Title
Comparison of the tibial mechanical joint orientation angles in dogs with cranial cruciate ligament rupture.

Journal
The Canadian veterinary journal = La revue veterinaire canadienne, 55(8)

ISSN
0008-5286

Authors
Fuller, Mark C
Kapatkin, Amy S
Bruecker, Kenneth A
et al.

Publication Date
2014-08-01

Peer reviewed

Article

Comparison of the tibial mechanical joint orientation angles in dogs with cranial cruciate ligament rupture

Mark C. Fuller, Amy S. Kapatkin, Kenneth A. Bruecker, Ian G. Holsworth, Philip H. Kass, Kei Hayashi

Abstract — Use of the tibial mechanical joint orientation angles is now the standard of care for evaluating tibial deformities, although they have not been used to evaluate dogs with cranial cruciate ligament (CrCL) rupture. The objective of this study was to compare the tibial mechanical joint orientation angles and tibial plateau angle (TPA) between dogs with bilateral CrCL rupture (BR) and unilateral CrCL rupture with (UR-SR) and without subsequent contralateral CrCL rupture (UR-w/o-SR) as risk factors for subsequent contralateral CrCL rupture. Twenty dogs (21.7%) were classified as BR, 38 (41.3%) were classified as UR-SR, and 34 (37.0%) were classified as UR-w/o-SR. The tibial mechanical joint orientation angles and TPA, in the range studied (< 35°), were not statistically different for dogs with BR, UR-SR, and UR-w/o-SR, and were not significant risk factors for subsequent contralateral CrCL rupture.

Résumé — Comparaison des angles tibials mécaniques chez les chiens diagnostiqués avec une rupture du ligament croisé cranial. Bien que l'usage de l'angle tibial mécanique constitue la norme d'évaluation des déformations du tibia, cette méthode n'a pas encore été décrite pour l'évaluation des patients canins atteints de rupture du ligament croisé cranial. L'objectif de cette étude était de comparer les valeurs des angles mécaniques tibials avec l'angle du plateau tibial chez les chiens atteints de rupture bilatérale (BR) du ligament croisé cranial, ou atteints de rupture unilatérale suivie de la rupture du ligament croisé cranial contra-lateral (UR-SR), ou atteints seulement de rupture du ligament croisé unilateral (UR-w/o-SR); additionnellement l'objectif de cette étude était d'identifier les facteurs prédisposant la rupture du ligament croisé cranial contralatéral. Vingt chiens (21,7 %) furent diagnostiqués avec BR, 38 (41,3 %) furent diagnostiqués avec UR-SR et 34 (37,0 %) avec UR-w/o-SR. L'analyse statistique n'a pas révélé de différence statistique entre les angles tibials mécaniques et l'angle du plateau tibial dans le range d'angles etudiés (< 35°) chez les différentes catégories de patients. De plus, aucun facteur de risque predisposant pour la rupture du ligament croisé cranial contralatéral ne fût identifié.

(Traduit par les auteurs)

Can Vet J 2014;55:757–764

Introduction

Cranial cruciate ligament (CrCL) rupture is a leading cause of lameness in dogs, although the pathogenesis remains unclear (1,2). While some dogs develop CrCL rupture as a result of trauma, most dogs are believed to develop CrCL rupture from progressive ligamentous failure under conditions of normal loading (2). An increasing amount of information suggests that intrinsic factors play a significant role in the pathogenesis of CrCL rupture, including an increased prevalence associated with neutering, the high lifetime prevalence of bilateral CrCL rupture, altered pelvic limb kinetics in predisposed dogs, and specific breed predilections including a genetic basis identified in Newfoundlands (1,3–9).

Conformational abnormalities leading to altered biomechanics in the stifle joint have long been thought to be a significant risk factor for CrCL rupture. This notion is supported by histologic analysis in which CrCL rupture was suspected to be secondary to repetitive micro-injury during mechanical loading

Departments of Surgical and Radiological Sciences (Fuller, Kapatkin) and Population Health and Reproduction (Kass), School of Veterinary Medicine, University of California-Davis, One Shields Avenue, Davis, California 95616, USA; Veterinary Medical and Surgical Group, Ventura, California 93003, USA (Bruecker, Holsworth); Department of Clinical Sciences, College of Veterinary Medicine, Cornell University, Ithaca, New York, USA 14853 (Hayashi).

Address all correspondence to Dr. Mark Fuller; e-mail: markfullerdvm@gmail.com

This study was not supported by any grant and was presented at the 40th Annual Veterinary Orthopedic Society Conference, Park City, Utah, USA, March 9–16, 2013.

(2). Many authorities have hypothesized that variations in stifle morphology, and in particular tibial morphology, can result in significant micro-injury to the CrCL (10–16). For example, an increased tibial plateau angle (TPA), increased patellar tendon angle, proximal tibial procurvatum, or relatively small proximal tibial width may result in micro-injury through increased ligament strain and total joint shear force (10–16). Femoral morphology has also been investigated with special attention to a narrow intercondylar notch, distal femoral torsion, and an increased femoral anteversion angle (16–18). Despite the fact that many of these variables were found to be significant risk factors for CrCL rupture, study comparisons were made between separate groups of dogs with and without CrCL rupture (10–18). Although associations and differences were found, causation remains unknown.

