Kinetic and kinematic analysis of the right hind limb during trotting on a treadmill in Labrador Retrievers presumed predisposed or not predisposed to cranial cruciate ligament disease

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Objective—To identify gait characteristics during trotting on a treadmill in nonlame Labrador Retrievers presumed predisposed or not predisposed to cranial cruciate ligament disease (CCLD).

Animals—Clinically normal Labrador Retrievers presumed predisposed (n = 10) or not predisposed (7) to CCLD.

Procedures—The right hind limb of each dog was classified by use of a predictive score equation that combined tibial plateau angle and femoral anteversion angle as presumed predisposed (high score [> –1.5]) or not predisposed (low score [≤ –1.5]) to CCLD. Tarsal joint, stifle joint, and hip joint kinematics, net moments, and powers were computed.

Results—The stifle joint was held at a greater degree of flexion in limbs presumed predisposed to CCLD (130.9° vs 139.3°). More power was generated by muscles acting on the stifle joint in the early stance phase of limbs presumed to be predisposed to CCLD (2.93 vs 1.64 W/kg). The tarsal joint did not reach the same degree of extension in limbs presumed predisposed to CCLD, compared with that in limbs presumed not predisposed to CCLD (179.0° vs 161.0°). Velocity, stance time, vertical and craniocaudal forces, angular velocities, and net joint muscle moments did not differ between groups.

Conclusions and Clinical Relevance—Gait mechanics of dogs with high (> –1.5) and low (≤ –1.5) tibial plateau angle and femoral anteversion angle scores were characterized on a treadmill, which may help in the identification of dogs predisposed to CCLD. (*Am J Vet Res* 2012;73:1171–1177)

Cranial cruciate ligament disease is one of the most common orthopedic problems in adult large-breed dogs.[1,2] The prevalence of CCLD has gradually increased from 1.81% to 4.87% during the past 40 years.[1] Controversies exist regarding the exact pathogenesis of CCLD, and little information has been published concerning preventive measures. Most CCL ruptures appear to occur secondary to progressive adaptive and degenerative changes attributable to repetitive microinjury.[3] Risk factors for CCLD include an excessively steep tibial plateau, cranial angulation of the proximal portion of the tibia, and torsion of the distal portion of the femur.[4] The combination of the TPA and FAA has been identified as the best method to discriminate limbs predisposed to CCLD from limbs not predisposed to CCLD in Labrador Retrievers, a breed predisposed to CCL deficiency.[5]

Gait analysis and inverse dynamics have greatly contributed to elucidating joint mechanics that predispose human female athletes to anterior cruciate ligament injury. Dominance of the quadriceps muscles over

Abbreviations

CCL	Cranial cruciate ligament
CCLD	Cranial cruciate ligament disease
FAA	Femoral anteversion angle
GRF	Ground reaction force
JRF	Joint reaction force
TPA	Tibial plateau angle

Received April 4, 2011.
Accepted July 27, 2011.

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This manuscript represents a portion of a dissertation submitted by the first author to the University of Illinois Department of Veterinary Clinical Medicine as partial fulfillment of the requirements for a Doctor of Philosophy degree.
Supported by the American Kennel Club.
The authors thank Dr. Rosario Vallefuoco, Chris Knowlton, and Philip Kwon for assistance with data collection and processing.

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the hamstring muscle group and increased laxity of the knee joint were identified as factors that predisposed female athletes to knee joint injuries, which provided the basis for neuromuscular exercise programs.[6–8] A dynamic imbalance in joint kinetics and kinematics around the stifle joint may also be present in dogs predisposed to CCLD. The peak stifle joint moment during the propulsion phase accounts for 30% of the total moment in Labrador Retrievers, compared with only 12% in Greyhounds (a breed at low risk for CCLD).[9] Moreover, the amplitude of the net flexor muscle moment across the stifle joint, which is an active restraint to cranial tibial thrust, was more than twice as high in Greyhounds during the early stance phase, compared with the value in Labrador Retrievers.[9] These results are encouraging because they support the concept that dynamic stifle joint instability may predispose Labrador Retrievers to CCLD. However, these results may also reflect differences in morphology between the 2 breeds.

