Chapter 6

Force plate analysis before and after dorsal decompression for treatment of degenerative lumbosacral stenosis in dogs

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Abstract

Objective - Using force plate analysis (FPA), determine ground reaction forces in dogs with degenerative lumbosacral stenosis (DLS) and evaluate the effects of lumbosacral decompressive surgery.

Study Design - Prospective clinical study.

Animals - Twelve dogs with DLS.

Methods - DLS was diagnosed by clinical signs, radiography, computed tomography, and/or magnetic resonance imaging. FPA was performed before surgery, and 3 days, 6 weeks, and 6 months after surgery. The mean peak braking (Fy^+), peak propulsive (Fy^-), and peak vertical (Fz^+) forces of 8 consecutive strides were determined. The ratio between the total Fy^- of the pelvic limbs and the total Fy^- of the thoracic limbs (P/TFy^-), reflecting the distribution of Fy^-, was analyzed to evaluate any changes in locomotion pattern postoperatively. Ground reaction force data for DLS dogs were compared with data derived from 24 healthy dogs (control).

Results - In dogs with DLS, the propulsive forces (Fy^-) of the pelvic limbs were significantly smaller than those of controls. P/TFy^- was significantly smaller in dogs with DLS than in control dogs, and increased during the follow-up period, reaching normal values 6 months after surgery.

Conclusions - Cauda equina compression in dogs with DLS decreases the propulsive force of the pelvic limbs and surgical treatment restores the propulsive force of the pelvic limbs in a 6-month period.

Clinical Relevance - In dogs with DLS, FPA is an effective method in evaluating the response to surgical treatment. Normal propulsive force in the pelvic limbs was restored during 6 months after decompressive surgery.

Keywords - degenerative lumbosacral stenosis, force plate, ground reaction forces, dogs.

Introduction

Degenerative lumbosacral stenosis (DLS) is the most common disease of the canine lumbosacral joint.[1] DLS involves multiple parts of the lumbosacral joint and is related to intervertebral disc disease resembling Hansen type II fibrinoid degeneration.[2] The lumbosacral joint has the highest mobility of the lumbar spine with considerable transfer of forces between the 7th lumbar vertebra (L7) and the sacrum, making it particularly susceptible to degenerative changes.[3] Flexion and extension are the main movements of the lumbosacral joint, but lateral and rotational movements also occur; ligamentous structures and the intervertebral disc limit motion. Degenerative changes in these structures may alter the mobility.[4] Abnormal lumbosacral motion leads to 1) skeletal changes, including sclerosis of the lumbosacral end plate, development of spondylosis deformans, osteophyte proliferation, and 2) soft tissue changes, including overgrowth of the joint capsules, hypertrophy of the dorsal longitudinal ligament and the interarcuate ligament, and bulging of the dorsal anulus.[5] These changes alone or together with lumbosacral instability may lead to compression of the cauda equina in the vertebral canal, its lateral recesses, and the intervertebral foramina.[6]

Cauda equina syndrome describes the clinical signs observed in conditions that cause compression, inflammation, destruction, displacement, or vascular disruption to the nerve roots of the cauda equina. DLS is a common cause of cauda equina syndrome in dogs. Affected dogs are usually admitted with lumbosacral pain, pelvic limb weakness, unilateral or bilateral pelvic limb lameness, and stilted gait. Owners frequently complain of the dog's unwillingness to jump and to climb stairs, and the dog's difficulty in rising. Partial or temporary response to anti-inflammatory medications is often noted.[1]

Surgery is indicated when pain is severe and/or does not respond to conservative treatment. Decompressive surgery has been the most widely used technique to treat DLS. Complete return to normal activity was reported in 78% of the dogs by Danielsson and Sjöström[7], whereas others have reported success rates of 66%,[8] 53%,[9] and 41%.[10] Comparison of studies is difficult because of differences in design or study populations (age, clinical signs, working dogs or not), differences in surgical technique and post-operative evaluation (follow-up time, evaluation by veterinarian or owner). Post-operative evaluation with questionnaires to owners or the veterinarian is a subjective method of evaluation. Measurements of ground reaction forces (GRFs) with a force plate objectively evaluates the kinetic forces of dogs with pathologic changes involving the appendicular skeleton,[11-14] but to our knowledge has not been reported in evaluation of pathology of the axial skeleton causing abnormal locomotion.