Prospective evaluation of a large population of dogs would be the ideal study design to evaluate conformational characteristics as risk factors for CrCL rupture; however, due to the relatively low prevalence of CrCL rupture (4.9%) a large sample population would be required to detect any differences (1). An alternative approach is to study conformation within groups of dogs with CrCL and determine whether differences exist with respect to the development of contralateral CrCL rupture or if conformational differences affect the rate of subsequent contralateral rupture. The relatively higher prevalence of contralateral rupture (59% to 61%) would allow for smaller sample sizes to be used (5,6). With regard to conformational variables, only the TPA has been evaluated using this approach; however, in these studies bilateral radiographs were not routinely taken and the TPA of the contralateral limb was only available for dogs with contralateral rupture (5,6,8). As a result, direct comparison of the contralateral TPA between dogs with and without contralateral rupture was not possible (5,6,8).

Recently, the principles of conformation assessment and angular limb deformity correction used in human orthopedics have become the standard of care in small animal orthopedics (19–21). This technique, called the center of rotation of angulation (CORA) method, involves assessing the anatomic and mechanical joint orientation angles of the individual long bones in both the sagittal and frontal planes (19–21). With respect to the canine tibia, normal reference ranges for the mechanical joint orientation angles have been reported and are being used in the planning of angular limb deformity correction (19–21). Despite the presumed role of conformation abnormalities in the pathogenesis of CrCL rupture, the tibial mechanical joint orientation angles have not been previously evaluated in dogs with or without CrCL rupture or in dogs with CrCL rupture with respect to the development of contralateral rupture.

The first objective of this study was to compare the TPA, tibial mechanical joint orientation angles, and tibial alignment between dogs with bilateral CrCL rupture (BR) and unilateral CrCL rupture with (UR-SR) and without subsequent contralateral CrCL rupture (UR-w/o-SR) in a large population of dogs for which bilateral radiographs were available. The second objective was to evaluate the TPA, tibial mechanical joint orientation angles and tibial alignment as risk factors for subsequent contralateral CrCL rupture for dogs initially presenting with unilateral rupture, while controlling for potential confounding variables. A previous study using this patient population identified a positive radiographic infrapatellar fat pad sign and osteophytosis of the contralateral stifle as significant prognostic factors for subsequent contralateral CrCL rupture (22). The null hypothesis was that the TPA, tibial mechanical joint orientation angles, and tibial alignment are not statistically different between dogs with BR, UR-SR, and UR-w/o-SR and are not significant risk factors of subsequent contralateral CrCL rupture.

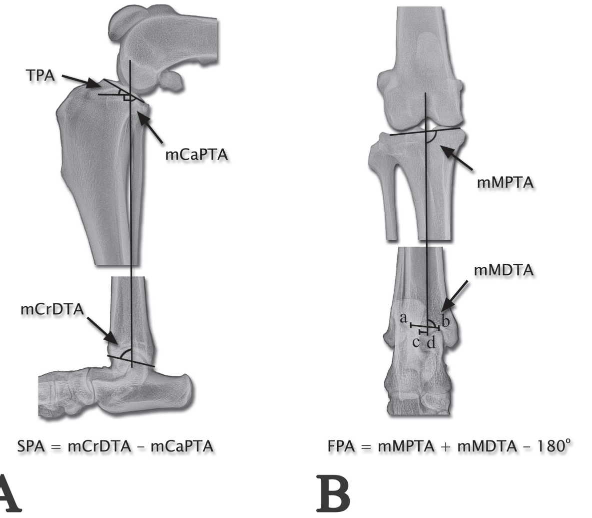

Figure 1. Schematic mediolateral (A) and caudocranial tibial radiographs (B) demonstrating measurement of the tibial mechanical joint orientation angles, alignment and percent deviation. Percent deviation = [(distance C-D)/(distance A-B)] × 100%; positive integers indicate lateral deviation and negative integers indicate medial deviation. TPA = tibial plateau angle = 90° – mCaPTA. mCaPTA = mechanical caudal proximal tibial angle, mCrDTA = mechanical cranial distal tibial angle, mMPTA = mechanical medial proximal tibial angle, mMDTA = mechanical medial distal tibial angle, SPA = sagittal plane alignment, FPA = frontal plane alignment, a = lateral arciform groove of the cochlea tibiae, b = medial arciform groove of the cochlea tibiae, c = medial aspect of the tuber calcaneus, d = distal intermediate ridge of the tibia.

Materials and methods

Case selection criteria

The medical records of consecutive dogs undergoing surgical treatment for CrCL rupture from July 1, 2006 to June 30, 2007 at a single institution were reviewed. Chondrodysplastic and toy breeds were excluded, along with cases with prior surgical treatment for CrCL rupture, historical, or concurrent medial patellar luxation, pelvic limb osteochondritis dissecans, or pelvic limb trauma resulting in a fracture or additional ligamentous injuries. CrCL rupture was confirmed arthroscopically for all cases and all orthopedic and arthroscopic evaluations were performed by a board-certified veterinary surgeon (KAB, IGH). Based on the standard of care at this hospital, preoperative bilateral orthogonal stifle radiographs were obtained for all cases, regardless of whether or not unilateral or bilateral rupture was suspected. If not already performed by the referring veterinarian, lateral and ventrodorsal hip-extended pelvic radiographs were obtained for cases in which coxofemoral joint abnormalities were identified