In addition, 37% to 48% of contralateral limbs have CCL deficiency 10 to 17 months after initial diagnosis of unilateral CCLD.[10,11] On the basis of the high incidence of contralateral rupture, the contralateral limb of dogs with unilateral CCLD may be considered predisposed. The limb mechanics of Labrador Retrievers with unilateral CCLD or that are free of orthopedic disease have been compared during trotting on the ground.[12] Gait analysis revealed increased propulsive forces and vertical impulse and greater power generation by the muscles around the stifle joint in contralateral limbs, compared with results for orthopedically normal limbs. This greater mobilization of the extensor muscles of the stifle joint at pushoff during extension of the stifle joint may increase the cranial tibial thrust, which is a force believed to contribute to the pathogenesis of CCLD.[13] However, because of the design of that previous gait mechanics study,[13] predisposing factors could not be differentiated from compensatory behaviors secondary to unilateral CCLD.

Most gait analyses in dogs involve trials conducted on the ground. Compared with these analyses, analyses conducted via treadmills instrumented with force platforms allow continuous measurement of GRF generated by all limbs during successive foot strikes. The ability to control the belt speed on a treadmill improves the reliability and consistency of subject velocity and acceleration and reduces the variability of measurements, compared with these factors in trials conducted in dogs trotting on the ground.[14–16] Analysis of gait while trotting on a treadmill has been extensively used for evaluating kinematics in humans and horses because the assessment can be performed in less space and with improved control of variables (velocity, surface, and positioning of cameras), compared with an assessment performed while trotting on the ground.

The objective of the study reported here was to identify gait characteristics during trotting on a treadmill in nonlame Labrador Retrievers classified as presumed predisposed or not predisposed to CCLD on the basis of the score of a radiographic combination of TPA and FAA. We hypothesized that an increased propulsive force and greater energy generation by the extensor muscles around the stifle joint would be identified in limbs classified as predisposed to CCLD (high TPA-FAA score [> –1.5]), compared with results for limbs presumed not predisposed to CCLD (low TPA-FAA score [≤ –1.5]).

Materials and Methods

Animals—Twenty client-owned Labrador Retrievers were recruited from the local pet population. Dogs were considered free of neurologic, orthopedic, or medical disease on the basis of history; results of physical, orthopedic, and neurologic examinations; and results of radiographic examination of both hip joints and both stifle joints. Informed consent was obtained from the owner of each dog for use in the study. The study was approved by the University of Illinois Institutional Animal Care and Use Committee.

Classification of limbs—Dogs were allocated into 2 groups. The right hind limb of each dog was classified as presumed predisposed to CCLD or not predisposed to CCLD on the basis of a predictive equation that combined the TPA and FAA.[5] The TPA and FAA were measured on radiographs (the mediolateral views of the tibia and femur and an extended craniocaudal femoral view), as described previously.[17] The equation was as follows[5]: CCL risk score = –33.49 + (0.37•FAA) + (0.82•TPA). The cutoff value used for the CCL risk score was –1.5, with limbs that had a score > –1.5 classified as predisposed to CCLD and limbs with a score ≤ –1.5 classified as not predisposed to CCLD. The mean ± SD TPA and FAA were higher in dogs presumed predisposed to CCLD (TPA, 28.6 ± 1.9°; FAA, 32.0 ± 6.2°) than in dogs presumed not predisposed to CCLD (TPA, 25.9 ± 1.8°; FAA, 26.3 ± 3.3°).

Procedures—Dogs had 2 training sessions to acclimate them to walking and trotting on a treadmill; these sessions were scheduled the day before and the day of collection of gait data. Each training session lasted until a consistent gait was observed for 10 minutes.

