Inclination of the patellar ligament in relation to flexion angle in stifle joints of dogs without degenerative joint disease

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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) throughout the full range of motion of the stifle joint in dogs and determine the flexion angles at which the patellar ligament is perpendicular to the tibial plateau or to the common tangent.

Sample Population—16 hind limbs from cadavers of 9 adult dogs without radiographically detectable degenerative joint disease.

Procedures—Mediolateral radiographic views of the stifle joints from full extension through full flexion were obtained (10° increments). Angles between the tibial and femoral long axes (β), between the patellar ligament and the tibial plateau (γ), and between the patellar ligament and the common tangent at TFCP (α) were measured. Data were analyzed via simple linear regression.

Results—In canine stifle joints, angles γ and α decreased linearly with increasing flexion (angle β). The patellar ligament was perpendicular to the tibial plateau and perpendicular to the common tangent at the TFCP at 90° and 110° of flexion, respectively.

Conclusions and Clinical Relevance—By use of the conventionally defined tibial plateau, data suggest that at approximately 90° of flexion in stifle joints of dogs, shear force in the sagittal plane exerted on the proximal portion of the tibia shifts the loading from the cranial to the caudal cruciate ligament. Analyses involving the common tangent at the TFCP (a more anatomically representative reference point) identified this crossover point at approximately 110° of joint flexion. (*Am J Vet Res* 2006;67:1849–1854)

movement of the joint. The craniomedial band remains taut during both flexion and extension, whereas the larger caudolateral band relaxes during flexion.[2,3] The CrCL is therefore critically important in stabilizing the stifle joint within its range of motion, and loss of the ligament results in instability, damage to secondary ligamentous constraints and menisci, and, ultimately, degeneration of cartilage.

Diagnosis and management of a CrCL rupture in dogs has been widely discussed in the veterinary literature, and numerous treatment protocols have been described.[1,4,5] Etiology of the disease remains unknown, but seems to be multifactorial. Direct trauma is the cause in some dogs.[5] Various risk factors contributing to ligament degeneration have been identified, including age-related degeneration,[6] body weight,[7] breed,[8] conformation abnormalities,[9–11] and immune-mediated arthropathies.[12,13] Also, genetic factors that initiate osteoarthritis as the primary lesion have been suggested.[14,15] Any or a combination of these factors can weaken the CrCL and lead to its mechanical failure.

It has been postulated that mechanical failure of the CrCL is caused by repetitive loads associated with cranial tibial thrust.[16,17] Cranial shift in CrCL-deficient stifle joints can be induced by the tibial compression test of Henderson and Milton (a useful diagnostic test).[18] Several studies[19–21] have attempted but failed to provide convincing evidence for an association between increased slope of the tibial plateau and CrCL rupture. The mean inclination angle of the tibial plateau (with respect to the functional axis of the tibia, as defined by Slocum and Devine[16]) in clinically normal dogs is 22.6°. Compared with anatomic measurements, conventional radiographic measurements underestimate the tibial slope, as determined in a recent study.[22] A new technique of radiographic measurements has been proposed in which a line tangential to the cranial linear portion of the medial tibial condyle at the TFCP is used, rather than focusing measurements on the nonarticulating cranial border of the tibial plateau. Measurements of the tibial plateau slope with the alternative radiographic technique did not differ significantly from the anatomic measurements, whereas the conventional measurements did.[22]

A mong the joints of dogs, the stifle joint is most commonly affected with disease. Most problems relate to joint instability and osteoarthritis as a result of degeneration and rupture of the CrCL.[1] In dogs, the CrCL is the primary restraint of cranial displacement of the tibia relative to the femur and of hyperextension of the stifle joint; it also limits internal rotation of the tibia relative to the femur by twisting against the CdCL. The CrCL is composed of several bundles of fibers, which become taut in different positions during

