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Asian Journal of Animal and Veterinary Advances

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Asian Journal of Animal and Veterinary Advances 10 (6): 247-259, 2015
ISSN 1683-9919 / DOI: 10.3923/ajava.2015.247.259

A Comparative Study of Range of Motion of Forelimb and Hind Limb in Walk Pattern and Trot Pattern of Chihuahua Dogs Affected and Non-Affected with Patellar Luxation

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ABSTRACT

The study compared the Ranges of Motion (ROM) of forelimb and hind limb, and the cycle speeds of healthy and Patellar Luxation (PL) dogs in walking and trotting. 21 dogs were divided into three groups: The 5 normal dogs, 6 unilateral PL (PL-1) dogs and 10 bilateral PL (PL-2) dogs. All dogs with PL did not present lameness. The dogs were walking and trotting on a treadmill for the video record. The Kinovea program was employed to evaluate the cycle speed, Maximum Extension Angle (MEA), Maximum Flexion Angle (MFA) and ROM of the shoulder, elbow, carpal, hip, stifle and tarsal joints. The results showed that both the limb sides of the dogs in all the groups in both walking and trotting motions had no significant difference ($p>0.05$). It was found that the ROM of the shoulder, carpal, hip and tarsal joints in PL dogs had significant difference ($p<0.05$) compared to the normal dog. In conclusion, the unilateral PL limb dogs showed no effect on the opposite limb, the unilateral and the bilateral PL dogs was an effect on the locomotion of the forelimb and the hind limb compared with the normal dogs.

Key words: Range of motion, dog, patellar luxation, walk, trot

INTRODUCTION

Patellar Luxation (PL) is one of the most common joint diseases in small breed dogs, particularly the breeds of Chihuahua, Pomeranian and Poodle (Bound *et al*., 2009; Hayes *et al*., 1994; Nganvongpanit and Yano, 2011). This disease is considered developmental and can result from a variety of anatomical abnormalities of the pelvic limbs, with patella finally getting displaced from the femoral groove, medial or lateral. At present, the etiology and the mechanism of this disease are still unclear; many factors can cause this disease, for example, genetics, malalignment of hind limb, muscle contraction, etc. (Chomdej *et al*., 2014; Lavrijsen *et al*., 2014; Soparat *et al*., 2012; Wangdee *et al*., 2014). The diagnosis of this disease is based on radiographic changes and the gold standard of diagnosis of this disease is palpation (Mortari *et al*., 2009). Some dogs present gait abnormality or lameness, while some dogs do not show gait abnormality.

The question investigated and discussed in this study is the observation from clinical practice that many dogs, although diagnosed by palpation as positive PL, did not present abnormal gait. We would like to evaluate the active Range of Motion (ROM) of dogs affected with patellar luxation in one leg and both the legs; additionally, we aim to examine whether PL affects or does not affect gait of fore- and hind limbs. For this we use kinematic analysis, by using a 2-D video system to evaluate. This kinematic analysis of gait is much more accurate and efficient than human observation (Faria *et al*., 2014; Gilette and Angle, 2008; Hyytiainen *et al*., 2013).

The active range of motion can be measured by subtracting the Maximum Flexion Angle (MFA) from the Maximum Extension Angle (MEA), both angles being calculated as those at which the animal is able to move on its own, as the active ROM has more reliability than the passive ROM. Joint motion plays an important role in maintaining the functions of the joints as many tissues are affected in the ROM, for example articular cartilage, joint capsule, tendon, ligament, bone and muscle. Various conditions have been reported as limiting the ROM: Septic arthritis, osteoarthritis, joint luxation, bone and articular fracture, ligament/tendon rupture and muscle contraction (Marsh *et al*., 2010; Miqueleto *et al*., 2013). Treatments of the disorders of those tissues are aimed at bringing about the re-function of the joints, thus returning the ROM to normal as a result of which the dog can walk, trot, canter, or gallop as normal.

As is well known, PL is a stifle disorder, in which the patella is dislocated out of the femoral trochlear, following the inward or outward rotation of tibia. It has been reported that compensatory load redistribution mechanisms occur after a limb injury or an episode of abnormal weight bearing (Abdelhadi *et al*., 2013). This can cause a change in the ROM of the other limb in PL dogs. So far, no scientific publication has reported changes in the ROM in dogs affected with patellar luxation. The aim of this study is to focus on the changes in the ROM in the forelimb and hind limb joints in medial PL dogs. We hypothesized that during the walk gait and the trot gait, the ROM of the pelvic limb will be different in the cases of dogs affected with PL and dogs not affected with PL and that the ROM of the thoracic limb will change in dogs affected with PL.

