Angle between the patellar ligament and tibial plateau in dogs with partial rupture of the cranial cruciate ligament

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Objective—To measure the angles between the patellar ligament and the tibial plateau and between the patellar ligament and the common tangent at the tibiofemoral contact point (TFCP) in stifle joints of dogs with partial rupture of the cranial cruciate ligament (CrCL) for comparison with data obtained for stifle joints in dogs with intact CrCLs.

Sample Population—60 stifle joints of 54 dogs with surgically confirmed partial CrCL rupture.

Procedures—Mediolateral radiographic views of the stifle joints were obtained, and the angles between the patellar ligament and the conventionally defined tibial plateau (angle γ) and between the patellar ligament and the common tangent to the TFCP (angle α) were measured at incidental stifle joint flexion (angle β) by 2 independent observers. Data underwent linear regression analysis and were compared with findings in joints of dogs without degenerative joint disease.

Results—In stifle joints of dogs with a partial rupture of the CrCL, angles γ and α were 5° and 2° larger than each corresponding angle in healthy canine joints. At 100° of flexion, the patellar ligament was perpendicular to the conventionally defined tibial plateau. At 110° of flexion, the patellar ligament was perpendicular to the common tangent at the TFCP.

Conclusions and Clinical Relevance—In dogs, stifle joints with partially ruptured CrCLs have marginally larger angles between the patellar ligament and the tibial plateau, compared with joints with intact CrCLs; at equivalent angles of flexion, comparatively greater shear force affects the CrCLs in stifle joints with partial CrCL ruptures. (Am J Vet Res 2006;67:1855–1860)

The CrCL is the main stabilizer of the stifle joint and counters acts shear forces in extended joints during walking and weight bearing, thereby preventing cranial translation of the tibia.1–3 The slope of the tibial plateau causes shear in the sagittal plane of the stifle joint and generates loading of the CrCL.4–5 A partial or complete rupture of the CrCL is the most frequent cause of stifle joint-associated lameness in dogs.3 Degenerative processes increasingly affect the CrCL with increasing age.6,7 A partial tear of the CrCL is associated with signs of pain and lameness in the affected stifle joint and typically progresses to complete rupture of the CrCL.8,4 On physical examination of an extended stifle joint with a partially ruptured CrCL, the cranial drawer sign is absent, but this may increase to a few millimeters of movement with flexion of the stifle.9 Complete rupture of the CrCL allows cranial translation of the tibia during both stifle joint flexion and extension.9 Surgical procedures that modify conformation of the stifle joint10–13 can obviate the need for a CrCL by minimizing this shear force and render the joint functionally stable. However, overcorrection of the slope of the tibial plateau generates increased loading of the CdCL.14 Shear force at the joint is minimized, and so is tension in the CrCL or the CdCL if the tibial plateau is approximately perpendicular to the patellar ligament.15

The tibial plateau has to be defined for measurement reasons. On mediolateral radiographic views, the tibial plateau is conventionally approximated by a line drawn to connect the CrCL and CdCL insertions on the tibial condyles.15–18 More relevant from a biomechanical point of view is the true inclination of the joint surfaces at the TFCP,19–21 which can be estimated by drawing their common tangent on mediolateral radiographs. Measurements of the angle between the tibial plateau and the long axis of the tibia have been reported for canine stifle joints with intact or ruptured CrCLs.3,16–18,20–24 The angle between the patellar ligament and the tibial plateau has been measured in humans19 and recently also in healthy dogs19 as a function of the stifle joint flexion. In the stifle joints of dogs, the angle between the patellar ligament and the conventionally defined tibial plateau, as well as between the patellar ligament and the common tangent at the TFCP, decreased approximately linearly with increasing joint flexion.14 The load to the CrCL in an extended stifle joint is shifting during a stride toward a load to the CdCL in a flexed stifle joint. In the stifle joints of dogs, the neutral point was determined to be at 90° of flexion (taking as a reference the conventionally defined tibial plateau) and at 110° of flexion (taking as a reference the common tangent to the TFCP).14 The purpose of the study reported here was to measure the angles between the patellar ligament and the tibial plateau and between the patellar ligament and the common

**ABBREVIATIONS**

CrCL Cranial cruciate ligament
CdCL Caudal cruciate ligament
TFCP Tibiofemoral contact point

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tangent at the TFCP in stifle joints of dogs with partial rupture of the CrCL for comparison with data obtained for stifle joints in dogs with intact CrCLs. We hypothesized that in dogs, the angle between the tibial plateau and the patellar ligament would be larger in stifle joints with evidence of a partial rupture of the CrCL, compared with angles in healthy stifle joints. The second aim of the study was to correlate measurements obtained with the conventionally defined tibial plateau as a reference with those obtained with the common tangent at the TFCP as a reference.