The functional axis of the tibia is nearly parallel to the common calcanean tendon. The Henderson-Milton tibial compression test generates an internal stifle force, which is nearly parallel to the calcanean tendon and hence parallel to the functional axis of the tibia. Setting the tibial plateau perpendicular to the axis of the tibia eliminates shear force in the joint and the need for the CrCL. This is the biomechanical rationale of the tibial plateau leveling osteotomy procedure proposed by Slocum and Slocum.[17]

However, in true weight bearing, the foot is loaded with a force instead of a moment as exerted in the tibial compression test.[23] The resulting joint force is nearly parallel to the patellar tendon rather than to the common calcanean tendon. In biomechanical models of the human knee, the resulting joint force has also been described as nearly parallel to the patellar tendon.[24] In dogs, there is an angle of approximately 15° between the common calcanean tendon and the patellar ligament during extension of the stifle joint. In other work[23] by our group, we have developed a 2-dimensional biomechanical model for the stifle joint in dogs in which the resulting joint force is parallel to the patellar ligament. This force can be divided into a compressive component and a tangential or shearing component. Corresponding to the human biomechanical model, the anterior shear vector of the patellar ligament force is maximal at full extension and decreases with flexion, reaching a near-zero shear zone when the active tibial surface is perpendicular to the patellar tendon. Further flexion generates a posterior shear force. To eliminate shear forces associated with normal walking, it would be sufficient to render the active tibial surface perpendicular to the patellar tendon instead of the common calcanean tendon.[23]

Determination of true joint forces under normal physiologic activities remains elusive, mostly because of the problems of muscle redundancy and co-contraction. Though simple static analysis does not represent the true biomechanical status of an active musculoskeletal linkage, it may still provide some useful guidelines for the surgical interventions devised to treat ruptured CrCLs in dogs.[23]

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 tangent at the TFCP in the sagittal plane throughout the full range of motion of the stifle joint in dogs without degenerative joint disease and determine the flexion angles at which the patellar ligament is perpendicular to the tibial plateau or to the common tangent (indicating the crossover point with near-zero shear force). It was thought that these data would increase the understanding of the pathogenesis of CrCL injury, provide a basis for identification of predisposing risk factors, and potentially enable development of a different surgical approach to treatment of ruptured CrCLs in dogs.

Materials and Methods

Data collection—Sixteen hind limbs of 9 adult dogs were examined for the study. The dogs had been euthanatized or had died because of problems that were unrelated to the stifle joint. Stifle joints with radiographic signs of degenerative joint disease were excluded from the study. In 2 dogs, only 1 hind limb could be used; the other limbs were excluded from the study because of multiple fractures caused by vehicular trauma in 1 dog and bone tumor in the other dog. The age of the dogs included in the study ranged from 3 to 10 years (mean age ± SD, 6.8 ± 2.3 years); the weight of the dogs ranged from 21 to 71 kg (mean weight ± SD, 35.3 ± 8.3 kg).

The limbs were disarticulated at the hip joint and the talocrural joint. All musculature was removed from each limb, but the capsule of the stifle joint was left intact. The quadriceps tendon was cut 1 to 2 cm proximal to the patella. The limbs were frozen at –20°C and thawed at room temperature (approx 23°C) 12 hours before radiography was performed. To keep the patellar tendon under tension during the radiographic examination, it was sutured to an elastic tape that was fixed to the femoral neck. The prepared limbs were affixed on a radiolucent plastic board and brought into an exact lateral position; the femoral condyles were superimposed fluoroscopically. Serial mediolateral radiographic views[a] were obtained with the beam centered over the femoral condyles; by including the hip joint and the talocrural joint (although not intact) in the view, the full length of the femur and the tibia were included in each image. Each stifle joint was moved through positions of full extension to full flexion in 10° increments; at each position, 1 radiograph was obtained.

Data management and analysis—The definitions of measurements concerning tibial and femoral long axes used in the study were adapted from those proposed by Nisell,[24] who defined the tibial and femoral long axes as the lines between the 2 shaft midpoints located at 75 and 150 mm from the condyle surfaces. To enable compilation of data from dogs of different sizes, the method was modified. The long axes of the femur and the tibia were defined from the radiographs as the lines between the 2 shaft midpoints at one third and two thirds of the femoral and tibial lengths from the TFCP. On each radiograph, the angle between these 2 lines (angle β) was measured to determine the degree of flexion (**Figure 1**).

