. The development of sophisticated pressure-sensitive software and equipment now allows us to isolate and evaluate GRFs from specific areas of the foot. The purpose of the study reported here was to document typical pressure distribution patterns in the pads of Greyhounds and Labrador Retrievers during walking.

We did not detect significant differences between the left and right forelimbs or left and right hind limbs for any pad in either breed. Vertical forces in the forelimbs were always greater than those in the hind limbs.

We detected significant differences in distribution patterns between Greyhounds and Labrador Retrievers. Potential causes for these differences may be related to variations in anatomy and gait of the breeds. Greyhounds have lean, muscular bodies, including thin, powerful legs and narrow feet, which make them ideal as a hunting breed built for speed. In contrast, Labrador Retrievers have a large frame, heavy body set, and wide-based feet that make them ideal as a working breed that is able to swim and run powerfully. Further evaluation of the feet in the 2 breeds reveals that Greyhounds have long, narrow feet with little distance separating the DPs from each other, whereas Labrador Retrievers have wide-based feet with greater distance between pads (Figure 1). In people, larger foot dimensions in relation to body weight result in reduced foot pressures by distributing GRFs across larger contact areas.[11] Anatomic differences may also lead to subtle gait differences that cannot be easily discernible but that may lead to variation in pressure patterns.

These anatomic variations may explain the significant differences evident in GRFs between the 2 breeds in the study. However, these differences are a potentially major limitation to the clinical application of this method of gait analysis. If pressure distributions vary among breeds, normal patterns will need to be established for each breed to enable clinicians to use this technique as a diagnostic tool. It is possible that distribution patterns would be similar within groups of dogs (eg, all sight hounds or working breeds may have similar patterns), which would allow comparisons to be made among breeds; however, it would be likely that groups of dogs could not be compared and that the technique would also not be applicable to mixed-breed dogs.

Although all dogs in the study reported here had normal results for physical examinations and did not have evidence of orthopedic or neurologic disease, there was a wide range of ages within each group. In people, age influences foot function. Compared with adults, children have considerably lower peak pressures for all anatomic structures of the foot.[12,13] Although these changes have not been documented in dogs, variations in GRF distribution patterns could be anticipated when comparing skeletally immature and mature canines. Therefore, age variation may account for the significant differences in GRFs detected within and between breeds in this study.

Documentation of typical plantar-pressure distribution patterns by use of gait analysis in humans has led to a more thorough understanding of the underlying pathologic alterations in several disease conditions, such as diabetic neuropathy,[14-18] rheumatoid arthritis,[19] and Parkinson's disease.[20] This in turn has led to advances in treatment and rehabilitation protocols and therefore a more favorable prognosis for patients.[14,16,19] Intuitively, it could be expected that variations from typical pad-pressure distributions in dogs could eventually be linked to disease processes and treatment protocols in veterinary medicine.

Pad-pressure distribution patterns may be most clinically relevant for the management of fractures of the metacarpals or metatarsals. A review of the literature would suggest that most of the load is transferred through the third and fourth metacarpal and metatarsal bones and that nonsurgical management should be considered only when both of these bones are intact.[9,21] When fractures involve more than 2 bones or both the third and fourth metacarpal (or metatarsal bones) in the same limb are affected, it has been recommended[9,21-24] that the fractures be treated by use of internal fixation techniques. In 1 study,[25] it was theorized that the load borne by the metatarsal bones would be concentrated in metatarsals 2 and 3 by virtue of the anatomy of the distal portion of the tibia and tibiotarsal joint, which may in part explain the reason for stress fractures of the third metatarsal bones in racing Greyhounds. Furthermore, it was theorized in that study[25] that the anatomic structures would decrease the loads on the lateral metatarsal bones and make them equivalent to the load transmitted by the intertarsal ligaments of metatarsal bones 4 and 5.