We hypothesized that DLS affects the propulsive forces in the pelvic limbs of dogs, and that decompressive surgery is effective in restoration of these forces. Thus, using force plate analysis (FPA), we conducted a prospective study to determine GRFs in dogs with DLS and to evaluate the effects of surgical treatment.

Materials and Methods

Criteria for inclusion

Dogs included in the study had a history of caudal lumbar pain, which was diagnosed as DLS and was treated by decompressive surgery between December 2001 and February 2003. Dogs with orthopedic diseases other than DLS were excluded from the study.

Clinical examination

Each dogs's locomotion was observed during walking, trotting, running, ascending, and descending steps. In a standing position, the posture of the pelvic limbs, the volume of gluteal and hamstrings muscles, postural reactions, and pelvic limb and tail muscle tone were examined. Manual pressure was applied directly over the lumbosacral space and the hips were individually extended, with and without added pressure over the lumbosacral junction. The lordosis test was performed by extending both hips with simultaneous dorsal pressure on the lumbosacral region. Orthopedic and neurologic examination of the thoracic and pelvic limbs was performed in lateral recumbency.

Imaging

With the dog sedated with medetomidine, ventrodorsal and lateral radiographic views were made with the lumbosacral spine in a neutral position. Computed tomography (CT) was performed in anesthetized dogs with a 3rd generation CT-scanner (Tomoscan CX/S, Philips NV, Eindhoven, The Netherlands). With the dogs in sternal recumbency, the pelvic limbs extended caudally and the lumbosacral spine extended, 2-mm thick contiguous slices were made from the caudal end of the 6th lumbar vertebra (L6) to the cranial end of the 2nd sacral vertebra (S2) in a plane halfway between the caudal end plate of the 7th lumbar vertebra (L7) and the cranial end plate of the 1st sacral vertebra (S1). These slices were made with 9 seconds of scanning time, at 120 kV and 220 mA.

Magnetic resonance imaging (MRI) was performed in anesthetized dogs, positioned as for CT, using a 0.2 T open field MRI-system (Magnetom Open Viva, Siemens AG, München, Germany). Three millimetre thick contiguous sagittal (T1- and T2- weighted, TR and TE, respectively) and transverse (T1- weighted, TR and TE) images were used for diagnosis.

Surgical technique

One surgeon (BPM) performed the surgical procedure as described by Denny et al.[15] Dorsal laminectomy was performed, using a motorized burr and Kerrison rongeurs, including the lamina of L7 and S1. After entering the spinal canal, the cauda equina nerve roots were inspected for swelling and adhesions. After decompression of the cauda equina, a free fat graft was placed in the laminectomy site.[16] The deep muscles and lumbodorsal fascia were closed with 2-0 polydioxanone interrupted sutures, and then the subcutaneous tissue and the skin were closed. Carprofen (2mg/kg, every 12 hours, orally, for 14 days) and amoxicillin/clavulanic acid (12.5 mg/kg, every 12 hours, orally, for 14 days) were administered after surgery. Dogs were restrained on a leash and were allowed only short walks for the first 6 weeks, followed by a gradual increase of excercise during the next 6 weeks.

FPA

Before surgery, dogs were guided over the force plate (FP). FPA was repeated 3 days, 6 weeks, and 6 months postoperatively. The FP was a quartz crystal piezo-electric force plate (Kistler type 9261, Charnwood Dynamics Limited, Rithlet, Leicestershire, UK), with Kistler 9865B charge amplifiers. The sampling rate was 100 Hz. The FP was built in level with the surface in the center of an 11 m long runway. The 5 m center of the runway was bordered by a 50 cm high fence to guide the dogs over the FP. The FP was 40 cm long and 60 cm wide. GRFs were measured by force transducers, located in every corner of the plate. Amplifiers were connected to a computer that stored the signals, which corresponded with GRFs in the mediolateral (Fx), craniocaudal (Fy), and vertical (Fz) directions. Before each recording session, the FP was calibrated with a standard weight.

The dogs' forward velocity was measured, using photoelectric switches and a millisecond timer. Starting and ending of the FP recording were automatically regulated when the dog passed the switches spaced 3 m apart in the fence and centered on the FP. The same single handler guided all dogs by a leash over the FP during all the recordings, at a constant speed (1.1 ± 0.2 m/s) in pace, to avoid gait variations. There was no acceleration at both ends of the runway, 5 m from the center of the FP. Each pass across the plate was also evaluated by an observer, to confirm foot strikes and gait. This observer remained the same throughout the study. Data recorded were considered valid when in the same run, the thoracic limb followed by the ipsilateral pelvic limb contacted the FP completely. Trials were discarded for distracting head motions or irregularities in the gait. A minimum of 8 recordings per thoracic and per pelvic limb were used for data processing.