A line was drawn along the tibial plateau from the point on the cranial margin of the tibial plateau at which the CrCL inserts to the point on the caudal margin of the tibia at which the CdCL inserts, as conventionally done by several authors.[16,19] The angle between the proximal border of the patellar ligament and the tibial plateau (angle γ; Figure 1) was measured; this angle represents patellar ligament inclination with respect to the conventionally defined tibial plateau.

The TFCP was defined by drawing 2 circles onto the radiographs; 1 circle represented the joint surface of the femoral condyles in the articulating area, and the other circle outlined the area of contact on the tibial plateau. A line was drawn between the midpoints of these 2 circles, and a second line was drawn perpendicular to the former within the tibiofemoral joint space. The second line represented the common tangent of the 2 circles and cut perpendicularly through the line between the midpoints of the 2 circles in the TFCP. The angle between the cranial border of the patellar ligament and the common tangent at the TFCP (angle α) was measured (Figure 1); this angle represents patellar ligament inclination in relation to the common tangent at the TFCP.

Data were analyzed by use of statistical software.[b] Relationships between angles β and γ or α were analyzed by use of simple linear regression, from which coefficients of correlation (r^2) were determined. A value of $P < 0.05$ was considered significant. To compare right and left limbs, each dog separately, and each limb separately, ANOVAs and
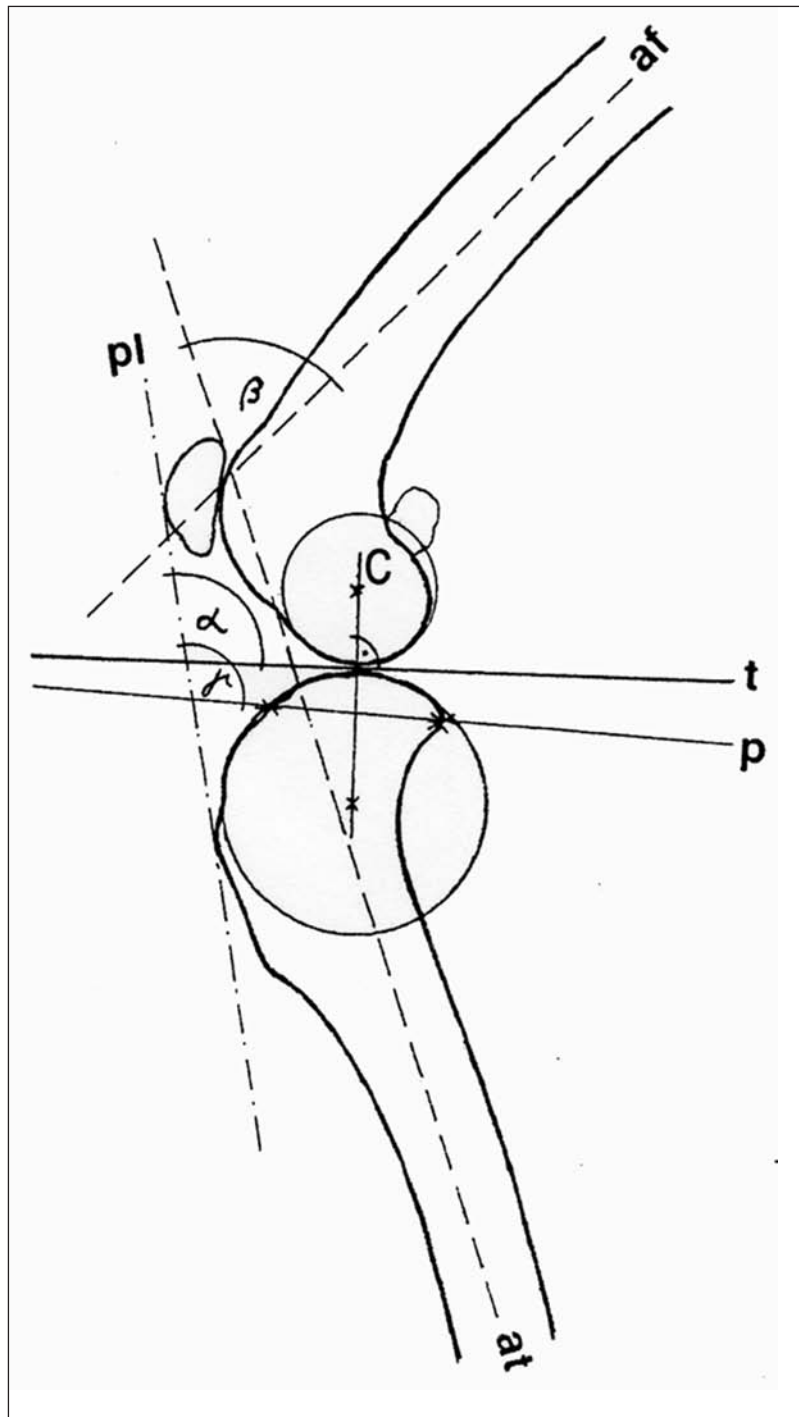
Figure 1—Illustration of the features of mediolateral radiographic views of stifle joints of cadaveric dogs (without degenerative joint disease) used to assess the inclination of the patellar ligament in relation to flexion angle. Femur, patella, 1 sesamoid bone of the gastrocnemius muscle, and tibia are outlined. The femoral (af) and tibial (at) long axes were defined as the lines between the 2 shaft midpoints at one third and two thirds of the femoral and tibial lengths from the TFCP. Angle β is representative of joint flexion. Line p was drawn along the tibial plateau from the CrCL insertion point to the CdCL insertion point. Angle γ was measured between the cranial border of the patellar ligament (pl) and the tibial plateau (p). The TFCP was defined by drawing a circle representing the joint surface of the femoral condyles in the articulating area and another circle outlining the area of contact on the tibial plateau. Line c was drawn between the midpoints of these 2 circles, and a second line (t) was drawn perpendicular to the former within the tibiofemoral joint space (representing the common tangent of the 2 circles); line t was perpendicular to line c at the TFCP. Angle α was measured between the cranial border of the patellar ligament (pl) and the common tangent (t) at the TFCP.