The right hind limb of each dog was categorized into thigh, crus, and foot segments in accordance with boundaries described previously.[18] The length, width, and girth of each hind limb segment were measured to calculate the segment mass, location of the center of mass, and mass moment of inertia by use of published predictive equations.[18] Reflective skin markers were placed on the skin to identify the thigh, crus, and foot segments of the right hind limbs for kinematic analysis.[12] Following application of the markers, the dogs were again allowed to become familiarized with the treadmill used for gait analysis before data were collected. Data for 3 consecutive trials were collected for each dog. All dogs were led by the same handler throughout the study to achieve a comfortable trotting velocity (mean treadmill speed, 2 m/s) on a split-belt instrumented treadmill.

Kinematic data were collected via a 6-camera optical-motion capture system[a] synchronized with the force plates positioned under the split-belt treadmill. The treadmill had the unique ability to record the magnitude and location of forces applied to each belt[b] (173 × 41 cm). Force and kinematic data were collected at 100 Hz.

All calculations were performed by use of a custom computer program.[c] The authors were not aware of the group classification of the dogs (presumed predisposed to CCLD or not predisposed to CCLD) during data collection.

Kinematic and kinetic data were filtered by use of a forward-backward fourth-order Butterworth low-pass filter with a cutoff frequency of 15 Hz. Each stance phase started at the point of ground contact of the right hind paw on the right belt of the treadmill and ended with the takeoff of the same hind paw from the belt, as defined by visual detection on the curve of vertical GRFs. Kinematic data obtained included duration of the stance phase; trotting velocity; and angular displacement and angular velocity in the sagittal plane of the tarsal joint, stifle joint, and hip joint, as determined via methods described previously.[12] Kinetic data obtained included GRF, net joint muscle moment, net joint muscle power, and net JRF in the sagittal plane for the tarsal joint, stifle joint, and hip joint, as determined via methods described elsewhere.[12]

The peak values of flexion and extension for angular position and velocity, flexor and extensor net joint muscle moment, power generation and absorption, and JRF for vertical, braking, and propulsive forces were determined for each joint of interest. In addition, the peak values of GRF for vertical, braking, and propulsive craniocaudal forces were determined for each joint. At the stifle joint, 2 peaks of power generation were recorded (early and late stance phases). The total impulse values of GRF and JRF (area under the force curve) were calculated. The peak and impulse values from each trial were determined, and mean values were calculated for each dog.

Statistical analysis—Groups were compared on the basis of age, body weight, and values of TPA and FAA. Kinematic variables compared between the 2 groups were stance time, trotting velocity, peak values of joint angular position, and velocity during flexion and extension at the tarsal joint, stifle joint, and hip joint. Kinetic variables compared between the 2 groups were peak and impulse values for vertical and craniocaudal GRF and JRF, peak values of net flexor and extensor muscle moments, and peak values of net muscle power generation and absorption at the tarsal joint, stifle joint, and hip joint. Normal distribution of data was tested with a Shapiro-Wilk normality test. For variables with a normal distribution, a Student *t* test was used when homogeneity of variance was assumed; a Welch *t* test was used when homogeneity of variance was rejected. A Mann-Whitney *U* test was used for variables without a normal distribution. Finally, sex distribution of groups was compared via a χ^2 test.[d] For all analyses, values of $P < 0.05$ were considered significant.

Table 1—Mean ± SD gait velocity, stance time, and peak GRFs and total impulse values of vertical and craniocaudal forces during the braking and propulsive phases for nonlame Labrador Retrievers presumed predisposed to CCLD or not predisposed to CCLD.*

Variable	Predisposed	Not predisposed
Velocity (m/s)	2.51 ± 0.14	2.40 ± 0.27
Stance time (s)	0.22 ± 0.02	0.22 ± 0.02
Peak vertical GRF (N/kg)	7.60 ± 0.64	7.69 ± 0.52
Peak braking GRF (N/kg)	0.70 ± 0.35	0.62 ± 0.24
Peak propulsion GRF (N/kg)	–1.05 ± 0.26	–1.08 ± 0.29
Vertical impulse GRF (N•s/kg)	0.90 ± 0.09	0.89 ± 0.14
Braking impulse GRF (N•s/kg)	0.04 ± 0.02	0.03 ± 0.02
Propulsive impulse GRF (N•s/kg)	–0.08 ± 0.04	–0.08 ± 0.03

For all variables, values did not differ significantly ($P \geq 0.05$) between groups.