Table 1. Signalment characteristics, duration of lameness, and presence of current hip disease

Variable	UR-w/o-SR (*n* = 34)	UR-SR (*n* = 38)	BR (*n* = 20)
Age (y)	5.2 ± 2.5 5.5 (1.0–9.2)	5.1 ± 2.2 5.4 (1.3–10.1)	5.5 ± 2.6 5.1 (1.1–11.0)
Body weight (kg)	37.7 ± 12.6 34.4 (21.5–85.0)	34.5 ± 10.1 33.1 (20.1–73.7)	36.3 ± 8.5 34.8 (22.0–57.9)
BCS (scale 1–9)	6.1 ± 1.3 6 (4–9)	6.0 ± 0.9 6 (4–8)	5.9 ± 0.9 6 (5–8)
Lameness duration (d)	100.5 ± 88.4 90 (3–420)	95.1 ± 120.7 60 (3–730)	185.9 ± 199.5 60 (7–730)
Sex			
Male intact	4 (11.8%)	1 (2.6%)	2 (10.0%)
Male neutered	12 (35.3%)	10 (26.3%)	5 (25.0%)
Female intact	1 (2.9%)	1 (2.6%)	1 (5.0%)
Female spayed	17 (50.0%)	26 (68.4%)	12 (60.0%)
Breed			
Labrador	11 (32.4%)	15 (39.5%)	8 (40.0%)
Predisposed	4 (11.8%)	8 (21.1%)	5 (25.0%)
Other	19 (55.9%)	15 (39.5%)	7 (35.0%)
Hip disease	5 (14.7%)	4 (10.5%)	3 (15.0%)
Fat pad sign	6 (17.6%)	30 (78.9%)	20 (100%)
Degenerative sign	10 (29.4%)	27 (71.1%)	19 (95.0%)

Age, body weight, BCS, and duration of lameness are shown as mean ± standard deviation and median (range). All other variables are shown as number (percent).
UR-w/o-SR — Unilateral cranial cruciate ligament rupture without subsequent rupture.
UR-SR — Unilateral cranial cruciate ligament rupture with subsequent rupture.
BR — Bilateral cranial cruciate ligament rupture.
BCS — Body condition score.

on orthopedic examination. A board-certified veterinary radiologist evaluated all radiographs prior to arthroscopic evaluation.

Data collection

Information obtained from each medical record included age, gender, reproductive status, breed, body weight, body condition score (23), duration of lameness, orthopedic examination, preoperative radiographic and arthroscopic findings. The preoperative radiology reports were reviewed and the presence or absence of a positive fat pad sign or osteophytosis of the contralateral stifle was recorded (22,24). The preoperative radiographs were reviewed and the 4 mechanical tibial joint orientation angles and TPA were measured for all dogs bilaterally, along with assessment of rotational or torsional deviation on the caudocranial radiographs as previously described (19–21). Radiographic measurements were performed by one author (MCF) using an image processing application (OsiriX, v3.8.1; Pixmeo, Bernex, Switzerland).

The distinction between unilateral CrCL rupture and bilateral CrCL rupture on initial presentation was based on the criteria used in previous studies (5,6,8). Unilateral CrCL rupture was defined as unilateral pelvic limb lameness, ipsilateral cranial tibial instability, or pain on full stifle extension, and arthroscopic confirmation of CrCL rupture. Bilateral CrCL rupture was defined as bilateral cranial tibial instability or pain on full stifle extension, with arthroscopic confirmation of CrCL rupture in at least 1 stifle, regardless of whether bilateral pelvic limb lameness was present on gait evaluation. Follow-up information for UR cases was obtained from the medical record and from telephone calls to the primary care veterinarian. A subsequent contralateral CrCL rupture was defined as an arthroscopically confirmed rupture or detection of cranial tibial instability on stifle palpation for patients whose owners declined surgical evaluation. The primary care veterinarian of patients, which had long-term follow-up at their clinic, was contacted and asked if the patient developed contralateral CrCL rupture based on surgical evaluation or detection of cranial tibial instability on stifle palpation. Patients were followed until subsequent contralateral CrCL rupture, the date of their last physical examination, or the end of the data collection period (July 15, 2011). Unilateral CrCL rupture cases were subdivided into cases with (UR-SR) or without (UR-w/o-SR) subsequent contralateral CrCL rupture, based on the contralateral CrCL outcome censored at 3 y from the initial diagnosis. Cases without subsequent contralateral CrCL rupture lacking a minimum of 3 y follow-up were excluded from the direct comparison analysis, but were included in the Cox proportional hazard regression models.