Calculations and statistics

The following variables were calculated in the analysis: the peak braking force (Fy^+), the peak vertical force (Fz^+) and the peak propulsive force (Fy^-). All forces in Newton (N) were normalized for body weight. A ratio reflecting the distribution of forces over the 4 limbs was calculated. A pelvic limb/thoracic limb ratio (P/T) for Fy^+ (P/TFy^+) was defined as the ratio between the sum of Fy^+ for the pelvic limbs and the sum of Fy^+ for the thoracic limbs. A P/T for Fz^+ (P/TFz^+) was defined as the ratio between the sum of Fz^+ for the pelvic limbs and the sum of Fz^+ for the thoracic limbs. A P/T for Fy^- (P/TFy^-) was defined as the ratio between the sum of Fy^- for the pelvic limbs and the sum of Fy^- for the thoracic limbs. Mean P/T of the DLS group was defined as the sum of the P/T ratios of all dogs divided by 12. For comparison of the mean P/T ratios over time, statistical analysis was conducted using the Friedman's test. A Student's *t*-test was used to compare the mean P/T of the DLS group and the control group. GRFs in the DLS group were compared with the corresponding GRFs in the control group, using the Student's *t*-test. Significance was set at $P<0.05$.

Results

Dogs

Twelve dogs (mean age, 4.7 ± 2.5 years; mean weight, 37.1 ± 12.8 kg) were studied. These dogs included 3 German Shepherds, 2 Great Danes, 1 German Longhaired Pointer, 1 Golden Retriever, 1 Weimaraner, 1 Border Collie, 1 Greyhound and 2 Crossbreeds (1 female, 4 castrated females, 3 males, 4 castrated males).

The control group of 24 healthy dogs (mean age, 1.8 ± 1.0 years; mean weight, 26.7 ± 3.3 kg) were used for FP data were free of orthopedic disease. These dogs were mixed Labrador Retrievers (16 females, 6 males, 2 castrated males).

Clinical examination

Seven dogs had pelvic lameness. All 12 dogs had problems with rising and jumping, 3 dogs kept the tail low. All dogs had a mild-to-severe pain reaction upon manual pressure of the lumbosacral junction and the lordosis test. Orthopedic and neurologic examinations were otherwise unremarkable.

Imaging

On radiographs, there was lumbosacral spondylosis in 5 dogs, sclerosis of the sacral end plate in 6 dogs, ventral subluxation of the sacrum relative to L7 in 7 dogs, and 1 dog had a transitional vertebra.

CT findings (11 dogs) included loss of epidural fat in 1 dog, protrusion of the intervertebral disc in 9 dogs, and swelling of the spinal roots in 6 dogs. MRI findings included loss of the white nucleus pulposus signal on T2-weighted MR images in all 6 dogs.

Surgical findings

Epidural fat was found dorsal to the cauda equina in 7 dogs, swelling of the spinal roots in 7 dogs, and protrusion of the intervertebral disc in 8 dogs. After lateral retraction of the cauda equina, additional ventral decompression of the cauda equina was achieved in 10 dogs through dorsal fenestration and partial discectomy of the degenerated disc.

FPA

Fy^- of the pelvic limbs of the DLS group (day 0) were significantly smaller than the Fy^- of the pelvic limbs of the control group (Figure 1). There was no significant difference between groups for Fy^+ or Fz^+ (Figure 1). P/T ratios for Fz^+ (Table 1), Fy^+ (Table 2) and Fy^- (Table 3) were calculated. There was no significant change in P/TFy^+ and P/TFz^+ over 6 months (Table 1, 2). When looking at the ratios for propulsion, 7 dogs had a large response, 3 dogs remained virtually the same, and 2 of the dogs actually decreased their ratios compared with preoperative values (Table 3). The mean ratio P/TFy^- initially decreased at 3 days then progressively increased to normal over 6 months (Table 3). There was no significant difference (P> 0.05, Student's t-test) between the DLS group and the control group for P/TFy^- at 6 months (Figure 2).