MATERIALS AND METHODS

Animals and treadmill training: A total of 61 Chihuahua dogs, of ages between 1 and 5 years were the subjects of this study, with exclusion criteria that included the following: presenting lameness during walk or trot, history of bone fracture, joint (except patellar luxation) and spinal diseases; in addition, dogs suffering from other diseases or abnormal conditions (i.e., pregnancy, obesity, etc.) were also excluded from this study. All the dogs were trained to walk and trot on treadmill (TREO model T121, China) at a frequency of 5-10 sessions per day for approximately 5-10 min per session, every 2 days for 1 month. It was observed that only 21 dogs were able to walk and trot on the treadmill comfortably and relax without a leash (Table 1); these dogs were used as the subjects of this study and the remaining 40 dogs were excluded from the study due to their inability to walk and trot on the treadmill.

The dogs were categorized into three groups; the normal group, unilateral Patellar Luxation (PL-1) group and bilateral Patellar Luxation (PL-2) group. Patellar luxation was confirmed with diagnosis by palpation technique, carried out by two veterinarians. Radiography of the forelimb and hind limb joints (shoulder, elbow, carpal, hip, stifle and tarsal joints) was performed in all the 21 dogs to confirm that none of the dogs had any diseases caused by abnormal bones and joints, in particular osteoarthritis. The radiographic diagnosis was carried out by two veterinarians with blinded to subject condition.

Table 1: Final number and information of dogs in three experimental groups

Groups	Total No.	Age	Weight	Sex: Male	Sex: Female	Patellar luxation grade (1, 2, 3, 4)
Normal	5	4.20±1.17	3.12±1.02	2	3	0-0-0-0
PL-1	6	3.67±0.75	2.44±0.97	2	4	0-4-2-0
PL-2	10	3.90±0.70	1.99±0.31	1	9	6-6-6-2

Age and the weight were not significantly different between the three groups

The experimental protocol was approved (2013) by the Faculty of Veterinary Medicine and the Ethics Committee, Chiang Mai University, Thailand. All pet owners have written informed consent form in our study.

Video recording and analysis of range of motion: Each of the dogs was tagged with a square marker on either side (right and left) of the body using a double-side adhesive tape; the hair was clipped before sticking the marker. A total of 10 markers were placed on the skin on each side of the body over the point of the cranial angle of the scapula, the acromium of the shoulder joint, the lateral epicondyle of the humerus, the styloid ulnar process, the distal lateral aspect of the fifth metacarpal bone, the cranial border of the dorsal point of the iliac crest, the eminence of the greater trochanter of the femur, the stifle joint between the lateral epicondyle of the femur and the fibular head, the lateral malleolus and the distal lateral digit aspect of the fifth metatarsus (Miqueleto *et al*., 2013). These markers were placed by the same investigator.

The dogs were made to stand on the treadmill before the start of the analysis; the treadmill was started at a low speed which was increased gradually until the dogs achieved a normal walking gait or trotting gait. The dogs were walking and running on the treadmill without a leash. The treadmill speed was maintained at approximately 0.55 m sec^{-1} for walk and 1.11 m sec^{-1} for trot. Each of the dogs was walking and trotting on the treadmill for 3 min of video recording, three times at a 2 day interval. Three valid trials of 3 min duration were obtained from each side of the dogs; in each trial, three completed strides were analyzed, which yielded a single mean value for each side of each dog. Two video cameras (E-PL5, Olympus) were set at 1 m distance from the dog on the treadmill on both its left-hand side and right-hand side. The movie from the video recordings were used to analyze the movement of the forelimb and the hind limb by using the Kinovea program (Guzman-Valdivia *et al*., 2013). The Maximum Flexion Angle (MFA) and the Maximum Extension Angle (MEA) were used to calculate the Range of Motion (ROM) of each of the joints, namely shoulder, elbow, carpal, hip, stifle and tarsal joints, of both the right and the left sides. Additionally, the gait cycle time (s) was also measured (Fig. 1).

Statistical analysis: SPSS statistics 17 was used for the statistical analysis. The variation in the data was analyzed using Shapiro-Wilk test and the comparison between the right and the left or the affected and the unaffected legs in the same group was performed using Student's t-test. One way ANOVA was using to compare the difference between the three groups by following the Fisher's least significant difference for confirming the groups of difference. A value of $p<0.05$ was considered as significantly different. The results are expressed as Mean±Standard Deviation (SD).