Radiographic technique

Mediolateral radiographs were performed with dogs in lateral recumbency with the tarsus and stifle at 90° flexion and the limb parallel to the digital image capture device (Sound-Eklin, Carlsbad, California, USA). The x-ray beam was centered over the proximal tibial diaphysis and collimated to

Table 2. Tibial mechanical joint orientation angles and alignment in the sagittal plane

Variable	UR-w/o-SR (*n* = 34)	UR-SR (*n* = 38)	BR (*n* = 20)
TPA (°)			
Index	28.0 ± 3.6 28.6 (19.4–33.8)	27.0 ± 3.9 27.2 (18.4–33.6)	26.4 ± 3.8 26.5 (20.5–31.8)
Contralateral	27.8 ± 3.3 27.8 (20.0–33.6)	26.8 ± 3.5 27.3 (20.3–33.6)	27.0 ± 2.9 27.7 (21.3–31.2)
mCaPTA (°)			
Index	62.0 ± 3.6 61.4 (56.2–70.6)	63.0 ± 3.9 62.8 (56.4–71.6)	63.6 ± 3.8 63.5 (58.2–69.5)
Contralateral	62.2 ± 3.3 62.4 (56.3–70.0)	63.2 ± 3.5 62.7 (56.4–69.7)	63.0 ± 2.9 62.3 (58.8–68.7)
mCrDTA (°)			
Index	80.8 ± 3.4 80.5 (73.8–94.7)	79.7 ± 2.8 79.5 (75.3–86.5)	80.5 ± 3.2 79.7 (76.2–88.4)
Contralateral	80.4 ± 3.3 80.4 (72.2–92.7)	80.2 ± 3.0 80.1 (73.5–85.9)	80.9 ± 3.2 80.0 (77.0–88.8)
SPA (°)			
Index	18.8 ± 5.7 18.5 (7.0–37.6)	16.7 ± 5.1 16.0 (6.5–30.1)	17.0 ± 5.9 16.0 (8.2–30.0)
Contralateral	18.2 ± 5.4 17.6 (9.3–36.3)	16.9 ± 4.6 17.0 (7.7–26.4)	17.9 ± 4.6 16.9 (9.7–30.0)

All variables are shown as mean ± standard deviation and median (range). For the BR group, the index and contralateral limbs are referencing the left and right limbs, respectively.
UR-w/o-SR — Unilateral cranial cruciate ligament rupture without subsequent rupture.
UR-SR — Unilateral cranial cruciate ligament rupture with subsequent rupture.
BR — Bilateral cranial cruciate ligament rupture.
TPA — Tibial plateau angle.
mCaPTA — Mechanical caudal proximal tibial angle.
mCrDTA — Mechanical cranial distal tibial angle.
SPA — Sagittal plane alignment.

include the tarsus, entire tibia, and distal third of the femur. Superimposition of the femoral condyles and talar trochlea was performed to achieve correct rotational alignment (20). Caudocranial radiographs were taken with the dog in sternal recumbency and the limb extended caudally, parallel to the digital image capture device. The x-ray beam was centered over the proximal tibia and collimated similar to the mediolateral radiographs. Correct rotational alignment was achieved by superimposing the fabellae on the femoral condyles with alignment of the medial aspect of the calcaneus to the distal intermediate ridge of the tibia (19). When there was a discrepancy for rotational alignment, preference was given to superimposing the fabellae on the femoral condyle.

Radiographic measurements

The mechanical caudal proximal tibial angle (mCaPTA) and mechanical cranial distal tibial angle (mCrDTA) were measured from the mediolateral tibial radiographs and the mechanical medial proximal tibial angle (mMPTA) and mechanical medial distal tibial angle (mMDTA) were measured from the caudocranial tibial radiographs (Figure 1) (19–21). The TPA was calculated from the mechanical caudal proximal tibial angle, as they are complimentary (TPA = 90° — mechanical caudal proximal tibial angle) (20).

Tibial sagittal plane alignment (SPA) was determined by subtracting the mCaPTA from the mCrDTA. Positive and negative integers were used to indicate procurvatum and recurvatum, respectively. Tibial frontal plane alignment (FPA) was determined by subtracting 180° from the summation of the mMPTA and mMDTA. Positive and negative and positive integers were used to indicate valgus and varus, respectively.

Assessment for rotational or torsional deviation was performed on the caudocranial tibial radiographs (Figure 1) (19). This value was expressed as the percent deviation. Positive integers were used to indicate lateral deviation and negative integers were used to indicate medial deviation of the calcaneus with respect to the distal intermediate ridge of the tibia.

Statistical analysis

The Kruskal-Wallis test was performed to evaluate for differences in age, body weight, and duration of lameness between the UR-w/o-SR, UR-SR, and BR groups. For statistical comparisons the term sex was used to indicate male intact, male castrated, female intact, or female spayed and gender was used to indicate male or female. For breed analysis, dogs were categorized into groups containing breeds predisposed and not predisposed to CrCL rupture. The predisposed group included Newfoundlands, Rottweilers, bulldogs, boxers, chow chows, and American Staffordshire terriers. Due to the high frequency, Labrador retrievers were placed in a separate group. All remaining non-predisposed breeds were placed in a separate group. The Fisher's exact test was used to evaluate for differences in sex, breed, reproductive status, and body condition score distribution among the UR-w/o-SR, UR-SR, and BR groups. The