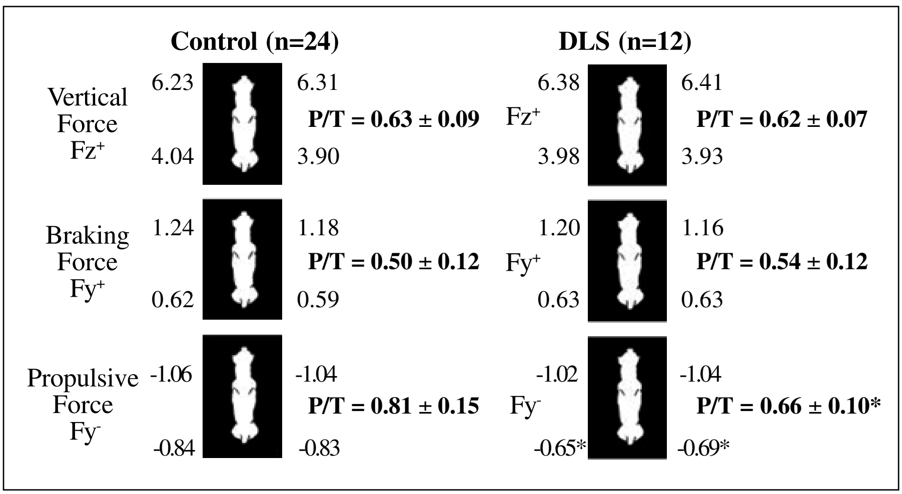

Figure 1. Mean ratio (± SD) between ground reaction forces (Fz^+, Fy^+, Fy^-) of pelvic limbs and thoracic limbs (P/T) in 24 healthy dogs (control) and 12 dogs with degenerative lumbosacral stenosis. Forces/kg body weight is in Newton. *$P < 0.05$, Student's t-test compared with the control group

Fz^+ for the control group (left thoracic limb [LT] = 6.23 ± 0.43 N, right thoracic limb [RT] = 6.31 ± 0.41 N, left pelvic limb [LP] = 4.04 ± 0.57 N, and right pelvic limb [RP] = 3.90 ± 0.57 N) had a distribution of percentage body weight on each limb at walk of 30.4%, 30.8%, 19.7%, and 19.0%, respectively. Fy^+ in the control group was LT 34.2%, RT 32.5%, LP 17.1%, and RP 16.3%, whereas Fy^- was LT 28.1%, RT 27.6%, LP 22.3%, and RP 22.0%. The distribution of Fy^- for the DLS group at day 0 was LT 30.0%, RT 30.6%, LP 19.1%, and RP 20.3%.

Table 1. Pelvic limb/Thoracic limb ratio (P/T) for the peak vertical force (Fz^+)

Patient Number	**P/T for Fz^+**			
	Preoperative	**3 days PO**	**6 weeks PO**	**6 months PO**
1	0.65	0.64	0.67	0.67
2	0.59	0.60	0.58	0.59
3	0.60	0.59	0.59	0.62
4	0.65	0.74	0.64	0.67
5	0.55	0.59	0.54	0.60
6	0.73	0.77	0.66	0.71
7	0.59	0.61	0.57	0.58
8	0.66	0.68	0.67	0.74
9	0.52	0.57	0.55	0.54
10	0.67	0.70	0.66	0.69
11	0.55	0.53	0.51	0.53
12	0.71	0.79	0.73	0.70
Mean	0.62	0.65	0.61	0.64
SD	0.07	0.09	0.07	0.07

SD, standard deviation; PO, postoperative.

Table 2. Pelvic limb/Thoracic limb ratio (P/T) for the peak braking force (Fy^+)

Patient Number	**P/T for Fy^+**			
	Preoperative	**3 days PO**	**6 weeks PO**	**6 months PO**
1	0.49	0.55	0.60	0.57
2	0.45	0.46	0.39	0.37
3	0.68	0.63	0.61	0.76
4	0.60	0.75	0.50	0.46
5	0.36	0.45	0.43	0.44
6	0.67	0.69	0.59	0.50
7	0.67	0.53	0.62	0.61
8	0.59	0.60	0.56	0.65
9	0.33	0.38	0.39	0.39
10	0.62	0.60	0.66	0.68
11	0.57	0.58	0.54	0.58
12	0.49	0.49	0.46	0.52
Mean	0.54	0.56	0.53	0.54
SD	0.12	0.11	0.09	0.12

SD, standard deviation; PO, postoperative.