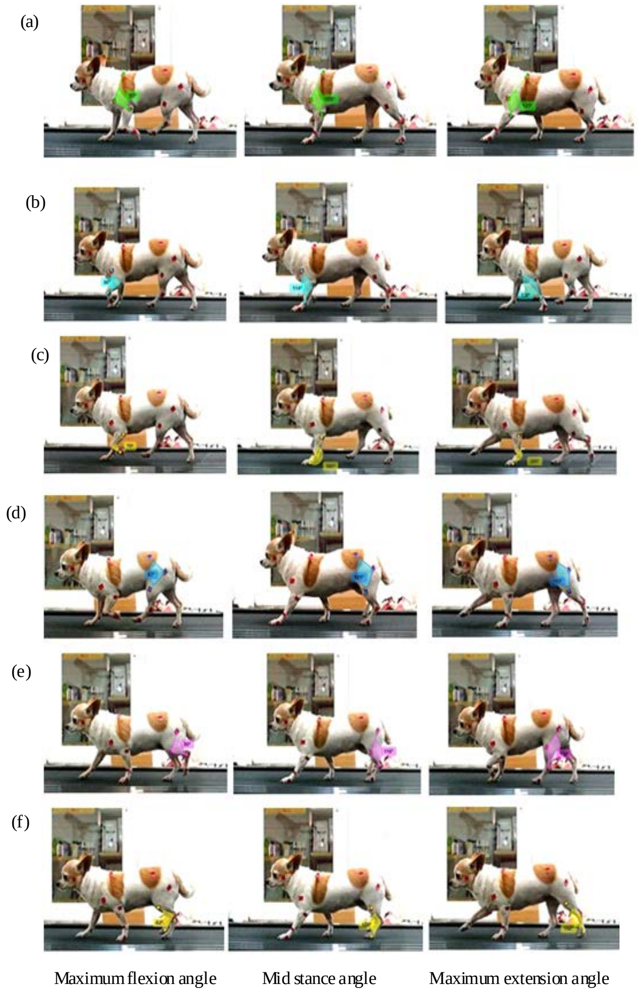

Fig. 1(a-f): Representative capture figure from the kinovea program for measuring the maximum flexion angle, mid stance angle and maximum extension angle in the (a) Shoulder, (b) Elbow, (c) Carpal, (d) Hip, (e) Stifle and (f) Tarsal joints

RESULTS

Comparison between limbs within experimental group: In all the three study dog groups, all of the parameters, namely MFA, MEA and ROM, were found to be not significantly different on either side in both walk and trot (Table 2-7). The gait cycle speed of each side of limb was calculated (Table 8) and there was no significant difference (p>0.05) found between the limbs on either side. Even in unilateral PL, there was no significant difference (p>0.05) observed between the limbs affected with PL and the normal limbs.

Comparison between experimental groups: It was found that there was no significant difference between the limbs of either side in dogs of all the three groups. The MFA, MEA and ROM of limbs on both the sides in each group were combined and presented as the Mean±SD of each group. Figure 2 and 3 present the MFA, MEA and ROM of the three experimental groups at walking gait and trotting gait.

Table 2: Comparative maximum flexion angle, maximum extension angle and range of motion between right limb and left limb in walk gait of normal group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Left	103.85±3.84	0.518	135.59±3.59	0.966	31.74±5.46	0.127
Right	105.59±6.91		135.48±4.41		29.89±4.49	
Elbow						
Left	82.76±6.83	0.868	143.59±4.49	0.279	60.83±8.93	0.650
Right	82.50±4.00		142.20±3.11		59.70±5.55	
Carpal						
Left	82.91±6.83	0.507	199.33±3.29	0.065	116.43±8.81	0.440
Right	83.76±8.56		201.54±2.93		117.78±10.37	
Hip						
Left	75.13±7.60	0.237	111.87±6.72	0.731	36.74±3.12	0.353
Right	76.65±6.19		112.39±6.39		35.74±2.13	
Stifle						
Left	78.70±9.00	0.425	124.89±5.52	0.872	46.18±4.89	0.468
Right	77.17±8.11		124.98±6.48		47.81±5.37	
Tarsal						
Left	89.00±9.80	0.148	142.39±6.38	0.752	53.39±5.71	0.479
Right	87.54±9.12		141.91±8.07		54.37±5.25	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

Table 3: Comparative maximum flexion angle, maximum extension angle and range of motion between affected and non-affected limbs in walk gait of PL-1 group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Affected	104.07±3.85	0.188	129.28±4.71	0.211	25.20±3.85	0.630
Non-affected	106.28±3.70		132.19±2.51		25.91±2.00	
Elbow						
Affected	77.72±5.85	0.164	140.28±3.42	0.266	62.56±6.27	0.724
Non-affected	79.35±6.30		142.59±4.37		63.24±3.52	
Carpal						
Affected	77.81±4.61	0.273	203.46±3.03	0.748	125.65±5.55	0.275
Non-affected	79.74±6.17		202.72±3.57		122.98±6.95	
Hip						
Affected	71.46±4.11	0.377	101.74±8.34	0.316	30.28±5.69	0.896
Non-affected	74.07±3.88		104.09±4.84		30.02±7.60	
Stifle						
Affected	75.43±6.24	0.734	123.56±4.34	0.594	48.13±4.52	0.490
Non-affected	76.06±2.19		123.15±2.97		47.09±2.01	
Tarsal						
Affected	94.19±5.51	0.062	142.02±6.10	0.406	47.83±7.64	0.875
Non-affected	95.48±4.62		129.28±4.71		25.20±3.85	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

In the case of shoulder joints, it was found that the ROM in the PL-1 group (25.55±2.94) was significantly lower ($p<0.05$) than the ROM in the PL-2 group (29.14±4.58) and the normal group (30.81±4.87) in walking. In the case of the trotting gait, as well, the result obtained was the same: the ROM in the PL-1 group (25.01±3.11) was significantly lower ($p<0.05$) than the ROM in the PL-2 group (28.35±4.29) and the normal group (30.44±4.59).