*The right hind limb of each dog was classified by use of a predictive score equation that combined TPA and FAA as presumed predisposed to CCLD (high score [> –1.5]) or not predisposed to CCLD (low score [≤ –1.5]).

Results

The right limbs of 20 adult Labrador Retrievers were evaluated. Valid kinetic trials could not be generated on the treadmill in 3 dogs because of invalid craniocaudal GRF measurements. Therefore, results were reported for only 17 dogs (10 neutered males, 1 sexually intact female, and 6 spayed females) with a median age of 50 months (range, 11.5 to 137 months) and a mean ± SD body weight of 27.6 ± 2.9 kg.

Review of the right limb radiographs resulted in 7 Labrador Retrievers classified as presumed not predisposed to CCLD (median CCL risk score, –2.6; range, –3.2 to –1.5), and 10 were classified as presumed predisposed to CCLD (median CCL risk score, 1.7; range, –1.2 to 6.4). The age of Labrador Retrievers presumed predisposed to CCLD (median age, 40 months; range, 11.5 to 137 months) was not significantly different from that of dogs presumed not predisposed to CCLD (median age, 69 months; range, 24.5 to 130 months). Mean ± SD body weight did not differ significantly between dogs predisposed (27.6 ± 2.7 kg) and not predisposed (27.5 ± 3.4 kg) to CCLD. Sex distribution was not significantly different between the 2 groups; the group of Labrador Retrievers presumed predisposed to CCLD was composed of 6 males and 4 females (9 neutered and 1 sexually intact), whereas the group of Labrador Retrievers presumed not predisposed to CCLD was composed of 4 males and 3 females (all neutered).

Three valid trials were used to evaluate the right pelvic limb of each dog, except in 2 dogs (both of which were in the group not predisposed to CCLD) for which only 2 valid trials were available for evaluation.

After data were collected and treadmill trials were completed, it was determined that the program for the treadmill resulted in an incorrect belt speed; thus, the mean ± SD actual belt speed for the trials was 2.47 ± 0.20 m/s. Trotting velocity of the dogs did not differ between groups **(Table 1)**.

Kinematic and inverse-dynamics results were determined **(Figure 1; Table 2)**. The stifle joint was held at a greater degree of flexion at midstance in limbs presumed predisposed to CCLD. In addition, more energy was generated by muscles acting on the stifle joint in the early stance phase during flexion of the stifle joint of limbs presumed predisposed to CCLD. The tarsal joint did not reach the same degree of extension at pushoff in limbs presumed predisposed to CCLD, compared with that for limbs presumed not predisposed to CCLD. Peak values of joint angular position of the hip joint and joint angular velocity of the tarsal joint, stifle joint, and hip joint did not differ between groups dur-