Table 3. Pelvic limb/Thoracic limb ratio (P/T) for the peak propulsive force (Fy^-)

Patient Number	P/T for Fy^-			
	Preoperative	**3 days PO**	**6 weeks PO**	**6 months PO**
1	0.72	0.62	0.66	0.65
2	0.65	0.67	0.69	0.75
3	0.71	0.58	0.69	0.73
4	0.57	0.44	0.66	0.66
5	0.62	0.51	0.67	0.67
6	0.70	0.69	0.74	0.74
7	0.70	0.84	0.73	0.81
8	0.65	0.62	0.65	0.67
9	0.75	0.48	0.75	0.73
10	0.66	0.57	0.62	0.85
11	0.40	0.16	0.47	0.41
12	0.74	0.74	0.91	0.90
Mean	0.66*	0.58*	0.69*†	0.71‡
SD	0.10	0.17	0.10	0.12

SD, standard deviation; PO, postoperative

* $P < 0.05$ (Student 's *t*-test), compared with control group value P/TFy^- = 0.81 ± 0.15

† $P < 0.05$ (Friedman 's test), compared with values 3 days after surgery

‡ $P < 0.05$ (Friedman 's test), compared with values 3 days and 6 weeks after surgery

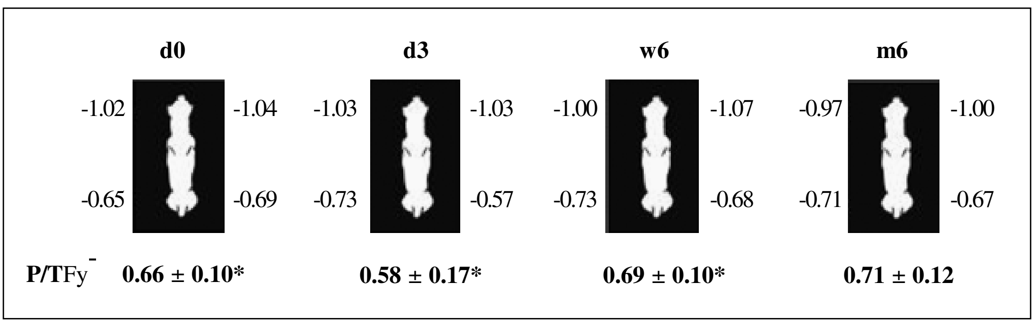

Figure 2. Mean ratio (± SD) between propulsive force Fy^- of pelvic limbs and thoracic limbs (P/TFy^-) in 12 dogs with degenerative lumbosacral stenosis before (d0), 3 days (d3), 6 weeks (w6), and 6 months (m6) after dorsal laminectomy. Forces/kg body weight are in Newton. * $P < 0.05$, Student's *t*-test compared with the control group value P/TFy^- = 0.81 ± 0.15 (Figure 1).

Discussion

In dogs with DLS, the propulsive forces (Fy^-) of the pelvic limbs were significantly smaller than those of the control dogs. The ratio pelvic/thoracic limb propulsive force (P/TFy^-) was significantly smaller in dogs with DLS than in control dogs, and increased during the follow-up period, reaching normal values 6 months after decompressive surgery.

The first clinical research that used FPA to evaluate gait in dogs compared total hip replacement with excisional arthroplasty for the treatment of hip dysplasia.[12] Since then FPA has been used for gait evaluation of healthy dogs[17,18] and for objective evaluation of gait in dogs after surgical treatment of cranial cruciate ligament rupture,[13] triple pelvic osteotomy for treatment of hip dysplasia,[14] surgical treatment of fragmented coronoid process,[11] and medical treatment[19] of disease of the appendicular skeleton but to our knowledge has not been evaluated for lumbosacral stenosis.

Two components in lumbosacral disease complicate its evaluation. First, DLS is a neuro-orthopedic condition involving cauda equina that can result in lameness whereas in most FPA studies the lameness has an orthopedic origin involving disruption of structure and function of muscles, tendons, bones, and joints. Second, DLS often results in bilateral pelvic limb lameness in contrast with other studies that evaluate the locomotion of dogs with unilateral lameness.

Several of the early clinical studies using FPA may have been invalid because they used the opposite limb as control. However, when evaluating unilateral lameness, GRFs on the opposite limb are disrupted and cannot be used as control. Also, most clinical patients are bilateral even if they show worse lameness in only 1 limb. Therefore, in the present study a group of control dogs was used to evaluate results in a valid manner.