In the case of elbow joints, it was found that the MFA in the PL-1 group (78.53±5.86) was significantly lower ($p<0.05$) than the MFA in the PL-2 groups (84.93±7.45), but that it did not show significant difference ($p>0.05$) compared to the normal group (82.62±5.34). In the trot gait, the MFA, MEA and ROM of the three groups were not found to be significantly different ($p>0.05$).

As far as the carpal joint is concerned, it was found that the MEA in the PL-2 group (204.30±4.68) was significantly higher ($p<0.05$) than the MEA in the normal group (200.43±3.18), but that it was not significantly different ($p>0.05$) compared to the PL-1 group (203.09±3.18). In the trot gait also, it was found that the MEA in the PL-2 group (209.04±4.35) was significantly higher

Table 4: Comparative maximum flexion angle, maximum extension angle and range of motion between right limb and left limb in walk gait of PL-2 group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Left	101.06±7.55	0.439	131.32±5.48	0.716	30.26±4.15	0.259
Right	102.57±9.48		130.59±8.64		28.02±4.96	
Elbow						
Left	84.25±7.77	0.557	145.11±7.07	0.232	60.86±6.88	0.712
Right	85.62±7.51		147.22±7.25		61.60±6.32	
Carpal						
Left	84.48±8.97	0.565	203.91±4.38	0.646	119.43±10.33	0.437
Right	83.63±6.55		204.69±5.19		121.06±7.16	
Hip						
Left	77.80±4.25	0.689	109.00±8.50	0.819	31.20±6.40	0.979
Right	77.27±2.69		108.51±6.23		31.23±4.89	
Stifle						
Left	77.31±5.21	0.943	128.23±3.68	0.163	50.93±5.08	0.296
Right	77.19±7.45		126.90±5.03		49.72±5.78	
Tarsal						
Left	95.36±5.83	0.889	142.99±4.03	0.076	47.63±4.59	0.150
Right	95.21±5.04		131.32±3.45		45.59±4.10	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

Table 5: Comparative maximum flexion angle, maximum extension angle and range of motion between right limb and left limb in trot gait of normal group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Left	103.26±2.80	0.396	133.67±4.93	0.374	30.41±4.68	0.962
Right	105.39±7.29		142.26±5.92		30.48±4.94	
Elbow						
Left	77.87±4.41	0.631	142.19±5.92	0.969	64.31±6.59	0.801
Right	77.07±5.11		142.26±3.97		65.19±6.21	
Carpal						
Left	75.33±6.49	0.778	204.54±3.85	0.181	129.20±6.25	0.360
Right	74.70±7.78		206.94±2.31		132.24±9.56	
Hip						
Left	73.72±7.60	0.289	109.85±8.16	0.685	36.13±4.78	0.547
Right	74.83±6.37		110.26±8.10		35.43±4.10	
Stifle						
Left	70.96±6.74	0.374	124.09±6.45	0.499	53.13±5.04	0.257
Right	69.50±6.53		124.83±7.50		55.33±5.08	
Tarsal						
Left	69.24±5.18	0.988	140.52±5.76	0.413	71.28±7.63	0.153
Right	69.28±5.16		142.04±7.47		72.76±6.91	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

($p<0.05$) than the MEA in the normal group (205.74±3.28), but that it was not significantly different ($p>0.05$) compared to the PL-1 group (208.28±2.13). Moreover, the MFA in the PL-1 group (67.65±5.53) was observed to be significantly lower ($p<0.05$) than the MFA in the normal group (75.01±6.84), but that it did not have significant difference ($p>0.05$) compared to the PL-2 group (72.09±6.31). The values of ROM in the PL-1 group (140.62±7.58) and the PL-2 group (136.95±7.48) were significantly higher ($p<0.05$) than the value of ROM in the normal group (130.72±7.86).