Materials and Methods

Mediolateral radiographic views of 60 stifle joints in 54 client-owned dogs (representing 23 large breeds) were examined. All owners signed a consent form allowing all documentation regarding their dog to be used for scientific research and publication. The dogs weighed 21 to 76 kg, and all had surgically confirmed partial ruptures of the CrCL.

The radiographic views of the affected stifle joint were obtained when the dogs were deeply sedated. The x-ray beam was centered on the tibiofemoral joint space so that measurements made on the radiographs would be comparable to those obtained in a study of stifle joints of dogs without degenerative joint disease. All radiographic views included the entire tibia with exact superposition of the femoral condyles and the femur (at least to the level of the mid diaphysis). The angles between the patellar ligament and the conventionally defined tibial plateau (γ), between the patellar ligament and the common tangent at the TFCP (α), and the incident flexion angle of the stifle joint (β) were measured on each radiograph. Landmarks for the conventionally defined tibial plateau method and the method by which the common tangent to the stifle joint at the TFCP, the outline of the patellar ligament, and the long axis of the tibia were delineated have been described and were used in this study to provide comparable data (Figure 1). The long axis of the femur was determined with the aid of templates because, in most instances, radiographic views of only the distal half of the femur were obtained. These templates were prepared by drawing contours and the long axes of 4 femurs of distinct shapes from radiographs obtained in a previous study on a transparent sheet and copying the sheets with varying degrees of magnification from 75% to 130% in increments of 5%. The sheets were superimposed on the radiograph to be assessed, and the outline that best matched the image of the femur in size and conformation was selected; this outline was then used to transfer the position of the femoral long axis onto the radiograph. Two independent observers determined the tibial and femoral long axes; identified the tibial plateau via the conventional method and the method involving the common tangent at the TFCP; outlined the patellar ligament; and measured the angles α, β, and γ for each stifle joint.

The mean and range of values for each of the angles were obtained, and linear regression analysis was performed. The reproducibility of measurements of α, β, and γ was assessed by means of regression analysis with calculation of 95% confidence intervals. Interobserver variability was calculated as SEs for coefficients. Angles α and γ were compared with values obtained from mediolateral radiographs of similarly positioned stifle joints with intact CrCLs at the corresponding flexion angle β. The regression models for stifle joints with partially ruptured CrCLs were compared with regression models of healthy stifle joints by calculating the ratio between the constants and the regression factors. Factorial ANOVA and ANCOVA were performed along with Bonferroni-Dunn post hoc tests. Analysis was performed by use of statistical software. A value of P ≤ 0.05 was defined as significant.
Results

Incidental flexion angles $\beta$ ranged from $44^\circ$ to $132^\circ$ (mean value, $80.3^\circ$). Among the stifles examined, angle $\alpha$ ranged from $86^\circ$ to $108^\circ$ (mean value, $96.5^\circ$) and angle $\gamma$ ranged from $70^\circ$ to $116^\circ$ (mean value, $96.0^\circ$). The equation derived by linear regression analysis of data for $\gamma$ versus $\beta$ was as follows: $\gamma = -0.33\beta + 123$ ($r^2 = 0.635; P \leq 0.001$; Figure 2). The equation derived by linear regression analysis of data for $\alpha$ versus $\beta$ was as follows: $\alpha = -0.21\beta + 113$ ($r^2 = 0.522; P \leq 0.001$). Via ANOVA, the 2 regressions were not significantly ($P > 0.99$) different. Analysis of covariance was performed involving the body side (right or left) of the affected limb, body weight of the dog, and length of the tibia but did not reveal any significant influence on the simple linear regression.

The measurements of 2 independent observers were consistent for $\alpha$, $\beta$, and $\gamma$ angles with $r^2$ values of 0.892, 0.943, and 0.863, respectively. The SE for angle measurements obtained with respect to the conventionally defined tibial plateau was ± 0.05°; the SE for angle measurements obtained by use of the tangent method was ± 0.08°. The consistency of measured angles was high ($P < 0.001$). All regression factors included the value 1.00 within the 95% confidence interval, implying no statistical difference among measurements. The 95% confidence intervals included 0 for the intercept for all angles, implying no constant difference between observers.

The patellar ligament was perpendicular (crossover point) to the conventionally defined tibial plateau at $100^\circ$ of stifle joint flexion (Figure 3). The ligament was perpendicular to the common tangent at the TFCP at $110^\circ$ of stifle joint flexion (Figure 4). Comparison of data (via ANOVA) obtained from canine stifles with intact CRCLs and stifle joints with partial rupture of the CRCL revealed a significant ($P < 0.05$) change in angles $\alpha$ and $\gamma$.