ANCOVAs were performed. Because of the small number of dogs, there were significant differences between individual dogs and between separate limbs, but the differences were so small that results (eg, equation of the linear regression lines) were not altered between the different models. Therefore, the authors decided to use simple linear regression; the additional data[c] are not included in this report.

Intravariability (assessment of the same radiograph 10 times by the same examiner) and intervariability (assessment of the same radiograph by 10 different examiners) among measurements were evaluated by means of coefficients of variability.

Results

The coefficients of variability for measurement intravariability and intervariability were 0.007 and 0.012, respectively. The maximum possible extension of the canine stifle joints ranged from 27° to 41° (mean ± SD maximum extension, 33.75 ± 4.4°). The maximum possible flexion of the canine stifle joints ranged from 147° to 158° (mean maximum flexion, 152.2 ± 3.7°).

Among the stifle joints examined, the maximum value of angle γ (ie, the inclination of the patellar ligament with respect to the conventionally defined tibial plateau in the sagittal plane) ranged from 100° to 114° (mean maximum γ, 107.3 ± 4.6°). The minimum value of angle γ ranged from 76° to 67° (mean SD minimum γ, 70.9 ± 2.7°). Statistical analysis revealed that the magnitude of angle γ decreased linearly with increasing stifle joint flexion (**Figure 2**). The equation of the linear regression line was as follows: γ = −0.31β + 118 ($r^2 = 0.925$; $P < 0.001$).