In the case of hip joints, it was found that the walk gait in the PL-1 group showed lower values for the MFA, MEA and ROM. The MFA in the PL-1 group (72.76±4.05) was significantly ($p<0.05$) lower than the MFA in the PL-2 group (77.53±3.46), but did not have significant difference ($p>0.05$) compared to the normal group (75.88±6.66). The MEA in the PL-1 group (102.91±6.62) was significantly ($p<0.05$) lower than the MEA in the normal group (112.12±6.26) and the PL-2 group (108.75±7.24). But the ROM values in both the PL-1 group (30.14±5.69) and the PL-2 (31.21±5.52)

Table 6: Comparative maximum flexion angle, maximum extension angle and range of motion between affected and non-affected limbs in trot gait of PL-1 group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Affected	106.59±4.37	0.373	131.00±6.04	0.231	24.41±4.04	0.345
Non-affected	108.20±4.31		133.83±3.15		25.63±2.00	
Elbow						
Affected	71.89±5.36	0.260	138.76±4.51	0.323	66.87±3.78	0.764
Non-affected	73.17±6.93		140.46±3.86		67.30±3.17	
Carpal						
Affected	67.46±5.62	0.801	208.41±2.53	0.873	140.94±7.58	0.688
Non-affected	67.85±5.96		208.17±1.90		140.31±6.51	
Hip						
Affected	68.39±4.72	0.585	100.50±8.30	0.209	32.11±4.52	0.128
Non-affected	69.04±3.51		103.61±5.90		34.57±2.81	
Stifle						
Affected	68.57±4.97	0.196	122.44±3.33	0.722	53.87±4.19	0.296
Non-affected	66.59±3.66		122.00±1.75		55.41±3.96	
Tarsal						
Affected	77.94±7.76	0.064	138.69±3.12	0.056	60.74±7.97	0.932
Non-affected	80.33±7.86		140.93±4.65		60.59±8.87	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

Table 7: Comparative maximum flexion angle, maximum extension angle and range of motion between right limb and left limb in trot gait of PL-2 group

Joints and sides	MFA	p-value	MEA	p-value	ROM	p-value
Shoulder						
Left	103.04±7.64	0.952	131.86±4.64	0.679	28.83±4.15	0.576
Right	103.10±8.85		130.99±8.42		27.89±4.64	
Elbow						
Left	76.53±7.19	0.618	141.16±5.93	0.139	64.63±8.56	0.149
Right	77.51±7.97		143.98±6.64		66.47±9.18	
Carpal						
Left	72.00±7.61	0.885	208.90±4.43	0.843	136.90±8.76	0.963
Right	72.20±5.16		209.20±4.53		137.00±6.51	
Hip						
Left	73.54±4.75	0.301	105.72±7.04	0.880	32.17±4.84	0.426
Right	74.95±2.92		106.04±5.60		31.09±5.07	
Stifle						
Left	71.57±5.82	0.731	127.04±4.09	0.868	55.47±5.41	0.583
Right	71.06±6.97		127.23±5.82		56.17±6.01	

MFA: Maximum flexion angle, MEA: Maximum extension angle, ROM: Range of motion

Table 8: Comparative cycle speed between right limb and left limb in walk gait and trot gait

Groups and sides	Walk	p-value	Trot	p-value
Normal				
Left	1.95±0.14	0.440	2.89±0.12	0.076
Right	1.94±0.14		2.85±0.10	
PL-1				
Affect	2.07±0.15	0.913	3.00±0.25	0.217
Non	2.07±0.14		2.95±0.19	
PL-2				
Left	2.06±0.08	0.066	3.03±0.16	0.880
Right	2.04±0.08		3.03±0.15	

Values are give in Mean±SD, PL: Patellar luxation

group were significantly lower ($p<0.05$) than the ROM values in the normal group (36.24±2.60). In trot gait, the MFA in the PL-1 group (68.71±3.98) was significantly ($p<0.05$) lower than the MFA in the normal group (74.27±6.71) and the PL-2 group (74.24±3.89). The MEA in the PL-1 group (102.05±7.06) was significantly ($p<0.05$) lower than the MEA in the normal group (110.05±7.75), but did not show any significant difference ($p>0.05$) compared to the PL-2 group (105.87±6.17). The ROM values in the PL-1 group (33.34±4.52) and the PL-2 group (31.62±4.83) were significantly ($p<0.05$) lower than the ROM values of the normal group (35.78±4.26).