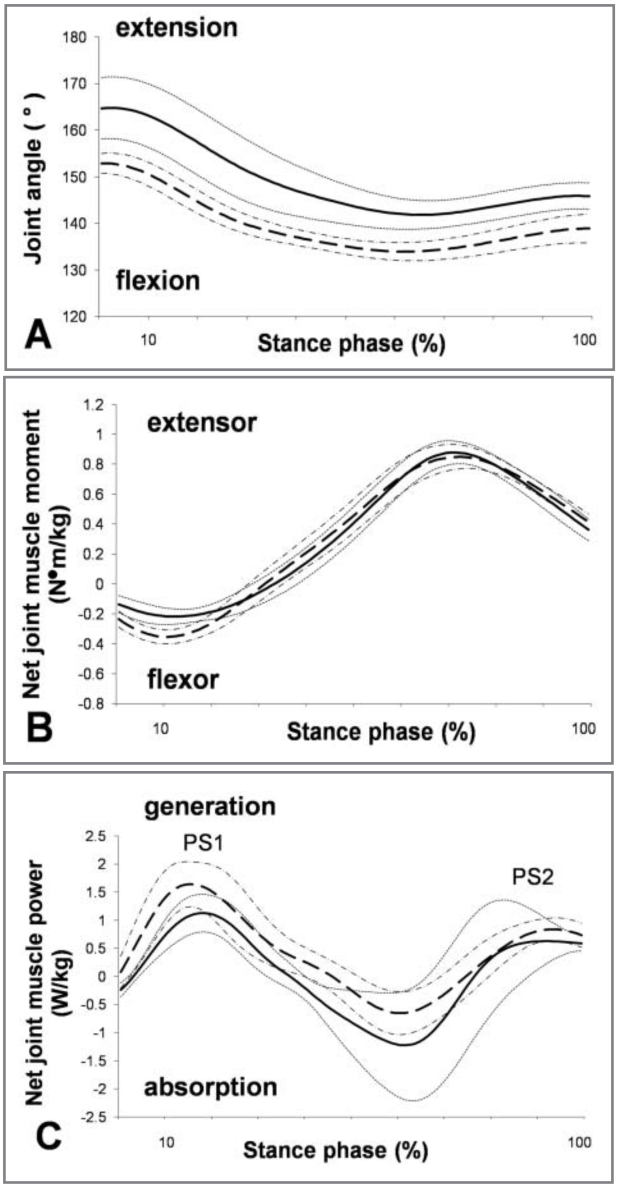

Figure 1—Mean ± SE angular position (A), net joint muscle moment (B), and net joint muscle power (C) at the right stifle joint of Labrador Retrievers during the stance phase for 10 limbs presumed predisposed to CCLD (dashed line) or 7 limbs presumed not predisposed to CCLD (solid line). Each limb was classified by use of a predictive score equation that combined TPA and FAA (presumed predisposed to CCLD [high score {> −1.5}] or not predisposed to CCLD [low score {≤ −1.5}]). Two peaks of power generation were recorded (during the early stance phase [PS1] and the late stance phase [PS2]). The SE values are indicated for the group presumed not predisposed to CCLD (thin gray lines) and for the group presumed predisposed to CCLD (dashed-and-dotted lines). Labrador Retrievers presumed predisposed to CCLD held their stifle joint at a greater degree of flexion at midstance and generated more energy around the stifle joint during PS1, compared with dogs presumed not predisposed to CCLD.

ing flexion and extension, nor did values differ between groups for net joint muscle moment at the tarsal joint, stifle joint, and hip joint and net joint power at the tarsal joint and hip joint. Stance time, vertical force, and craniocaudal GRF and JRF did not differ between limbs presumed predisposed to CCLD and limbs presumed not predisposed to CCLD.

Discussion

For Labrador Retrievers trotting on a treadmill, gait mechanics of dogs presumed predisposed or not predisposed to CCLD on the basis of their combined radiographic TPA-FAA score were characterized. Results of the present study indicated that Labrador Retrievers presumed predisposed to CCLD held their stifle joint at a greater degree of flexion and extended their tarsal joint less than did dogs presumed not predisposed to CCLD. In addition, more energy was generated by muscles acting on the stifle joint in the early stance phase of limbs of dogs presumed predisposed to CCLD.

According to previous reports[8,12,19] for dogs, flexion of the stifle joint during stance results from a concentric contraction of the stifle joint flexor muscles (mainly the hamstring muscle group and gastrocnemius muscles). In the present study, the stifle joint of dogs presumed predisposed to CCLD reached a greater degree of flexion during midstance (130.9° vs 139.3°), compared with that of dogs presumed not predisposed to CCLD. Moreover, the muscles acting around the stifle joint generated more energy during stifle joint flexion in early stance in dogs presumed predisposed to CCLD, compared with that in dogs presumed not predisposed to CCLD (2.93 vs 1.64 W/kg; Figure 1). Trotting on a treadmill stimulated flexor muscles of the stifle joint more in dogs presumed predisposed to CCLD, compared with that in dogs presumed not predisposed to CCLD, which resulted in greater flexion of the stifle joint. The existence of a fast-to-respond reflex arc from mechanoreceptors in the CCL to the hamstring muscle group was detected in cats with intact CCLs.[20] In that study,[20] the activity in the hamstring muscle group was increased, as determined on the basis of electromyographic analysis during loading of the CCL. This reflex arc may allow an antagonist muscle of a joint to act as a torque regulator that would be activated during ligament overloading to maintain joint stability. There may have been a similar reflex arc in the Labrador Retrievers of the present report. This reflex contraction of the hamstring muscle group may have been stimulated more in dogs presumed predisposed to CCLD, compared with that in dogs presumed not predisposed to CCLD. Fatigue of the hamstring muscle group may lead to overloading of the CCL and subsequent repetitive microtrauma and failure. Therefore, specific exercises targeted at strengthening the hamstring muscle group, such as walking on an inclined treadmill,[21] may be beneficial to decrease risk of CCL deficiency. However, these types of exercises may also cause increased stress on the CCL if the hamstring muscle group does not compensate.