The maximum value of angle α (ie, the inclination of the patellar ligament with respect to the common tangent at the TFCP) among the canine stifle joints ranged from 100° to 111° (mean maximum α, 104.3 ± 3.3°). The minimum value of α ranged from 87° to 77° (mean minimum α, 82.3 ± 2.9°). Statistical analysis revealed that the magnitude of angle α decreased linearly with increasing stifle joint flexion (**Figure 3**). The equation of the linear regression line was as follows: α = −0.19β + 111 ($r^2 = 0.874$; $P < 0.001$).

Discussion

Data obtained in the present study were based on measurements of angles on mediolateral radiographs of stifle joints of dogs with no degenerative joint disease. The measured angle β repre-
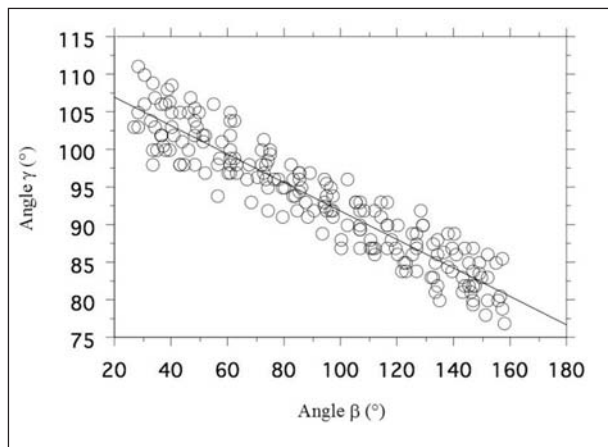
Figure 2—Graph depicting changes in angle γ (the inclination of the patellar ligament with respect to the conventionally defined tibial plateau in the sagittal plane) with increasing joint flexion (angle β) assessed radiographically in 16 stifle joints of 9 cadaveric dogs (without degenerative joint disease). For each stifle joint, 1 radiograph was obtained for analysis at 10° increments through the range of motion (2 joints with 13 datum points, 12 joints with 12 datum points, and 2 joints with 11 datum points; collectively, 192 datum points). The magnitude of angle α decreased linearly with increasing stifle joint flexion; the equation of the linear regression line was as follows: γ = –0.31β + 118 (r^2 = 0.925; P < 0.001). The crossover point, where the tibial plateau was perpendicular to the patellar ligament and the shear force approached zero, was reached during stifle joint flexion of approximately 90°.
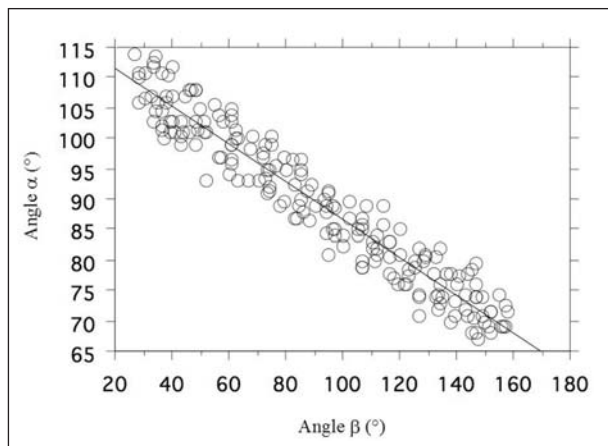

Figure 3—Graph depicting changes in angle α (the inclination of the patellar ligament with respect to the common tangent at the TFCP) with increasing joint flexion (angle β) assessed radiographically in 16 stifle joints of 9 cadaveric dogs (without degenerative joint disease). For each stifle joint, 1 radiograph was obtained for analysis at 10° increments through the range of motion (2 joints with 13 datum points, 12 joints with 12 datum points, and 2 stifles with 11 datum points; collectively, 192 datum points). The magnitude of angle α decreased linearly with increasing stifle joint flexion; the equation of the linear regression line was as follows: α = –0.19 + 111 (r^2 = 0.874; P < 0.001). The crossover point, where the common tangent was perpendicular to the patellar ligament and the shear force approached zero, was reached at stifle joint flexion of approximately 110°.