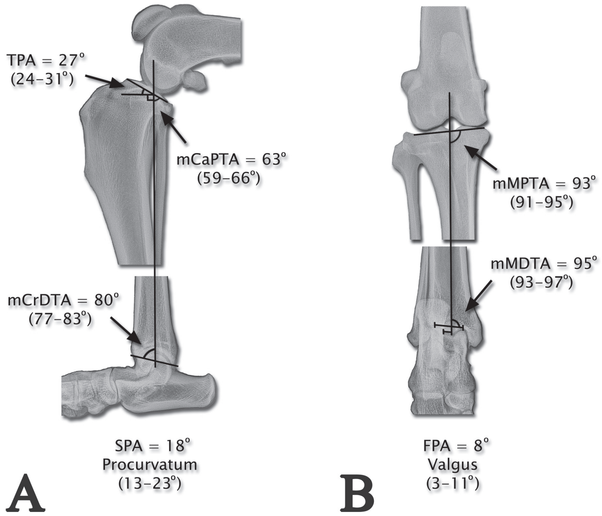

Figure 2. The mean ± standard deviation of the tibial mechanical joint orientation angles and alignment in the sagittal (A) and frontal (B) planes for all dogs.

chi-square test of homogeneity was used to evaluate for differences in gender distribution among the UR-w/o-SR, UR-SR, and BR groups.

The Wilcoxon signed rank test for paired data was used to compare the tibial mechanical joint orientation angles (mCaPTA, mCrDTA, mMPTA, mMDTA), TPA and percent deviation of the index and contralateral limbs for the UR-w/o-SR and UR-SR groups and left and right limbs for the BR group. The Kruskal-Wallis test was used to the compare the TPA, tibial mechanical joint orientation angles, tibial alignment, and percent deviation between groups, with respect to the index and contralateral limbs of the UR-w/o-SR and UR-SR groups and the left and right limbs of the BR group.

The associations of the TPA, tibial mechanical joint orientation angles, and tibial alignment with the rates of subsequent contralateral CrCL rupture were evaluated using Cox proportional hazards regression models for the dogs with unilateral CrCL rupture. Both univariate and multivariate models were performed for each angle. Multivariate models included a single angle with age, sex, breed, body weight, body condition score, lameness duration, positive contralateral fat pad sign, and osteophytosis as confounding variables. Proportionality was verified by examining the interaction between variables and the natural log of time. Results are presented as hazard ratios (HR) with 95% confidence intervals (95% CI). *P*-values < 0.05 were considered statistically significant. All statistical analyses were performed using a commercially available software program (SPSS, v20.0.0, IBM, Armonk, New York, USA).

Results

Of the 182 dogs that underwent stifle arthroscopy for CrCL rupture during the study period, 64 dogs were excluded due to prior surgical treatment for CrCL rupture, concurrent or historical medial patellar luxation, pelvic limb osteochondritis dissecans, or pelvic limb trauma resulting in a fracture or additional ligamentous injuries. Twelve chondrodysplastic or toy breed dogs were also excluded. All remaining dogs (n = 106) had completed medical records and bilateral radiographs available. Among these dogs, 86 (81.1%) had unilateral CrCL rupture and 20 (18.9%) had bilateral CrCL rupture. There were 14 dogs with unilateral CrCL rupture that did not develop subsequent contralateral CrCL rupture but lacked 3-year follow-up. These dogs were included in the risk factor analysis, but were excluded in the direct comparison assessment. When censored at 3-year follow-up, there were 34 (37.0%) dogs with UR-w/o-SR, 38 (41.3%) dogs with UR-SR, and 20 (21.7%) dogs with BR. For the UR-w/o-SR group, the last date of follow-up was performed by a board-certified surgeon in 11.8% (4/34) of cases; the primary care veterinarian evaluated the remaining dogs. For the UR-SR group, subsequent contralateral CrCL rupture was confirmed surgically in 86.8% (33/38) of the dogs. The remaining subsequent contralateral CrCL ruptures were based on the presence of cranial tibial instability on palpation because the owners declined further surgical intervention.

The signalment characteristics, duration of lameness, presence of concurrent hip disease, contralateral radiographic fat pad sign and osteophytosis for the 3 groups are presented in Table 1. The median age (P = 0.97), median body weight (P = 0.50), body condition score (P = 0.27), and duration of lameness (P = 0.35) at time of initial presentation were not statistically different between groups. Similarly, breed (P = 0.50), sex (P = 0.58), gender (P = 0.29), and reproductive status (P = 0.32) distribution were not statistically different between groups. Data on the presence of a contralateral radiographic fat pad sign and osteophytosis are presented elsewhere (22).

The mean ± standard deviation (SD), median, and range of the sagittal plane angles and tibial alignment for the 3 groups are presented in Table 2. Inter- and intra-group comparisons of the median TPA, mCaPTA, mCrDTA and tibial sagittal plane alignment were not statistically different for the index and contralateral limbs of the UR-w/o-SR group and UR-SR group and for the left and right limbs of the BR group. The mean ± SD of the sagittal plane angles and tibial alignment for all dogs are displayed in Figure 2A.

The mean ± SD, median, and range of the frontal plane angles, tibial alignment and percent deviation for the 3 groups are presented in Table 3. Inter- and intra-group comparisons of the median mMPTA, mMDTA and tibial frontal plane alignment were not statistically different for the index and contralateral limbs of the UR-w/o-SR group and UR-SR group and for the left and right limbs of the BR group. The median percent deviation of the index and contralateral limbs was significantly different for the UR-w/o-SR group (P = 0.032) and the median percent deviation was significantly different for the contralateral limbs of the UR-w/o-SR and UR-SR groups (P = 0.008). The mean ± SD of the frontal plane angles and tibial alignment for all dogs are displayed in Figure 2B.