The greater energy generated by flexor muscles of the stifle joint may also have been secondary to increased activity of the gastrocnemius muscle, another muscle that is part of the flexor muscles of the stifle joint. Contraction of the gastrocnemius muscle contributes to cranial tibial thrust and CCL loading.[13] Therefore, increased recruitment of the gastrocnemius muscle observed in limbs presumed predisposed to CCLD may lead to repetitive microtrauma and weakening of the ligament over time. This result confirms a previous report[22] of a suspected increase in recruitment

Table 2—Mean ± SD values of peak kinematic and kinetic variables for the tarsal joint, stifle joint, and hip joint in Labrador Retrievers presumed predisposed to CCLD or not predisposed to CCLD.*

	Tarsal joint		Stifle joint		Hip joint	
Variable	**Predisposed**	**Not predisposed**	**Predisposed**	**Not predisposed**	**Predisposed**	**Not predisposed**
Angular position (°)						
Extension	161.0 ± 9.2†	179.0 ± 10.4	155.6 ± 6.3	165.3 ± 17.6	137.9 ± 5.4	136.9 ± 14.2
Flexion	116.4 ± 10.7	125.6 ± 12.1	130.9 ± 6.7†	139.3 ± 7.9	109.4 ± 8.2	112.0 ± 16.4
Angular velocity (°/s)						
Extension	593 ± 104	675 ± 174	204 ± 113	181 ± 67	297 ± 75	324 ± 134
Flexion	–908 ± 269	–983 ± 246	–426 ± 126	–401 ± 166	–52 ± 57	–92 ± 107
Moment (N•m/kg)						
Flexor peak	NA	NA	–0.46 ± 0.14	–0.31 ± 0.15	–1.12 ± 0.24	–1.08 ± 0.32
Extensor peak	0.44 ± 0.13	0.36 ± 0.13	0.95 ± 0.23	0.94 ± 0.20	0.94 ± 0.28	0.68 ± 0.24
Power (W/kg)						
Generation peak	1.76 ± 1.01	1.66 ± 0.84	2.93 ± 1.34†	1.64 ± 0.84	3.12 ± 2.08	2.89 ± 1.23
Second generation peak	NA	NA	1.84 ± 1.11	1.53 ± 0.91	NA	NA
Absorption peak	–4.90 ± 2.73	–4.57 ± 1.86	–1.91 ± 1.02	–2.10 ± 2.52	–3.58 ± 1.95	–3.13 ± 1.62
Vertical peak JRF (N/kg)	–7.47 ± 0.61	–7.58 ± 0.54	–7.09 ± 0.57	–7.21 ± 0.53	–6.20 ± 0.62	–6.12 ± 0.31
Vertical impulse (N•s/kg)	–0.85 ± 0.09	–0.84 ± 0.13	–0.81 ± 0.09	–0.79 ± 0.13	–0.70 ± 0.09	–0.67 ± 0.12
Propulsion peak JRF (N/kg)	1.12 ± 0.22	1.14 ± 0.39	1.30 ± 0.22	1.32 ± 0.41	1.71 ± 0.23	1.81 ± 0.38
Propulsion impulse (N•s/kg)	0.08 ± 0.03	0.08 ± 0.04	0.09 ± 0.04	0.09 ± 0.04	0.11 ± 0.04	0.11 ± 0.04
Braking peak JRF (N/kg)	–1.10 ± 0.38	–0.86 ± 0.32	–1.69 ± 0.49	–1.32 ± 0.48	–2.13 ± 0.52	–1.67 ± 0.64
Braking impulse (N•s/kg)	–0.05 ± 0.03	–0.04 ± 0.02	–0.07 ± 0.03	–0.06 ± 0.02	–0.10 ± 0.03	–0.08 ± 0.03