sented joint flexion. The method of measurement was adopted from that proposed by Nisell[24] and modified to allow comparison of dogs of different conformations.[23] Angle γ represented the inclination of the patellar ligament in relation to the tibial plateau, which was conventionally defined by a line through the insertion points of the CrCL and CdCL on the tibia. Methods of evaluating the tibial plateau slope have been introduced previously.[16,19,20] The slope of the plateau with respect to the tibial functional or anatomic long axis was not measured. In a recent study,[22] it was determined that the conventional radiographic method of assessing the tibial plateau is based on landmarks that do not represent the articulating surface of the medial condyle of the tibia. Also, those landmarks on the tibial surface may not correspond to the biomechanically important functional insertion points of the cruciate ligaments. Development of a reliable method that uses the actively articulating convex surfaces as a reference and takes into account the caudally rolling motion of the femoral condyles during flexion is warranted. The TFCP moves caudally because of the rolling motion of the femoral condyles during increasing joint flexion, and it is chosen as the origin in calculations of moments and forces by several investigators.[16,17,23] The distance from the TFCP to the patellar ligament (the patellar ligament moment arm) is a determinant of the magnitudes of the joint forces in the stifle joint.[24] To our knowledge, there are no published data in the veterinary medical literature regarding determination of the TFCP with means other than crude estimation. The method of TFCP determination used in the study of this report is still an estimation, but analysis of intravariability and intervariability revealed high consistency and little variability among measurements. To apply this method, exact mediolateral radiographic views of the stifle joint (with superimposition of the femoral condyles) have to be obtained; the x-ray beam has to be centered on the tibiofemoral joint space.

Because of muscle redundancy and co-contraction, it is difficult to calculate true joint forces from biomechanical models. In the canine stifle joint model introduced by our group,[23] the resulting joint force has both a compressive (or normal) and a shear (or tangential) component. Magnitudes of these components change inversely as the extent of joint flexion changes. In the knee joint of humans, anterior shear force is greatest during full extension and posterior shear force is greatest during full flexion. The tibiofemoral shear force changes from cranial shearing to caudal shearing between 50° and 90° of joint flexion depending on the magnitude of the external force acting on the tibia and its moment arm.[24] In humans, the patellar ligament pulls the tibia forward in relation to the femur during full extension; during flexion > 100°, the patellar ligament pulls the tibia backward. This switching of direction depends mostly on the angle between the patellar ligament and the tibial plateau.[24] The results of the study reported here suggest that the angle between the patellar ligament and the tibial plateau decreases linearly with increasing stifle joint flexion in dogs, which is similar to the findings in knee joints of humans. Analysis of the data obtained by use of standard geometric representation of the tibial plateau suggested that the crossover point in dogs was achieved at 90° flexion of the stifle joint. At this flexion angle, the shear component of the total joint force is at the zero value, the point at which the cranial shift of the extended stifle joint is converted into a caudal shift of

the flexed stifle joint and the load is shifted from the CrCL to the CdCL.

In the present study of canine stifle joints, the angle α of the patellar ligament was measured with the common tangent at the TFCP as the reference. Angle α also decreased in a linear manner with increasing stifle joint flexion. By use of the equation of the linear regression line, the mean flexion-extension angle at which α was 90° (ie, at which the common tangent was perpendicular to the patellar ligament) in canine stifle joints was 110°. Considering the caudally rolling movement of the femoral condyles over the convex tibial plateau, a less pronounced decrease of angle α with increasing flexion (compared with that detected for angle γ) was to be expected. Because tibiofemoral contact does imply the rolling movement of the femur relative to the tibia, the TFCP more accurately reflects the instant center of rotation than the more statically positioned tibial plateau. Use of the TFCP and the associated common tangent as a reference seems to be anatomically more adequate than use of the tibial plateau to represent the convex articulating surfaces of the stifle joint in dogs.