Analysis of results of the study reported here confirmed assumptions that DP-3 and -4 are the major weight-bearing pads in the feet of dogs. However, loads are more evenly distributed than suggested in other studies,[25] and DP-5 and the McP or MtP bear a substantial amount of load in both breeds. Although vertical forces measured on the pads do not directly correlate to the load on the metacarpal and metatarsal bones, it seems reasonable to assume that when a load is not concentrated on a particular digit, it will not likely be concentrated on the associated metacarpal or metatarsal bone. Therefore, on the basis of data obtained in this study, it could be concluded that the decision for nonsurgical management of metacarpal or metatarsal bones should be a bit more liberal than currently proposed, perhaps suggesting that when any 2 bones are intact, nonsurgical management could be pursued. This conclusion is supported by a retrospective study[26] in which investigators found that there was no significant difference in the successful outcome for dogs that had nonsurgical or surgical management of multiple metacarpal or metatarsal fractures.

Pressure distribution patterns may also prove to be valuable for use in the diagnosis and treatment of elbow dysplasia, specifically disease of the medial coronoid process. Subjectively, dogs with a **fragmented medial coronoid process (FCP)** shift their weight by adducting their cubital (ie, elbow) joints in an attempt to transfer the load laterally to the unaffected area of the elbow joint. With the change in limb position, it could be expected that there would be a corresponding redistribution of the forces transferred through the limb, which would be represented in plantar pressure distributions. Furthermore, it was documented in a study[27] that dogs with FCP may not have subjective or radiographic evidence of disease and may not have vertical forces that are consistent with disease in the affected limb. Documentation of abnormal pad-pressure patterns confirming that a dog is shifting its weight in a medial-to-lateral direction may provide supporting evidence that the dog has pain in the medial compartment of the elbow. Changes in pressure distribution patterns evident before radiographic changes may lead to earlier surgical intervention and possibly a more favorable prognosis for affected patients. In addition, as new modalities such as corrective osteotomies are developed for the treatment of patients with elbow dysplasia, researchers will have greater ability to document the therapeutic effectiveness of such procedures.

Another example of when pad-pressure distribution patterns may be useful is during the treatment of animals with angular limb deformities. Under- or overcorrection of a deformity can lead to abnormal forces being transferred though an affected joint, with consequences such as continuation of lameness and the potential for degenerative changes. Current surgical techniques require radiographic evaluation to assess limb alignment after correction of angular deformities. However, although radiographic alignment may be apparent, dogs may have some degree of lameness after surgery. Evaluation of pressure profiles, especially when distraction osteogenesis is used, may lead to a more favorable outcome because the alignment can be improved such that the forces are transferred through the limb in a more normal fashion.

Certainly, the point of the study reported here was not to suggest that these specific clinical examples are factual, only that a clinical situation may be evident in which pad-pressure distributions are useful. Without data from clinically normal dogs, hypotheses cannot be reasonably generated and tested.

The study reported here documented the typical plantar-pressure distribution patterns in Greyhounds and Labrador Retrievers. Furthermore, we believe it provides a noninvasive method to measure and interpret pressure distribution patterns in dogs with normal and abnormal gaits and may improve the understanding of disease processes, help in the development of treatment protocols, and assist in evaluation of protocols for use in postoperative recovery and rehabilitation of dogs.

[a]MatScan, Tekscan Inc, South Boston, Mass.
[b]Latitude CPx personal laptop, Dell Computer Corp, Round Rock, Tex.
[c]I-scan industrial sensing pressure measurement system, version 4.20, Tekscan Inc, South Boston, Mass.