Discussion

In the present study in dogs, the decision to assess only stiffe joints with surgically proven partial ruptures of the CRCL was made because such partial ruptures allow only minimal subluxation of the CRCL with respect to the femur unless the stiffe joint is in marked flexion. Measurements of the angle between the patellar ligament and the plateau of the CRCL on conventional radiographs of stiffe joints would be inconsistent in a potentially subluxated joint with a complete rupture of the CRCL. Investigation of stiffe joints with complete rupture of the CRCL would also be interesting, but subluxation of the CRCL would have to be avoided during radiography.

The data obtained in our study were derived from living dogs, unlike...
and 194 healthy stifle joints) were omitted for clarity. The muscles in heavily muscled dogs may hinder the later-...mrium of both femoral condyles on the radiographic views (the latter. Examination of the stifle joints of those cadaveric limbs...data in the present study related to stifle joint flexion in the range of 40° to 100° (mean of all data, 80.3°). The values for patellar ligament inclination determined by both methods were approximately equal within this range of flexion, which becomes apparent by the crossing of the 2 regression lines at stifle joint flexion of approximately 80°. Thus, both methods can equally be used in stifle joints that are moderately flexed (40° to 100°). With regard to which is the most adequate method, one has to consider that the conventionally defined tibial plateau may be more familiar to most examiners, but at extension or increased flexion of the stifle joint, the common tangent method would be more precise and should be the method of choice because the common tangent follows the rolling movement of the femoral condyles over the convex tibial condyles that is caused by flexion of the stifle joint. The conventional linear approximation for the tibial plateau is fixed with respect to the tibia and thus not affected by the convex shape of the tibial condyles and the movement of the TFCP with stifle joint flexion. Both methods have small interobserver variability: SE of ± 0.03° for the conventional method and ± 0.08° for the tangent method. Intraobserver variability could not be determined because data were measured only once by each observer. There was no significant difference in the values obtained by the 2 methods. By contrast, a significant difference in the values obtained by the 2 methods was detected in healthy canine stifle joints. One explanation may be that 70% of the data obtained in the present study related to stifle joint flexion in the range of 40° to 100° (mean of all data, 80.3°). The values for patellar ligament inclination determined by both methods were approximately equal within this range of flexion, which becomes apparent by the crossing of the 2 regression lines at stifle joint flexion of approximately 80°. Thus, both methods can equally be used in stifle joints that are moderately flexed (40° to 100°). With regard to which is the most adequate method, one has to consider that the conventionally defined tibial plateau may be more familiar to most examiners, but at extension or increased flexion of the stifle joint, the common tangent method would be more precise and should be the method of choice because the common tangent follows the rolling movement of the femoral condyles over the convex tibial condyles that is caused by flexion of the stifle joint.

Factorial ANOVA and ANCOVA were performed to compare left or right limbs, body weight, and length of the tibia as a covariant. The differences were so minimal that the equations of the linear regression lines were not altered in the different models in all calculations; therefore, the simple linear regression analysis could be used.

The angles between the patellar ligament and the conventionally defined tibial plateau (γ) in the stifle joint...
joints of dogs with partial ruptures of the CrCL were compared with the values of the same angle in stifle joints with intact CrCLs. The 2 regression lines had similar slope coefficients (–0.33 for joints with partially ruptured CrCLs and –0.31 for joints with intact CrCLs), but the offset constant in the regression analysis of stifle joints with partially ruptured CrCLs (123) was larger than the offset constant in the regression analysis of healthy stifle joints (118). The difference between offset constants was 250 times as great as the coefficient difference/12. Therefore, the main difference was nearly a constant in the present analysis. In moderate flexion, angle $\gamma$ in stifle joints with partial ruptures of the CrCL was approximately 5° larger than the corresponding angle in healthy joints. Statistically, this difference was significant.

The angles between the patellar ligament and the common tangent at the TFCP (\(\alpha\)) in the stifle joints of dogs with partial rupture of the CrCL were compared with the values of the same angle in stifle joints with intact CrCLs. On analysis, both data sets had similar coefficients of regression (–0.21 for joints with partially ruptured CrCLs and –0.19 for joints with intact CrCLs), but the offset constant in the regression analysis of stifle joints with partially ruptured CrCLs (113) was larger than the constant in the regression analysis of healthy stifles joints (111). The difference between offset constants was 140 times as great as the coefficient difference/12. Consequently, the main difference was nearly a constant in the present analysis. In moderate flexion, angle $\alpha$ in stifle joints with partial tears of the CrCL was approximately 2° larger than the corresponding angle in healthy joints. Statistically, this difference was significant.