At 110° of stifle joint flexion, the common tangent and the patellar ligament force were perpendicular to each other. The patellar ligament moment arm and the common tangent were coincident, and the moment arm was maximally long. In regard to the results of the biomechanical model of Nisell[24] and those of the present study, a flexed stifle joint is an effective way to avoid inclination of the patellar ligament with respect to the tibial plateau, thereby reducing the cranial shift of the tibia at the beginning of the weight-bearing phase of the stride.

In humans, the tibial plateau slopes posteriorly (in relation to the tibial long axis) at 7.2° in women and 9.2° in men. In dogs, the mean inclination angle of the tibial plateau with respect to the tibial long axis is approximately 20°. Despite differences in the tibial plateau slope and the physiologic range of motion between humans and dogs, the angles between the patellar ligament and the tibial plateau are comparable in those species, and an angle of 90° is included approximately at the middle of the flexion range. Korwick et al[25] determined that dogs with deficient CrCLs carried their limbs in greater flexion throughout the gait cycle. According to Slocum and Devine,[16] cranial translation of the tibia is actively opposed by the flexors of the stifle joint. The results of the biomechanical model of Nisell[24] and those of the present study suggest that a flexed stifle joint is an effective way to avoid inclination of the patellar ligament with respect to the tibial plateau, thereby reducing the cranial shift of the tibia at the beginning of the weight-bearing phase of the stride. Further studies are necessary to establish whether dogs with partial ruptures of the CrCL have significantly different angles between the patellar ligament and the tibial plateau or between the patellar ligament and the common tangent at the TFCP, compared with dogs with intact CrCLs.[26] Among humans, women have smaller patellar tendon moment arms, and therefore larger joint forces, than men. Degenerative joint disease is also more prevalent in women. It remains to be ascertained whether dogs with a small tibial tuberosity (and thus a short patellar ligament moment arm) are more likely to rupture the CrCL than dogs with a large tibial tuberosity. Also, straight hind limbs and a steep tibial plateau influence (ie, increase) the angle between the patellar ligament and the tibial plateau and thus generate a cranial shift. Investigation of cranial tibial shift dependence on stifle joint flexion, inclinations of the patellar ligament and the tibial plateau, patellar ligament moment arm, and magnitude of patellar ligament force may improve our understanding of normal, pathologic, and reconstructive biomechanics of the stifle joint in dogs.

Our data have indicated that exact mediolateral radiographic views of the stifle joints of dogs can be used to determine stifle joint flexion, the angle between the patellar ligament and the tibial plateau, and the angle between the patellar ligament and the common tangent at the TFCP with accuracy and consistency. At a joint flexion of 90°, the patellar ligament is perpendicular to the tibial plateau in dogs without degenerative joint disease. At a joint flexion of 110°, the patellar ligament is perpendicular to the common tangent at the TFCP. A cranial tibial shift (ie, loading of the CrCL) in the canine stifle joint would be exerted on the proximal portion of the tibia by the patellar ligament at stifle joint flexion < 110°; a caudal tibial shift (ie, loading of the CdCL) would be expected at stifle joint flexion > 110°. The magnitude of the cranial tibial shift is dependent on the direction and magnitude of the patellar ligament force, which in turn is dependent on the tibial plateau slope and the common tangent at the TFCP.

References

1.   Vasseur PB. Stifle joint. In: Slatter D, ed. *Textbook of small animal surgery*. 3rd ed. Philadelphia: WB Saunders Co, 2003;2090–2133.

2.   Arnoczky SP, Marshall JL. The cruciate ligaments of the canine stifle: an anatomical and functional analysis. *Am J Vet Res* 1977;38:1807–1814.

3.   Heffron LE, Campell JR. Morphology, histology and functional anatomy of the canine cranial cruciate ligament. *Vet Rec* 1978;102:280–283.

4.   Pond MJ, Campell JR. The canine stifle joint: I. Rupture of the anterior cruciate ligament: an assessment of conservative and surgical treatment. *J Small Anim Pract* 1972;13:1–10.