Univariate and multivariate analyses of the index and contralateral tibial mechanical joint orientation angles, TPA and tibial alignment were not significant risk factors for subsequent contralateral CrCL rupture (Table 4).

ARTICLE

Table 3. Tibial mechanical joint orientation angles and alignment in the frontal plane

Variable	UR-w/o-SR (n = 34)	UR-SR (n = 38)	BR (n = 20)
mMPTA (°)			
Index	93.1 ± 2.6 93.2 (89.4–98.5)	92.6 ± 2.2 92.3 (87.3–96.6)	93.3 ± 1.8 92.7 (90.5–97.4)
Contralateral	92.7 ± 2.1 93.0 (87.6–96.4)	93.0 ± 2.2 93.4 (87.8–96.9)	93.4 ± 1.9 93.0 (90.1–97.9)
mMDTA (°)			
Index	94.9 ± 2.0 95.1 (90.1–98.5)	95.6 ± 1.9 95.6 (91.5–100.7)	95.8 ± 1.9 96.5 (91.4–98.5)
Contralateral	94.7 ± 1.9 95.1 (89.4–97.6)	95.4 ± 2.4 95.6 (90.5–100.8)	96.0 ±1.9 96.0 (91.8–100.5)
FPA (°)			
Index	8.0 ± 3.5 8.5 (1.6–15.0)	8.2 ± 2.8 8.0 (1.0–13.8)	9.1 ± 2.3 9.2 (4.2–13.6)
Contralateral	7.3 ± 3.2 8.0 (0.6–11.8)	8.0 ± 2.7 7.9 (–0.1–13.7)	9.2 ± 2.8 8.6 (5.6–15.5)
Percent deviation			
Index	10.9 ± 16.1 13.5 (–30.1–38.6)[a]	16.5 ± 15.6 17.3 (–15.8–52.0)	11.0 ± 13.5 10.0 (–11.1–36.9)
Contralateral	4.6 ± 15.8 6.3 (–48.3–53.7)[a,b]	15.1 ± 15.3 13.2 (–10.4–60.2)[b]	9.8 ± 13.2 8.0 (–7.0–30.4)

All variables are shown as mean ± standard deviation and median (range). For the BR group, the index and contralateral limbs are referencing the left and right limbs, respectively. Percent deviation is the deviation of the medial aspect of the calcaneus to the center of the distal intermediate ridge of the tibia, where positive integers indicate lateral deviation (internal rotation or torsion) and negative integers indicate medial deviation (external rotation or torsion).
UR-w/o-SR — Unilateral cranial cruciate ligament rupture without subsequent rupture.
UR-SR — Unilateral cranial cruciate ligament rupture with subsequent rupture.
BR — Bilateral cranial cruciate ligament rupture.
mMPTA — Mechanical medial proximal tibial angle.
mMDTA — Mechanical distal tibial angle.
FPA — Frontal plane alignment.
[a] $P = 0.032$.
[b] $P = 0.008$.

Discussion

The null hypothesis was accepted; the tibial mechanical joint orientation angles and TPA, in the range studied (< 35°), were not statistically different for dogs with BR, UR-SR, and UR-w/o-SR and were not significant risk factors for subsequent contralateral CrCL rupture. These results do not necessarily suggest that tibial morphology is not involved in the development of CrCL rupture, but rather that analysis of the tibial mechanical joint orientation angles did not successfully distinguish between dogs at low and high risk for the development of contralateral CrCL rupture. In another study, dogs with CrCL rupture were more likely to have proximal tibial procurvatum, when assessed using anatomic methods (13). Interestingly in that study, the TPA was also increased in dogs with CrCL rupture compared to dogs without, which has not been substantiated in other studies (12,13). Further assessment of the tibial morphology using anatomic joint orientation angles as risk factors of CrCL rupture is warranted.

Given the complexity of the stifle joint, it is possible that alterations in both the tibial and femoral morphology have an impact on the development of CrCL rupture. The results of another study suggest that the combination of femoral anteversion and the TPA was successful in distinguishing between predisposed and non-predisposed limbs for CrCL rupture in Labrador retrievers (18). In that study, comparisons were made between dogs with and without CrCL rupture, making causation assessment difficult (18). Future evaluation of femoral and tibial morphology characteristics as risk factors for subsequent contralateral CrCL rupture is also indicated.

An increasing TPA of the index limb has been associated with a shorter time to subsequent contralateral CrCL rupture; however, the contralateral TPA was not evaluated in that study due to a lack of bilateral stifle radiographs (8). In this study it is possible that a type II statistical error occurred due to the smaller sample size; however, both the index and contralateral TPAs were trending in the opposite direction, whereby a decreasing TPA was associated with a shorter time to subsequent rupture (8). In the present study, the TPA for both the index and contralateral limb were evaluated and were not found to be significant risk factors for subsequent contralateral CrCL rupture. The hazard ratios were not provided in the previous study, although we suspect the overall influence of the TPA on the rate of subsequent rupture was low based on the flat slope of the regression lines (8). The mean tibial mechanical joint orientation angles in the present study are similar to the normal reference ranges reported in previous studies (19,20). This suggests that the tibial morphology of the dogs used in this study was similar to that of the dogs in other studies (19,20). Based on the absence of