The crossover point at which the shear force to the CrCL changed to a shear force to the CdCL was at 90° of flexion for angle $\gamma$ and at 110° of flexion for angle $\alpha$ in healthy stifle joints.19 The crossover point for stifle joints with partial rupture of the CrCL was at 100° of flexion for angle $\gamma$ and at 110° flexion for $\alpha$ in the present study. The dogs with partial rupture of the CrCL had to carry their limb more flexed (by 10°) than the dogs with healthy stifle joints to neutralize the shear force to the CrCL, as determined by the conventional method that uses the tibial plateau as the reference. The crossover point for angle $\alpha$, as determined by the method that uses the common tangent as the reference, was equivalent in stifle joints with partially deficient CrCLs and those with intact CrCLs. The small difference in angle $\alpha$ values between the 2 groups may explain the lack of deviation at this point.

Data obtained in the present study indicated that stifle joints of dogs with partial rupture of the CrCL have significantly but only slightly larger inclination angles (5° and 2° for angles $\gamma$ and $\alpha$, respectively, as measured by 2 methods) between the patellar ligament and the tibial plateau than stifle joints of dogs with intact CrCLs. A larger plateau angle at a given stifle flexion will increase the shear force to the CrCL, an anisotropic structure. It is not easy to determine whether this increase in shear force to the CrCL is responsible for the damage to the CrCL by repeatedly exerted small traumata throughout a dog’s lifetime. The angle of inclination between patellar ligament and tibial plateau is changing constantly with the changing stifle flexion throughout the stride. During the weight-bearing phase, the CrCL is loaded at stifle joint flexion angles that are greater than the crossover point, and the CdCL is loaded at stifle joint flexion angles that are less than the crossover point. This appears to correlate with findings of another study25 in which it was determined that dogs with complete rupture of the CrCL compensate at the affected stifle joint with more flexion. More flexion of the stifle joint would reduce or even eliminate the cranial subluxation of the tibia and reduce pain elicited by the subluxation movement. A dog that physiologically maintains its stifle joint in a more extended position is exerting more shear force to the CrCL than a dog that physiologically maintains its stifle joint in a more flexed position.

The larger inclination angles between the patellar ligament and the tibial plateau identified in the stifle joints of the present study must be the result of an anatomic feature and not a response to injury. A stifle joint with a partially ruptured CrCL is providing only minimal instability; the possible pressure of cranial subluxation of the tibia would decrease the angle of inclination between the patellar ligament and the tibial plateau. Despite the small numbers for differences in inclinations, we can assign them a greater weight than changes in stifle joint flexion because a 1° change in angle $\gamma$ could only be compensated by a stifle joint that was in 4.8° more flexion and a 1° change in angle $\alpha$ could only be compensated by a stifle joint that was in 3° more flexion. Other factors like the form of the femoral condyles, femoral trochlea, or tibial tuberosity may play a role in this interaction of forces, as configurational differences in these structures alter the inclination of the patellar ligament in respect to the conventional tibial plateau or the common tangent. Further clinical investigation is required in this area.

In undertaking the present study, the authors were hoping to identify differences in the inclination of the tibial plateau between healthy stifle joints and stifle joints with damage to the CrCL (before its complete rupture) that could be used as a diagnostic tool. This was not achieved. The modest number of dogs used for this morphometric study as well as the small differences in findings between the healthy stifle joints and those with partial rupture of the CrCL did not allow a causal effect to be stated with enough certainty.

In future studies, it would be interesting to compare data obtained from stifle joints with repaired CrCLs with the data obtained from healthy stifle joints and stifle joints with partially ruptured CrCLs. However, a surgical intervention to modify the geometry of the proximal tibia may influence biomechanics of the entire stifle joint and not only the slope of the tibial plateau.

Overall, the data obtained in our study in dogs indicated that consistent measurement of patellar ligament inclination can be done in stifle joints with partial rupture of the CrCL because subluxation of the tibia with respect to the femur is negligible except during marked joint flexion. Both the conventionally defined tibial plateau and the common tangent at the

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TFCP can be used as a reference for measurements made on mediolateral radiographic views of moderately flexed, well-positioned stifle joints. Although the difference was statistically significant, the angles between the patellar ligament and the tibial plateau in stifle joints with partially ruptured CrCLs appear to be only marginally larger than the angles in healthy stifle joints. Compared with dogs with intact CrCLs, the stifle joint flexion angle at which the shear force to the CrCL changed to a shear force to the CdCL was 10° greater in dogs with partial rupture of the CrCL, as determined by use of the conventionally defined tibial plateau angle as a reference.