5.   Johnson JM, Johnson AL. Cranial cruciate ligament rupture: pathogenesis, diagnosis, and postoperative rehabilitation. *Vet Clin North Am* 1993;23:717–731.

6.   Vasseur PB, Pool RR, Arnoczky SP, et al. Correlative biomechanical and histological study of the cranial cruciate ligament in dogs. *Am J Vet Res* 1985;46:1842–1854.

7.   Duval JM, Budsberg SC, Flo GL, et al. Breed, sex, and body weight as risk factors for rupture of the cranial cruciate ligament in young dogs. *J Am Vet Med Assoc* 1999;215:811–814.

8.   Whitehair JG, Vasseur PB, Willits NH. Epidemiology of cranial cruciate ligament rupture in dogs. *J Am Vet Med Assoc* 1993;203:1016–1019.

9.   Read RA, Robins GM. Deformity of the proximal tibia in dogs. *Vet Rec* 1982;111:295–298.

10. Aiken SW, Kass PH, Toombs JP. Intercondylar notch widths in dogs with and without cranial cruciate ligament injuries. *Vet Comp Orthop Traumatol* 1995;8:128–132.

11. Selmi AL, Padilha Filho JG. Rupture of the cranial cruciate ligament associated with deformity of the proximal tibia in five dogs. *J Small Anim Pract* 2001;42:390–393.

12. Lawrence D, Bao S, Canfield PJ, et al. Elevation of immunoglobulin deposition in the synovial membrane of dogs with cranial cruciate ligament rupture. *Vet Immunol Immunopathol* 1998;65:89–96.

13. Galloway RH, Lester SJ. Histopathological evaluation of canine stifle joint synovial membrane collected at the time of repair of cranial cruciate ligament rupture. *J Am Anim Hosp Assoc* 1995;31:289–294.

14. Bennett D, Tennant B, Lewis DG, et al. A reappraisal of anterior cruciate ligament disease in the dog. *J Small Anim Pract* 1988;29:275–279.

15. Hulse DA, Aron DN. Advances in small animal orthopedics. *Compend Contin Educ Pract Vet* 1994;16:831–832.

16. Slocum B, Devine T. Cranial tibial thrust: a primary force in the canine stifle. *J Am Vet Med Assoc* 1983;183:456–459.

17. Slocum B, Slocum TD. Tibia plateau levelling osteotomy for repair of cranial cruciate ligament rupture in the canine. *Vet Clin North Am Small Anim Pract* 1993;23:777–795.

18. Henderson R, Milton J. The tibial compression mechanism: a diagnostic aid in stifle injuries. *J Am Anim Hosp Assoc* 1978;14:474–479.

19. 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.

20. Wilke VL, Conzemius MG, Besancon MF, et al. 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.

21. Zeltzman PA, Pare B, Johnson GM, et al. Relationship between age and tibial plateau angle in dogs with cranial cruciate rupture. *J Am Anim Hosp Assoc* 2005;41:117–120.

22. Baroni E, Matthias RR, Marcellin-Little, et al. Comparison of radiographic assessments of the tibial plateau slope in dogs. *Am J Vet Res* 2003;61:586–589.

23. Tepic S, Damur D, Montavon PM. Biomechanics of the stifle joint, in *Proceedings*. 1st World Vet Orthop Cong Euro Soc Vet Orthop Traumatol Vet Orthop Soc 2002;189–190.

24. Nisell R. Mechanics of the knee: a study of joint and muscle load with clinical applications. *Acta Orthop Scand Suppl* 1985;216:1–42.

25. Korwick D, Pijanowski G, Schaeffer D. Three-dimensional kinematics of the intact and cranial cruciate ligament-deficient stifle of dogs. *J Biomech* 1994;27:77–87.

26. Schwandt CS, Bohorquez-Vanelli A, Tepic S, et al. Angle between the patellar ligament and tibial plateau in dogs with partial rupture of the cranial cruciate ligament. *Am J Vet Res* 2006;67:1855–1860.