Kinematic variables include peak values of joint angular position and velocity during flexion and extension. Kinetic variables include peak values of net joint muscle moment and net joint muscle power and peak and impulse values of net JRFs in the vertical and craniocaudal directions.

†Within a joint, values differ significantly ($P < 0.05$) between groups.

See Table 1 for remainder of key.

of the gastrocnemius muscle in limbs predisposed to CCLD.

The mass of the gastrocnemius muscle and the ratios of lean content of the gastrocnemius muscle to the hamstring muscle group and of the gastrocnemius muscle to the quadriceps muscle of the contralateral limbs predisposed to CCLD in dogs with unilateral CCLD are increased, compared with values in healthy control limbs, as determined on the basis of densitometric measures.[22] However, the use of CCL-deficient dogs precluded differentiation between compensatory behavior and factors that predispose to CCLD in that study.[22] Alternatively, the activity of extensor muscles of the stifle joint (primarily the quadriceps muscle) may have been decreased in limbs predisposed to CCLD in the previous study.[22] Future studies should integrate electromyographic data to confirm these findings and allow differentiation among antagonist muscles.

In dogs, it has been suggested that the joint force generated on the stifle joint during weight bearing is almost parallel to the patellar ligament. This force causes a tibiofemoral shear force in a cranially oriented direction during extension of the stifle joint, reaches zero at flexion when the patellar ligament is perpendicular to the tibial plateau, and shifts to the caudal cruciate ligament with further flexion of the joint.[23] Increased flexion of the stifle joint may be an adaptation to decrease the cranial tibial thrust by bringing the tibial plateau more parallel to the ground. The assignment of dogs into predisposed or not predisposed groups in the present study was on the basis of values of the TPA and FAA. A higher mean TPA and FAA were measured in dogs presumed predisposed to CCLD, compared with values for dogs presumed not predisposed to CCLD. A greater tibial plateau slope is believed to increase the cranial tibial thrust.[13] Therefore, the observed difference in gait mechanics between groups could have been secondary to the difference in conformation of the hind limbs in addition to, or instead of, a reflection of the predisposition to CCL deficiency.

The tarsal joint, stifle joint, and hip joint follow an extension pattern just before takeoff (end of the stance phase).[12,24] In the present study, Labrador Retrievers classified as presumed predisposed to CCLD extended their tarsal joint less (161.0° vs 179.0°) when trotting on a treadmill, compared with extension in dogs presumed not predisposed to CCLD. This lesser extension of the tarsal joint in limbs presumed predisposed to CCLD may have reflected adjustments of the gait and lesser recruitment of the extensor muscles of the tarsal joint (primarily the gastrocnemius muscle) at the end of the stance phase.[9] Alternatively, the activity of flexor muscles of the tarsal joint may have been increased in limbs presumed predisposed to CCLD. Therefore, trotting on a treadmill may modify activity of the gastrocnemius muscle in a bimodal way in dogs presumed predisposed to CCLD, thereby increasing its activity during the early stance phase (when the stifle joint is flexed) and decreasing its activity at pushoff during extension of the stifle joint. Electromyographic analysis should be integrated in future studies to better characterize the recruitment of the gastrocnemius muscle.

Findings for the present study differ from previous findings regarding the predisposed contralateral limbs of dogs with unilateral CCLD. In a previous study,[12] gait analysis was used to identify increased propulsive forces and vertical impulse and greater power generation by the muscles around the stifle joint in contralateral limbs, compared with results for orthopedically normal limbs. In the study reported here, the data did not support our hypothesis that an increased propulsive force and greater energy generation by the extensor muscles around the stifle joint would be identified in limbs presumed predisposed to CCLD. Therefore, the greater forces and mobilization of the extensor muscles of the stifle joint at pushoff during extension of the stifle joint in contralateral limbs may represent compensatory behaviors secondary to unilateral CCLD, instead of factors that predispose to CCLD.