Table 4. Univariate and multivariate analysis for the TPA and tibial mechanical joint orientation angles as risk factors for subsequent contralateral CrCL rupture

	Univariate			Multivariate		
Variable	Hazard ratio	95% CI	*P*-value	Hazard ratio	95% CI	*P*-value
TPA (°)						
Index	1.0	0.9–1.0	0.34	0.9	0.9–1.0	0.18
Contralateral	0.9	0.9–1.0	0.16	0.9	0.8–1.0	0.23
mCaPTA (°)						
Index	1.0	1.0–1.1	0.34	1.1	1.0–1.2	0.18
Contralateral	1.1	1.0–1.2	0.16	1.1	1.0–1.2	0.23
mCrDTA (°)						
Index	1.0	0.9–1.1	0.45	0.9	0.8–1.1	0.37
Contralateral	1.0	0.9–1.1	0.71	1.0	0.8–1.1	0.52
SPA (°)						
Index	1.0	0.9–1.0	0.26	0.9	0.9–1.0	0.11
Contralateral	1.0	0.9–1.0	0.48	1.0	0.9–1.0	0.23
mMPTA (°)						
Index	0.9	0.8–1.0	0.18	1.0	0.9–1.2	0.83
Contralateral	1.0	0.9–1.1	0.64	1.1	0.9–1.2	0.38
mMDTA (°)						
Index	1.2	1.0–1.4	0.18	1.2	1.0–1.4	0.11
Contralateral	1.2	1.0–1.4	0.076	1.2	1.0–1.4	0.10
FPA (°)						
Index	1.0	0.9–1.1	0.88	1.1	1.0–1.2	0.16
Contralateral	1.0	0.9–1.1	0.44	1.1	1.0–1.2	0.12

95% CI — 95% confidence interval.
TPA — Tibial plateau angle; mCaPTA — Mechanical caudal proximal tibial angle; mCrDTA — Mechanical cranial distal tibial angle; SPA — Sagittal plane alignment; mMPTA — Mechanical medial proximal tibial angle; mMDTA — Mechanical medial distal tibial angle; FPA — Frontal plane alignment.

dogs having an index or contralateral TPA greater than 35°, we were unable to evaluate the risk of an excessive TPA on the rate of subsequent contralateral CrCL rupture.

The aim of this study was to focus on the TPA and tibial mechanical joint orientation angles. The lack of differences found with respect to age, breed, gender, and body condition score might represent a type II statistical error. The difference in follow-up data collection between the UR-w/o-SR and UR-SR groups is a study limitation. Board-certified surgeons (KAB, IGH) evaluated most of the dogs diagnosed with subsequent contralateral CrCL rupture (UR-SR), while primary care veterinarians evaluated the majority of dogs not diagnosed with subsequent rupture (UR-w/o-SR). The use of telephone conversations for data collection for the UR-w/o-SR group relied on subjective data. This is common in retrospective studies in which referral practices do not perform long-term follow-up on their surgical patients unless there are concerns. Another limitation was the dependence on clients for seeking veterinary care for evaluation of a potential subsequent contralateral CrCL rupture. This type of population bias is inherent in retrospective clinical studies. Many owners may become aware of a contralateral lameness but choose to wait before presenting their dog due to financial or other reasons. There can also be a lack of long-term follow-up with the initial primary care veterinarian for many reasons.

The population of dogs used in this study was used in a another study for assessment of the presence of a positive contralateral radiographic fat pad sign or degenerative changes as risk factors for subsequent contralateral CrCL rupture (22). The results of that study showed that radiographic abnormalities of the contralateral stifle, particularly a positive radiographic fat pad sign, are highly prevalent and significant prognostic factors for the development of subsequent contralateral CrCL rupture (22). These results suggest that bilateral CrCL rupture on initial presentation may be under diagnosed (22). In this study, the presence of a contralateral radiographic fat pad sign or contralateral degenerative changes was accounted for in the multivariate analyses.

The significant differences for the percent deviation between the contralateral limb of the UR-w/o-SR group with the index limb of the UR-w/o-SR group and the contralateral limb of the UR-SR group are likely due to positional differences during the radiographic examination, and less likely due to differences of tibial torsion. The percent deviation for the contralateral limbs of the UR-w/o-SR group was the smallest, indicating the least amount of internal rotation; the CrCL protects against excessive internal rotation and for the contralateral limb of the UR-w/o-SR group the CrCL was intact. The high percentage of a positive fat pad sign in the contralateral limb of the UR-SR group suggests that many had pathology in the contralateral stifle, which may have lead to an increased degree of internal rotation during radiographic positioning.