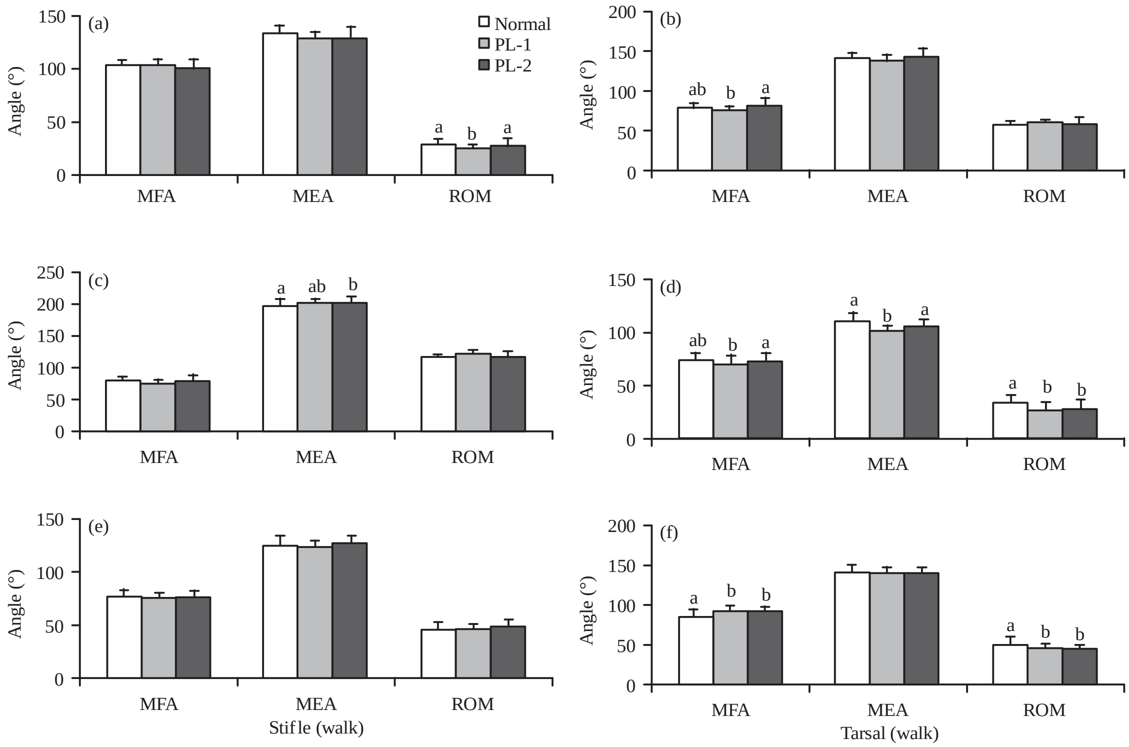

Fig. 2(a-f): Comparison of maximum flexion angle, maximum extension angle and range of motion between the experimental groups in the walk gait, (a) Shoulder, (b) Elbow, (c) Carpal, (d) Hip, (e) Stifle and (f) Tarsal. Values with different superscripts (a, b) are significantly different ($p<0.05$) when compared between 3 groups, MFA: Maximum flexion angle MEA: Maximum extension angle, ROM: Range of motion

As far as the stifle joint is concerned, no significant difference ($p>0.05$) was observed in the MFA, MEA and ROM between the three experimental groups in the walking gait. But in the trotting gait, it was found that the MEA in the PL-1 group (122.22±2.55) was significantly ($p<0.05$) lower than the MEA in the PL-2 group (127.13±4.88), but that there was no significant difference ($p>0.05$) compared to the MEA in the normal group (124.46±6.68).

In the case of the tarsal joint, the walking gait showed that the MFA in the PL-1 group (94.83±4.90) and the PL-2 group (95.28±5.29) were significantly higher ($p<0.05$) than the MFA in the normal group (88.26±9.06). In contrast, the ROM values in the PL-1 group (48.00±7.64) and in the PL-2 group (46.61±4.35) were significantly lower ($p<0.05$) than the ROM values in the normal group (53.87±5.25). The trotting gait was also found to have the same result. The MFA in the PL-1 group (79.13±7.55) and the PL-2 group (138.93±4.98) were significantly higher ($p<0.05$) than the MFA in the control group (69.25±4.93). On the other hand, the ROM values in the PL-1 group (60.66±7.97) and the PL-2 group (59.98±6.27) were significantly lower ($p<0.05$) than the ROM values in the normal group (72.01±6.98).

The walking cycle speed values (Fig. 4) in the PL-1 group (2.07±0.08) and the PL-2 group (2.04±0.14) were significantly higher ($p<0.05$) than the walking cycle speed values in the normal group (1.94±0.13). However, the trotting cycle speed values in the PL-2 group (3.02±0.21) were