The present study had several limitations, including the definition of predisposed to CCLD. Distinguishing limbs not predisposed to CCLD versus limbs predisposed to CCLD is a limitation inherent to investigations into the pathogenesis of CCLD. In Labrador Retrievers, 48% of dogs with unilateral CCLD develop contralateral CCL deficiency, which provides a rationale for considering the contralateral limbs as predisposed.[10] However, the effect of lameness attributable to unilateral CCLD is a confounding factor when investigating the role of muscular conformation or gait characteristics as potential causative factors for bilateral disease.[3]

In previous studies,[9,12,25,26] investigators used Greyhounds (a breed at low risk for CCLD) or older dogs (because the likelihood to develop CCLD decreases with time) as a control group to assess risk factors for CCLD. However, these alternatives introduce age and interbreed difference as variables between the affected and orthopedically normal populations. A predictive equation model (combined radiographic TPA-FAA score) has been developed to assess the risk for CCLD in Labrador Retrievers,[5] which was used to classify dogs as presumed predisposed or not predisposed to CCLD in the present study. The authors elected to use the combined radiographic TPA-FAA score in the present study because of the good sensitivity and specificity of the method for use in discriminating dogs predisposed to CCLD or not predisposed to CCLD in a previous study.[5] Moreover, the authors are not aware of any other method currently available to potentially predict predisposition to CCLD in individual dogs. However, to validate this method, large-scale prospective studies should be undertaken to compare the long-term outcome for dogs considered predisposed to CCL deficiency and not predisposed to CCL deficiency.

Another limitation of the present study stemmed from the evaluation of the gait obtained while trotting on a treadmill and use of a split-belt treadmill. Although a treadmill offers a convenient and controlled environment for studying the canine gait, there may be a greater demand on a dog's proprioception skills during treadmill trials, perhaps as a means of avoiding falling off the back of the treadmill or maintaining its speed consistent with that of the belt.[27] Moreover, subjects should be habituated to locomotion on a treadmill.[27,28] After allowing dogs to acclimate on a treadmill at a walking pace for 2 minutes, consistent kinematics of the elbow joint and stifle joint were obtained for treadmill-naïve Greyhounds within only 30 seconds.[29] However, in another study, angular displacements and velocities remained variable in treadmill-naïve Labrador Retrievers within and between five 2-minute trotting sessions.[30] These observations emphasized the importance of acclimatization, a learning phase during which a subject develops subtle changes in gait that eventually lead to habituation, which is characterized by a steady, repeatable gait. In the present study, we elected to train the dogs during two 10-minute treadmill sessions (the day before and the day of data collection). According to the handler, a consistent trotting gait on the treadmill was obtained at the end of the second training period. However, because of the use of a spilt-belt treadmill, data analysis was based on only 2 or 3 consecutive cycles, which may have impacted our results. We experienced difficulties with regard to dogs trotting in a straight line on the treadmill such that the hind limbs remained over the respective belt and force plate. Finally, the actual treadmill speed was found to be at a higher velocity than expected because of technical difficulties with the controller program. Future studies should be conducted to determine the optimum amount of time for a habituation period and the optimum treadmill speed for use in evaluating gait mechanics in Labrador Retrievers.

In the study reported here, Labrador Retrievers presumed predisposed to CCLD, as determined on the basis of their combined radiographic TPA-FAA score, held their stifle joint at a greater degree of flexion, extended their tarsal joint less, and generated more energy around the stifle joint when trotting on a treadmill, compared with dogs presumed not predisposed to CCLD. These results provide preliminary information on characteristics of treadmill gait patterns that may prove helpful in the identification of dogs predisposed to CCLD.

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b. Bertec Corp, Columbus, Ohio.
c. MATLAB, MathWorks Inc, Natick, Mass.
d. Systat, version 11, Systat Inc, Richmond, Calif.

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