In conclusion, the tibial mechanical joint orientation angles and TPA, in the range studied (< 35°) were similar among dogs with BR, UR-SR, and UR-w/o-SR and variations of these angles were not significant risk factors for the development of subsequent contralateral CrCL rupture. Future evaluation of anatomic tibial and femoral as risk factors for subsequent contralateral CrCL rupture should be performed. CVJ

References

1. Witsberger TH, Villamil JA, Schultz LG, Hahn AW, Cook JL. Prevalence of and risk factors for hip dysplasia and cranial cruciate ligament deficiency in dogs. J Am Vet Med Assoc 2008;232:1818–1824.
2. Hayashi K, Frank JD, Dubinsky C, et al. Histologic changes in ruptured canine cranial cruciate ligament. Vet Surg 2003;32:269–277.
3. Doverspike M, Vasseur PB, Harb MF, Walls CM. Contralateral cranial cruciate ligament rupture: Incidence in 114 dogs. J Am Anim Hosp Assoc 1993;29:167–170.
4. Wilke VL, Conzemius MG, Kinghorn BP, Macrossan PE, Cai W, Rothschild MF. Inheritance of rupture of the cranial cruciate ligament in Newfoundlands. J Am Vet Med Assoc 2006;228:61–64.
5. Cabrera SY, Owen TJ, Mueller MG, Kass PH. Comparison of tibial plateau angles in dogs with unilateral versus bilateral cranial cruciate ligament rupture: 150 cases (2000–2006). J Am Vet Med Assoc 2008; 232:889–892.
6. Buote N, Fusco J, Radasch R. Age, tibial plateau angle, sex, and weight as risk factors for contralateral rupture of the cranial cruciate ligament in Labradors. Vet Surg 2009;38:481–489.
7. Wilke VL, Zhang S, Evans RB, Conzemius MG, Rothschild MF. Identification of chromosomal regions associated with cranial cruciate ligament rupture in a population of Newfoundlands. Am J Vet Res 2009;70:1013–1017.
8. Muir P, Schwartz Z, Malek S, et al. Contralateral cruciate survival in dogs with unilateral non-contact cranial cruciate ligament rupture. PLoS One 2011;6:e25331.
9. Ragetly CA, Griffon DJ, Hsu MK, Klump LM, Hsiao-Wecksler ET. 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. Am J Vet Res 2012; 73:1171–1177.
10. Morris E, Lipowitz AJ. Comparison of tibial plateau angles in dogs with and without cranial cruciate ligament injuries. J Am Vet Med Assoc 2001;218:363–366.
11. Wilke VL, Conzemius MG, Besancon MF, Evans RB, Ritter M. Comparison of tibial plateau angle between clinically normal Greyhounds and Labrador Retrievers with and without rupture of the cranial cruciate ligament. J Am Vet Med Assoc 2002;221:1426–1429.
12. Reif U, Probst CW. Comparison of tibial plateau angles in normal and cranial cruciate deficient stifles of Labrador retrievers. Vet Surg 2003;32:385–389.
13. Osmond CS, Marcellin-Little DJ, Harrysson OL, Kidd LB. Morphometric assessment of the proximal portion of the tibia in dogs with and without cranial cruciate ligament rupture. Vet Radiol Ultrasound 2006;47:136–141.
14. Guerrero TG, Geyer H, Hassig M, Montavon PM. Effect of conformation of the distal portion of the femur and proximal portion of the tibia on the pathogenesis of cranial cruciate ligament disease in dogs. Am J Vet Res 2007;68:1332–1337.
15. Inauen R, Koch D, Bass M, Haessig M. Tibial tuberosity conformation as a risk factor for cranial cruciate ligament rupture in the dog. Vet Comp Orthop Traumatol 2009;22:16–20.
16. Ragetly CA, Evans R, Mostafa AA, Griffon DJ. Multivariate analysis of morphometric characteristics to evaluate risk factors for cranial cruciate ligament deficiency in Labrador retrievers. Vet Surg 2011;40:327–333.
17. Lewis BA, Allen DA, Henrikson TD, Lehenbauer TW. Computed tomographic evaluation of the canine intercondylar notch in normal and cruciate deficient stifles. Vet Comp Orthop Traumatol 2008;21:119–124.
18. Mostafa AA, Griffon DJ, Thomas MW, Constable PD. Morphometric characteristics of the pelvic limbs of Labrador Retrievers with and without cranial cruciate ligament deficiency. Am J Vet Res 2009;70: 498–507.
19. Dismukes DI, Tomlinson JL, Fox DB, Cook JL, Song KJ. Radiographic measurement of the proximal and distal mechanical joint angles in the canine tibia. Vet Surg 2007;36:699–704.
20. Dismukes DI, Tomlinson JL, Fox DB, Cook JL, Witsberger TH. Radiographic measurement of canine tibial angles in the sagittal plane. Vet Surg 2008;37:300–305.
21. Fox DB, Tomlinson JL. Principles of angular limb deformity correction. In: Tobias KM, Johnston SA, eds. Veterinary Surgery: Small Animal. Vol. 1. St. Louis, Missouri: Saunders Elsevier, 2012:657–668.
22. Fuller MC, Hayashi K, Bruecker KA, et al. Radiographic infrapatellar fat pad sign of the contralateral stifle: A prevalent and important risk factor for subsequent contralateral cranial cruciate ligament rupture in dogs with unilateral rupture. J Am Vet Med Assoc 2013. *In press.*
23. Laflamme DP. Development and validation of a body condition score system for dogs. Canine Pract 1997;22:10–15.
24. Kowaleski MP, Boudrieau RJ, Pozzi A. Stifle joint. In: Tobias KM, Johnston SA, eds. Veterinary Surgery: Small Animal. Vol. 1. St. Louis, Missouri: Saunders Elsevier, 2012:914–920.