References

1. Budsberg SC. Long-term temporal evaluation of ground reaction forces during development of experimentally induced osteoarthritis in dogs. *Am J Vet Res* 2001;62:1207–1211.
2. Budsberg SC, Verstraete MC, Soutas-Little RW. Force plate analysis of the walking gait in healthy dogs. *Am J Vet Res* 1987;48:915–918.
3. Budsberg SC, Verstraete MC, Brown J, et al. Vertical loading rates in clinically normal dogs at a trot. *Am J Vet Res* 1995; 56:1275–1280.
4. Jevens DJ, DeCamp CE, Hauptman J, et al. Use of force-plate analysis of gait to compare two surgical techniques for treatment of cranial cruciate ligament rupture in dogs. *Am J Vet Res* 1996; 57:389–393.
5. Roush JK, McLaughlin RM Jr. Effects of subject stance time and velocity on ground reaction forces in clinically normal Greyhounds at the walk. *Am J Vet Res* 1994;55:1672–1676.
6. Rumph PF, Lander JE, Kincaid SA, et al. Ground reaction force profiles from force platform gait analyses of clinically normal mesomorphic dogs at the trot. *Am J Vet Res* 1994;55:756–761.
7. Rumph PF, Kincaid SA, Visco DM, et al. Redistribution of vertical ground reaction in dogs with experimentally induced chronic hind limb lameness. *Vet Surg* 1995;24:384–389.
8. Besancon MF, Conzemius MG, Derrick TR, et al. Comparison of vertical forces in normal Greyhounds between force platform and pressure walkway measurement systems. *Vet Comp Orthop Traumatol* 2003;16:153–157.
9. Early TD, Dee JF. Trauma to the carpus, tarsus, and phalanges of dogs and cats. *Vet Clin North Am Small Anim Pract* 1980; 10:717–747.
10. *I-scan user's manual: version 4.20 edition*. South Boston, Mass: Tekscan Inc, 2000;1–13;70–72.
11. Hennig EM, Staats A, Rosenbaum D. Plantar pressure distribution patterns of young school children in comparison with adults. *Foot Ankle* 1994;15:35–40.
12. Hutton WC, Dhanendran M. Study of the distribution of load under the normal foot during walking. *Int Orthop* 1979;3:153–157.
13. Hennig EM, Rosenbaum D. Pressure distribution patterns under the feet of children in comparison with adults. *Foot Ankle* 1991; 11:306–311.
14. Albert S, Rinoie C. Effect of custom orthotics on plantar pressure distribution in the pronated diabetic foot. *J Foot Ankle Surg* 1994;33:598–604.
15. Garbalosa JC, Cavanagh PR, Wu G, et al. Foot function in diabetic patients after partial amputation. *Foot Ankle Int* 1996;17:43–48.
16. Kato H, Takada T, Kawamura T, et al. The reduction and redistribution of plantar pressures using foot orthoses in diabetic patients. *Diabetes Res Clin Pract* 1996;31:115–118.
17. Lavery LA, Lavery DC, Quebedeax-Farnham TL. Increased foot pressures after great toe amputation in diabetes. *Diabetes Care* 1995;18:1460–1462.
18. Pitei DL, Lord M, Watkins PJ, et al. Plantar pressures are elevated in the neuroischemic and the neuropathic diabetic foot. *Diabetes Care* 1999;22:1966–1970.
19. Li CY, Imaishi K, Shiba N, et al. Biomechanical evaluation of foot pressure and loading force during gait in rheumatoid arthritic patients with and without foot orthosis. *Kurume Med J* 2000; 47:211–217.
20. Nieuwboer A, De Weerdt W, Dom R, et al. Plantar force distribution in Parkinsonian gait: a comparison between patients and age-matched control subjects. *Scand J Rehabil Med* 1999;31:185–192.
21. Piermattei DL, Flo GL. Fractures of the carpus, metacarpus and phalanges. In: Bronker WO, Piermattei DL, Flo GL, eds. *Brinker, Piermattei, and Flo's handbook of small animal orthopedics and fracture repair*. 3rd ed. Philadelphia: WB Saunders Co, 1997;374–389.
22. Manley PA. Distal extremity fractures in small animals. *J Vet Orthop* 1983;2:38–48.
23. Muir P, Norris JL. Metacarpal and metatarsal fractures in dogs. *J Small Anim Pract* 1997;38:344–348.
24. Newton CD. Fracture and dislocation of metacarpal bones, metacarpophalangeal joints, phalanges, and interphalangeal joints. In: Newton CD, Nunamaker DM, eds. *Textbook of small animal orthopedics*. Philadelphia: Lippincott Williams & Wilkins, 1985;387–391.
25. Ness MG. Metatarsal III fractures in the racing Greyhound. *J Am Anim Pract* 1993;34:85–89.
26. Kapatkin A, Howe-Smith R, Shofer F. Conservative versus surgical treatment of metacarpal and metatarsal fractures in dogs. *Vet Comp Orthop Traumatol* 2000;13:123–127.
27. Theyse LF, Hazzewinkel HA, van den Brom WE. Force plate analyses before and after surgical treatment of unilateral fragmented coronoid process. *Vet Comp Orthop Traumatol* 2000;13:135–140.