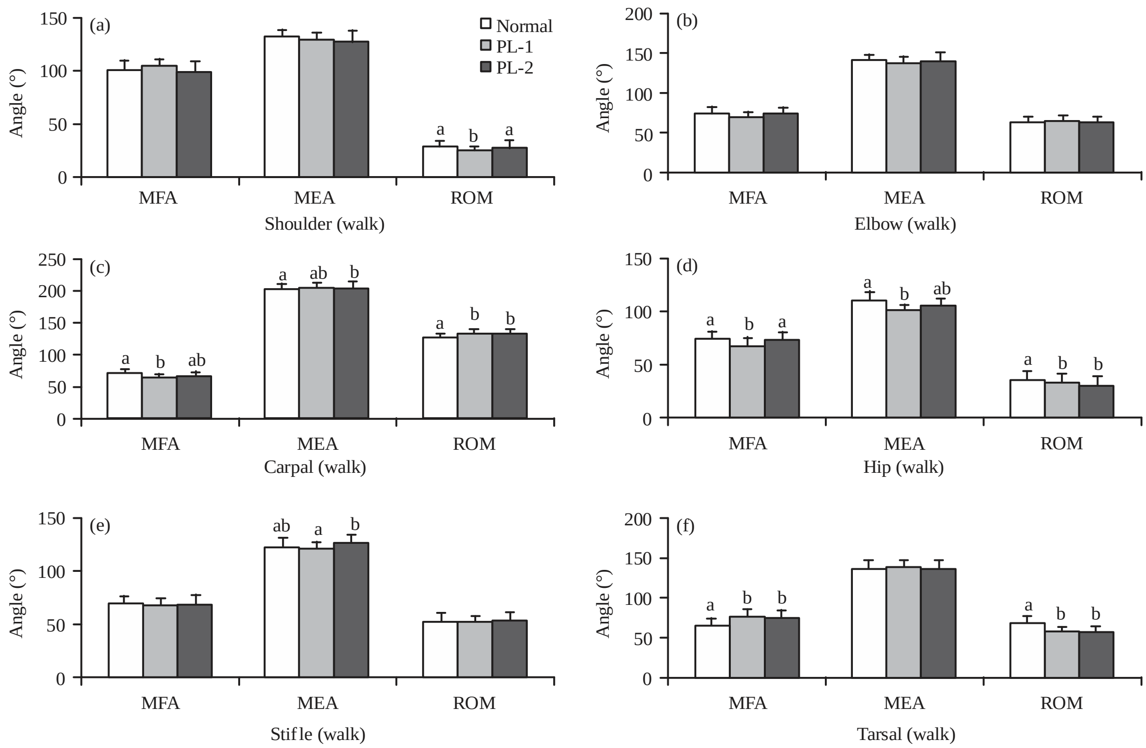

Fig. 3(a-f): Comparison of maximum flexion angle, maximum extension angle and range of motion between the experimental groups in the trot gait, (a) Shoulder, (b) Elbow, (c) Carpal, (d) Hip, (e) Stifle and (f) Tarsal. Values with different superscripts (a, b) are significantly different (p<0.05) when compared between 3 groups, MFA: Maximum flexion angle MEA: Maximum extension angle, ROM: Range of motion

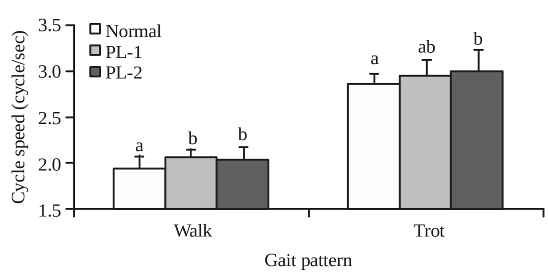

Fig. 4: Comparison between the cycle speeds of the experimental groups in walk gait and trot gait. Values with different superscripts (a, b) are significantly different (p < 0.05) when compared between 3 groups

significantly higher (p<0.05) than the trotting cycle speed values in the normal group (2.86±0.10), but there was no significant difference (p>0.05) compared to the trotting cycle speed values in the PL-1 group (2.97±0.15).

DISCUSSION

This study first demonstrated that in unilateral PL, the affected limb has no effect on the ROM of the unaffected limb, but upon performing a comparison between normal, unilateral and bilateral PL dogs, it was observed that unilateral PL and bilateral PL had an effect on the ROM of forelimb and hind limb.

It was found that either the forelimb or the hind limb was not capable of normal weight bearing because of reasons such as joint immobilization, joint disorder, fracture, muscle disorder, or limb amputation. The body will compensate by increasing or decreasing the ROM in the cervicothoracic and thoracolumbar vertebral regions (Eward *et al*., 2003; Hogy *et al*., 2013; Marsh *et al*., 2010; Miqueleto *et al*., 2013). Our study found in the trotting gait of dogs affected with bilateral PL that bilateral PL was the cause of the increase in the ROM of the carpal joint, while unilateral PL was found to be the cause of a decrease in the ROM of the shoulder, in comparison with unaffected dogs. In the walking gait, a decrease in the shoulder ROM in dogs affected with unilateral PL was observed compared to normal dogs. This indicates that both unilateral PL and bilateral PL have an effect on forelimb movement. During both walk gait and trot gait, in the hind limb, we found that the ROM values of the hip and the tarsal joints in the unilateral PL and bilateral PL had decreased compared to the ROM values of the normal. On the other hand, the ROM of stifle joint where patella is located was not found to be significantly different.