In a previous FPA study on dogs with unilateral lameness associated with fragmented coronoid process, the symmetry index (SI) was defined as the ratio between the affected side and the contralateral side. SI was a valuable tool to determine the shift of GRFs in the thoracic limbs. Based on data of normal dogs, a SI $\geqslant 0.90$ was considered normal.[11] P/T, the ratio of GRFs between pelvic and thoracic limbs was developed similarly to assess distribution of GRFs. Bilateral pelvic limb lameness may result in a decrease of GRFs of the pelvic limbs and a shift of body weight to the thoracic limbs thereby increasing the GRFs of the thoracic limbs and decreasing the P/T.

Fz^+ for our control group has a distribution of percentage body weight in each limb at walk that was in agreement with a study by Budsberg in normal dogs and with studies performed in horses.[17,20,21] For DLS dogs, the distribution of body weight during walking was not different from normal dogs. The distribution of Fy^+ and Fy^- confirms the theory that the thoracic limbs mainly decelerate the dog and the pelvic limbs propel the animal forward.[11,17,22] Because the pelvic limbs are mainly for propulsion and not for braking, this may explain why a significant difference for the propulsive force was observed but not for the braking force.

The significantly lower Fy^- of both pelvic limbs in dogs with DLS compared with control dogs resembles FPA findings in dogs with Hip dysplasia (HD)[12,14] and explained by the clinical resemblance of dogs with HD or DLS. The decrease in Fy^- in dogs with DLS may be explained by the biomechanical consequence of extension of the lumbosacral joint in case of extension of the pelvic limbs.[3]

Dogs with cauda equina compression prevent extension of the caudal lumbar spine by limiting extension of the pelvic limbs explaining difficulties with rising, jumping, climbing stairs, and a pain response to the lumbosacral pressure test. Less use of the pelvic limbs results in a decrease in muscle tone and muscle atrophy. Therefore, decreased propulsion of the pelvic limbs in dogs with DLS may be because of a combination of pain upon hyperextension of the lumbosacral joint and in the long term also because of a decreased ability for forward motion. In accordance with this, the P/TFy^- in DLS patients (0.66) was significantly smaller than the P/TFy^- in the healthy dogs (0.81). After an initial decrease of the P/TFy^- at 3 days, it significantly increased at 6 weeks and 6 months. The initial decrease in P/TFy^- after surgery may be explained by a direct postoperative weakening effect on propulsive forces after surgery. The dogs had cage rest for 3 days before they were guided over the force plate. After 6 weeks of strict rest with short-leash walks, the P/TFy^- (0.69) was still significantly different from the control group. Apparently, at 6 weeks after surgery the dogs, although clinically improved and pain free, had not regained normal pelvic limb muscle strength and volume. A gradual increase in physical activity in the period from 6 weeks to 6 months resulted in an improved P/TFy^- of 0.71, although the propulsive forces never equalled those of control dogs. A possible explaination for this is that full restoration of muscle function and muscle volume requires more time than 6 months. Also, there was a considerable variation in the relatively small group of 12 dogs with DLS; 2 of the dogs actually decreased their ratios compared with the preoperative values and this is reflected in the ratio at 6 months after surgery.

FPA is an objective method for gait analysis but a constant walking speed is essential for verifiable data.[23-27] Different handlers attributed only a small amount of variation in FP data, indicating that multiple handlers may be used in experiments without affecting the results.[27] In our study, the velocity of the dogs was constant during all FP runs at the 4 consecutive dates as monitored by photo-electric control.

For the evaluation of DLS patients, FPA is a valuable tool to detect altered gait that may not be apparent with visual observation alone. The signs of DLS are often vague, some dogs show no lameness on visual observation, but FPA revealed decreased propulsive forces in the pelvic limbs. FPA enabled quantification of lameness, however, it must be realized that the force was measured during a single limb-plate contact time. FPA is not able to measure the complete complex of disturbed locomotion involving $\geqslant 2$ limbs at the same time (e.g., difficulty in rising or jumping, stiffness or lameness after a period of exercise). Kinetics may not be sensitive enough to distinguish subtle gait differences. In that case kinematics may be more helpful in explaining the gait differences observed.

We conclude that a combination of the Fy^- and P/TFy^- rather than Fy^+ and Fz^+ is important for evaluating gait in dogs with DLS. The ratio between the sum of the peak propulsive forces of both pelvic limbs and the sum of the peak propulsive forces of both thoracic limbs reflects the distribution of the propulsive forces. This ratio was smaller in dogs with DLS than in normal dogs and the ratio increased from 6 weeks to 6 months after surgery. Surgical treatment of dogs with DLS resulted in restoration of the propulsive forces in the pelvic limbs 6 months period after surgery.

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