The treadmill is suitable for gait analysis because it enables the dog to walk and trot at a constant speed. However, some animals such as horses reported different movement over ground as compared to on a treadmill (Buchner *et al*., 1994). But almost all studies on humans (Parvataneni *et al*., 2009), mice (Herbin *et al*., 2007) and dogs (Gilette and Angle, 2008) have reported no difference of kinematics between walk on overground and walk on treadmill. For this result, we do believe that the ROM from dogs walking or trotting on treadmill can be a good representation of dogs walking or trotting on natural overground. Additionally, publications have reported treadmill inclination as affecting joint kinematics (Lauer *et al*., 2009), but in our study, the design of the treadmill was without inclination in order to avoid the effect from this instrument. Moreover, the dogs' walking and trotting lasted about 3 min in each pattern. This amount of time was not enough to induce fatigue. In addition, all the dogs were trained on a treadmill for more than 1 month before their performance for the experiment. For these reasons, we do believe that the ROM was directly caused by PL and not from muscle fatigue, or the dog would have refused to walk on the treadmill.

Regarding the carpal joint, the dogs affected with bilateral PL extended the angle higher than the normal dogs. According to a previous study, kinematic analysis in healthy and hip-dysplastic German Shepherd dogs (Miqueleto *et al*., 2013) showed more extension of the carpal joint, which could be associated with the additional weight bearing in the forelimb. Similar to this study, it was found that the hind limb of the PL dogs caused the increase in the MEA and the ROM of the carpal joint.

In our study, it was found that the ROM of the stifle joint showed no significant difference in all the three groups. This may have resulted from compensatory mechanism; thus, it is evident that it had no effect on the stifle joint. Patellar luxation also results from skeletal abnormalities of hind limb. These disarrangements were considered to be the underlying cause of the complex sequence of skeletal changes in the hind limb. The typical deformities include decrease in femoral anteversion (relative retroversion), coxavara (decreased femoral neck-shaft angle), coxavalga (increased femoral neck-shaft angle), femoral varus, a shallow trochlear groove, dysplasia of the femoral condyle, medial displacement of the tibial tuberosity and internal rotation of the hind limb (Mortari *et al*., 2009). Therefore, these deformities of PL may affect the ROM of the hip joint and the tarsal joint rather than the stifle joint, a finding that is in agreement with our result that the ROM in the hip joint and the tarsal joint in PL dogs is significantly lower than in normal dogs.

The PL dogs had higher cycle speed in walking and trotting than the healthy dogs. This is probably a compensatory mechanism due to PL or a mechanism of this abnormality. Because most of the ROM values in PL dogs (shoulder, hip and tarsal joints) were significantly lower than the ROM values in normal dogs, it can be concluded that there is a decrease in time in the swing phase of each stride in PL dogs. For this reason, PL dogs had higher cycle speed, but that does not mean that PL dogs could walk or trot faster than normal dogs. This study had the limitation of having to measure the distance of each stride to compare the lengths of the strides between PL dogs and normal dogs because the study was carried out on a treadmill. In conclusion, the walking or the trotting speed between PL dogs and normal dogs had to have two parameters: length of strides and cycle speed.

Kim *et al*. (2008) reported kinematic analysis using a 2-D video system which provided accurate and repeatable data of the sagittal angular motion of canines. Using that report, we did the experiment by using a 2-D video system because our objective was to study the ROM of the joints in the forelimb and the hind limb. However, it should be taken into consideration that this study had several limitations. The PL group was not categorized into PL-grade (1-4) because the number of animals would then be low and it would not qualify for statistical analysis. Moreover, most bilateral PL dogs show difference in PL grades (Nganvongpanit and Yano, 2011), which makes it very difficult to conclude the result. Second limitation involves the movement of the skin at the place where the marker is attached, as mentioned in many dog kinematic studies (Carr *et al*., 2013; Gilette and Angle, 2008; Millard *et al*., 2010), because dogs have highly moveable skin compared to other animals. However, this movement has not strongly affected the data collected in this study as the experiment was conducted in triplicate trials and all the Chihuahua dogs in our study had less skin movement by palpation. For these reasons, we do believe that the collected data were accurate.

Future studies are required for understanding the kinematics of PL dogs, including studies that use electromyography (EMG) to measure electrical signal transmission in muscle fibers. The advantage of this instrument is that it is able to detect the activity of specific muscles during locomotion (Gilette and Angle, 2008). The other related study is force plate analysis which is able to analyze ground reaction forces (Abdelhadi *et al*., 2012).

CONCLUSION

In conclusion, the comparison between either side of the legs in each group in both walking and trotting revealed no significant difference. The dogs with PL had higher cycle speed in walking and trotting than the normal dogs. There was significant difference in terms of the ROM between the three groups even though the dogs did not show clinical signs of lameness. In the walking pattern, different ROM values were found for the shoulder, hip and tarsal joints and in the trotting pattern, different ROM values were observed in the shoulder, carpal and tarsal joints.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support via research grants from the Faculty of Veterinary Medicine, Chiang Mai University, Chiang Mai, Thailand. Sincere thanks are also extended to all the pet owners for kindly providing their dogs for use in this study.

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